PRODUCTION OF BIOGAS FROM COTTON WASTE

U19CE801 – PROJECT WORK

A PROJECT REPORT

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BONAFIDE CERTIFICATE

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DECLARATION

We jointly declare that the project report on “**PRODUCTION OF BIOGAS FROM COTTON WASTE**” is the result of original work done by us and best of our knowledge, similar works has not been submitted to "ANNA UNIVERSITY : CHENNAI" for the requirement of Degree of Bachelor of Civil Engineering. This project report is submitted on the partial fulfilment of the requirement of the award of degree of Bachelor of Engineering.

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ABSTRACT

This study presents with the rising need for renewable energy sources, converting agricultural waste into biogas presents a sustainable solution. This project focuses on utilizing cotton waste, a byproduct of the textile and agricultural industries, as a raw material for biogas production. Typically, cotton waste is either incinerated or disposed of, contributing to environmental concerns. Through anaerobic digestion, the organic components of cotton waste can be broken down by microorganisms to generate methane-rich biogas, which can serve as an alternative energy source.

This study examines the efficiency of biogas production from cotton waste by analyzing factors such as pre-treatment methods, digestion conditions, and microbial activity. Experimental trials are conducted to optimize parameters like pH and retention time to maximize gas yield. The composition of the produced biogas is assessed to determine its suitability for energy applications. By repurposing cotton waste for bioenergy generation, this project aims to minimize waste accumulation, reduce reliance on fossil fuels, and promote a circular economy. The results offer insights into enhancing waste-to-energy technologies, contributing to sustainable development and environmental conservation.

This project explores the production of biogas from cotton waste, presenting it as a sustainable alternative to LPG. Biogas, generated through anaerobic digestion, offers a cost-effective and eco-friendly energy source. Compared to LPG, biogas reduces dependency on fossil fuels and minimizes carbon emissions. For farmers, utilizing agricultural cotton waste enhances waste management and provides free energy for cooking and farming needs. It benefits common people by lowering fuel costs and promoting clean energy usage. The initiative supports rural energy independence, reduces environmental impact, and contributes to a circular economy by turning waste into valuable bioenergy

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Biogas/ is a renewable source of energy that is produced through the anaerobic digestion of organic matter by microorganisms in an oxygen-free environment. This process leads to the formation of a gaseous mixture primarily composed of methane (CH_4) and carbon dioxide (CO_2), which can be utilized as a sustainable alternative to conventional fossil fuels.

The growing need for eco-friendly energy solutions has made biogas an attractive option, contributing to reduced greenhouse gas emissions, improved waste management, and energy self-sufficiency.

The increasing depletion of non-renewable energy sources and the environmental concerns associated with fossil fuel usage necessitate the exploration of alternative energy sources. Biogas production not only provides a clean energy solution but also effectively addresses the problem of organic waste disposal. By utilizing waste materials such as agricultural residues, food waste, animal manure, and industrial by-products, biogas technology offers a sustainable means of energy generation while promoting environmental conservation.

Among various organic waste materials, cotton waste is one of the most underutilized resources for biogas production. Cotton waste, which includes cotton stalks, fabric trimmings, and lint, is generated in large quantities by the textile and agricultural industries. The improper disposal of this waste leads to environmental issues such as soil pollution, water contamination, and excessive landfill accumulation. Therefore, its conversion into biogas can serve a dual purpose—waste management and renewable energy production.

The potential of cotton waste in biogas production lies in its high cellulose content. Cellulose is a complex carbohydrate that can be broken down by anaerobic microorganisms to release methane. Although cotton waste primarily consists of cellulose, hemicellulose, and lignin, the digestion process can be optimized through pre-treatment methods such as hydrolysis, microbial inoculation, or co-digestion with other biodegradable materials. The relevance of biogas technology is particularly significant in developing countries where energy security and waste management are pressing concerns. Many rural and semi-urban areas lack access to reliable electricity sources, making biogas an ideal solution for decentralized energy generation. Small-scale biogas digesters can be implemented at household or community levels to provide cooking fuel, electricity, and even biofertilizer in the form of digestate. Additionally, industries that generate substantial amounts of cotton waste, such as textile mills and cotton processing plants, can integrate biogas technology into their waste management strategies to reduce operational costs and environmental impact.

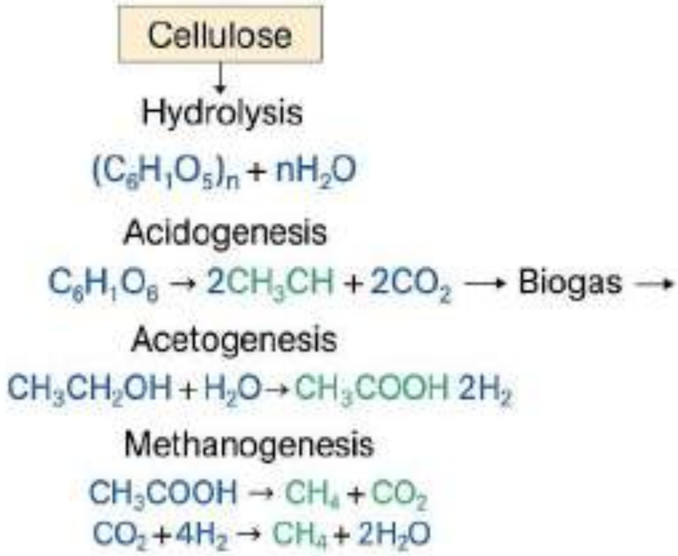

Fig 1.1 Chemical Reaction of Biogas

Furthermore, biogas production aligns with global efforts to combat climate change. The methane captured during the digestion process can be used as an energy source instead of being released into the atmosphere, where it would otherwise contribute to global warming. Additionally, the use of biogas reduces reliance on fossil fuels, which are major contributors to carbon emissions. By adopting biogas technology, industries, communities, and governments can work towards a more sustainable future.

In conclusion, biogas production from cotton waste is an innovative and practical approach to addressing energy and waste management challenges. This project aims to explore the feasibility of utilizing cotton waste as a biogas substrate, evaluating its efficiency, economic viability, and potential environmental benefits. By investigating the biochemical and technical aspects of the anaerobic digestion of cotton waste, we aim to contribute to the advancement of renewable energy solutions and sustainable waste disposal practices.

1.2 BACKGROUND AND EVOLUTION OF BIOGAS

The concept of harnessing energy from decomposing organic matter isn't new. Historical records suggest that ancient civilizations, particularly in Assyria around 900 B.C., noticed the flammable nature of gases released from decomposing waste. In the 17th century, scientists began to understand the biological processes involved in gas formation. The actual development of biogas technology, however, began much later. In 1859, the first anaerobic digester was built in India at a leper colony in Bombay, marking a significant milestone in the practical application of biogas.

The evolution of biogas technology progressed rapidly in the 20th century, especially in rural parts of countries like China and India. In these regions, biogas was used for basic household needs such as cooking and lighting. In India, the Khadi and Village Industries Commission (KVIC) played a key role in promoting small-scale biogas plants under rural development programs. Over time, these plants became more efficient, cost-effective, and accessible to common households. China also saw the construction of millions of family-sized biogas plants, helping rural communities become more self-sufficient and sustainable.

As the world became more focused on sustainable energy in the 21st century, biogas gained even more importance. With growing concerns over climate change, fossil fuel depletion, and environmental pollution, the ability of biogas systems to reduce greenhouse gas emissions while producing renewable energy has made them a key player in the global energy transition. Moreover, the use of biogas plants helps reduce dependency on chemical fertilizers, as the leftover slurry can be used as an organic fertilizer rich in nutrients.

In modern times, biogas technology has expanded beyond household use. It is now used in commercial setups, municipal waste management, and even in large-scale electricity generation. Innovations such as upgrading biogas to biomethane—almost pure methane—have made it usable as a vehicle fuel or injectable into natural gas pipelines. Biogas plants today use a wide variety of feedstocks, including kitchen waste, cow dung, agricultural residues, and industrial organic waste.

In conclusion, biogas has evolved from a simple discovery of flammable gas to a robust, sustainable energy solution with global relevance. It represents a powerful combination of waste management, energy production, and environmental conservation. As technology advances and awareness grows, biogas will continue to play a significant role in building a cleaner, greener future.

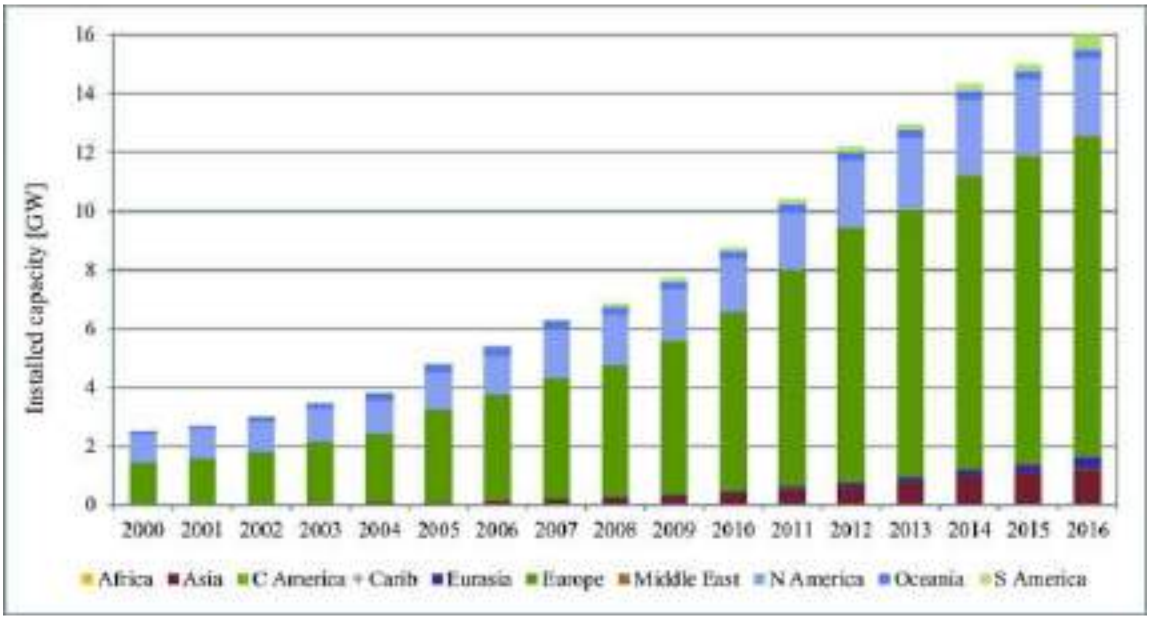

Fig 1.2 Rise of Usage and Evolution of Biogas

To obtain significant biogas production, the amount of feedstock required depends on the type and gas yield potential of the waste material. For example, to produce about 100 cubic meters of biogas, one would need approximately 1 ton of high-yield food waste. In contrast, producing the same amount from cow dung may require around 3 to 5 tons due to its lower gas yield. Agricultural residues like cotton waste might need about 2 to 3 tons for a similar output, depending on their composition and level of pre-treatment. Efficient digestion also requires maintaining a balanced mixture of carbon and nitrogen-rich materials, proper moisture content, and controlled environmental conditions. Thus, both the quantity and quality of feedstock play crucial roles in achieving optimal biogas production.

1.3 PROBLEM STATEMENT

1.3.1 FOSSIL FUEL DEPENDENCY

- Excessive reliance on fossil fuels is a major contributor to greenhouse gas (GHG) emissions.
- Fossil fuel combustion is the leading cause of climate change and global warming.

1.3.2 NEED FOR ALTERNATIVE ENERGY SOURCES

- There is an urgent global demand for renewable, sustainable, and eco-friendly energy alternatives.
- Biogas is seen as a potential substitute to reduce fossil fuel consumption.

1.3.3 IMPROPER DISPOSAL OF ORGANIC WASTE

- Agricultural and textile waste, including cotton waste, often ends up in landfills.
- Improper disposal leads to:

- Landfill overflow
- Water pollution
- Soil contamination

1.3.4 ENVIRONMENTAL HAZARDS FROM COTTON WASTE

- Cotton waste generates methane emissions when decomposed anaerobically in landfills.
- Textile residues may contain dyes and chemicals that pollute water and soil.

1.3.5 URBAN AND INDUSTRIAL PRESSURE

- Waste management is a pressing issue in urban areas, especially where textile industries are concentrated.
- Conventional methods like incineration lead to air pollution and toxic emissions.

1.3.6 HIGH CELLULOSE CONTENT, LOW UTILIZATION

- Cotton waste contains 60–80% cellulose, making it an excellent candidate for biogas production.
- Despite this, it is underused in comparison to food waste, manure, or crop residues.

1.3.7 SUSTAINABLE ENERGY GENERATION

- Utilizing cotton waste for biogas could offer a renewable and clean energy source.
- This approach helps reduce dependence on non-renewable energy.

1.3.8 ENVIRONMENTAL AND ECONOMIC BENEFITS

- Reduces environmental pollution.
- Generates energy for rural or industrial use.
- Presents a feasible long-term solution with potential economic viability.

1.4 NOVELTY

- **Utilization of an unconventional biomass**: Cotton waste is typically considered a low-value by-product and often disposed of through burning or landfilling, causing pollution. By converting this waste into biogas, the project presents a dual solution for waste management and renewable energy generation.
- **Short retention time with high gas yield**: Unlike conventional digesters that require long retention times, this study shows that cotton waste can produce a significant amount of biogas even within 24 hours, indicating potential for continuous and rapid digestion systems.
- **Insight into substrate composition and pretreatment**: The project goes beyond just gas measurement by analyzing the chemical composition of cotton waste (cellulose, hemicellulose, lignin), which helps understand and improve digestibility and methane yield. This lays a foundation for future process optimization through tailored pretreatment methods.
- **Focus on low-cost, decentralized application**: The experimental setup and methodology are designed to be cost-effective and replicable in rural or semi-urban settings, making the technology accessible for local communities, especially in cotton-producing regions.
- **Environmental impact**: By preventing open disposal or burning of cotton

waste, the project reduces greenhouse gas emissions and promotes a circular economy model in the textile and agriculture sectors.

1.5 REASON FOR COTTON WASTE IN BIOGAS PRODUCTION

- **Abundant Availability:** Cotton waste is generated in large quantities by the textile and agricultural industries.
- **High Cellulose Content:** Cotton waste is rich in cellulose, which can be effectively broken down by anaerobic bacteria to produce biogas.
- **Environmental Concern:** Improper disposal of cotton waste leads to environmental pollution; converting it to biogas mitigates this issue.
- **Economic Potential:** Utilizing cotton waste for energy production can provide an additional revenue stream for industries.
- **Sustainability:** Recycling cotton waste into biogas supports the circular economy and promotes sustainable energy practices.
- **Reduction of Landfill Waste:** Converting cotton waste into biogas decreases landfill accumulation and associated environmental risks.

1.6 SIGNIFICANCE OF THE PROJECT

This project holds significant importance in multiple areas, including environmental conservation, scientific research, industrial application, and community development. By utilizing cotton waste for biogas production, we contribute to sustainable waste management while promoting renewable energy solutions. The significance of this project can be categorized as follows:

1.6.1 ENVIRONMENTAL IMPACT

Utilizing cotton waste for biogas production significantly reduces environmental pollution. Cotton waste, if left untreated, contributes to landfill accumulation, water contamination, and greenhouse gas emissions. By converting it into biogas, we reduce waste and lower carbon footprints, supporting eco-friendly practices and sustainability goals.

1.6.2 SCIENTIFIC CONTRIBUTION

This project adds valuable knowledge to the field of renewable energy and biogas technology. It helps in understanding the biodegradability of cotton waste, optimizing digestion processes, and improving biogas yield. The research findings can benefit academic and industrial researchers exploring similar sustainable energy sources.

1.6.3 ECONOMIC AND INDUSTRIAL RELEVANCE

Industries producing large amounts of cotton waste can benefit economically by converting waste into usable energy. This reduces disposal costs and provides an alternative fuel source, enhancing energy efficiency in manufacturing sectors such as textiles and agriculture.

1.6.4 COMMUNITY BENEFITS

Biogas technology can provide energy solutions for rural and underprivileged communities. Households and small enterprises can use biogas for cooking, heating, and electricity, improving their living standards and energy security. Additionally, promoting waste-to-energy conversion can create job opportunities in waste management and biogas production sectors.

By highlighting these factors, this project underscores the transformative potential of biogas technology in achieving sustainability, economic growth, and environmental preservation.

Additionally, biogas technology has the potential to create new job opportunities in the renewable energy sector, promoting economic growth and technological advancements. The development and maintenance of biogas plants require skilled labor, creating employment opportunities in engineering, construction, and environmental sciences. Furthermore, biogas production supports the concept of a circular economy, where waste materials are repurposed into valuable resources, contributing to overall sustainability.

1.7 OBJECTIVES OF THE PROJECT

The main objectives of this project are:

- To evaluate the feasibility of using cotton waste as a raw material for biogas production.
- To analyze the efficiency of biogas yield from cotton waste compared to other organic materials.
- To study the environmental benefits of utilizing cotton waste for renewable energy generation.
- To design and develop a small-scale biogas digester suitable for processing cotton waste.
- To assess the economic viability and sustainability of the proposed biogas production method.
- To promote the concept of waste-to-energy conversion among industries and

communities.

- To provide recommendations for optimizing biogas production from cotton waste.

1.8 SCOPE OF THE PROJECT

This project covers various aspects related to biogas production from cotton waste, including:

- Identifying and collecting different types of cotton waste from textile and agricultural sources.
- Conducting experimental analysis to determine the biodegradability and methane potential of cotton waste.
- Designing and constructing an anaerobic digester specifically for cotton waste.
- Monitoring and analyzing the biogas production process, including factors affecting efficiency.
- Comparing biogas yield from cotton waste with other organic substrates.
- Evaluating the economic and environmental implications of using cotton waste for biogas generation.
- Exploring potential applications and future developments for large-scale implementation.

The scope of this project extends beyond academic research, aiming to create practical solutions for industries and communities dealing with cotton waste disposal. The project integrates both theoretical and experimental methodologies, involving laboratory-scale experiments to assess biogas yield and system efficiency. Additionally, the study investigates different parameters influencing biogas production, such as temperature, pH levels, retention time, and microbial activity.

This research also considers the feasibility of scaling up biogas production from cotton waste for industrial and commercial applications. By analyzing cost factors, energy output, and sustainability measures, the study seeks to provide insights into the economic viability of implementing biogas plants using cotton waste as a feedstock. Furthermore, the project will explore potential policies and incentives that could encourage industries to adopt biogas technology as part of their waste management strategy.

1.9 PROJECT CLAIMS AND CORE OUTCOMES

- The anaerobic digestion process successfully converted cotton waste into biogas, with methane content ranging between 55%–65%, making it suitable for cooking and electricity generation.
- Optimal digestion conditions were identified:
    - pH range: 6.5 to 7.5
    - Temperature: Mesophilic conditions (30°C to 40°C)
    - Retention time: 24 hours resulted in a gas yield of approximately 200 liters/day from 2 kg of cotton waste.
- The presence of cellulose and hemicellulose in cotton waste made it highly biodegradable, contributing to efficient methane generation.
- The data collected and analyzed confirmed the efficiency of cotton waste as a reliable substrate, showing its potential in renewable energy applications, especially in rural or agro-based areas.

CHAPTER 2
LITERATURE REVIEW

2.1 GENERAL

Biogas technology is a sustainable energy solution that produces methane-rich gas through the anaerobic digestion of organic waste such as agricultural residues, animal manure, and food waste. This process occurs in four main stages—hydrolysis, acidogenesis, acetogenesis, and methanogenesis—where complex organic compounds are gradually broken down into methane and carbon dioxide by microorganisms. The efficiency of biogas production depends on factors like feedstock type, temperature, pH, retention time, and microbial communities. Widely adopted for rural electrification, waste management, and clean energy generation, biogas significantly reduces greenhouse gas emissions and dependence on fossil fuels. Governments and institutions worldwide promote its use through policies and subsidies, although optimizing feedstock use and improving digester performance remain key challenges for large-scale implementation.

2.2 LITERATURE

Weiland.P (2010) A study investigating the biogas potential of maize silage, wheat straw, and cattle manure revealed key insights into feedstock efficiency in anaerobic digestion. Maize silage emerged as the most effective due to its high carbohydrate content, which supports rapid microbial metabolism and high methane yields. Wheat straw showed lower biogas potential because of its lignocellulosic structure, but pretreatment methods like mechanical grinding or chemical hydrolysis can enhance its digestibility. Cattle manure, though lower in energy, contributes vital microbial communities and buffering capacity, stabilizing the digestion process. The study emphasized that combining maize silage and cattle manure offers synergistic benefits—energy from silage and microbes from manure.

Additionally, treated wheat straw can expand feedstock diversity. Overall, optimizing feedstock selection and treatment is key for efficient and sustainable biogas production.

Angelidaki.I and Ellegaard.I (2003) Angelidaki and Ellegaard emphasized co-digestion, where mixing food waste and manure improves microbial activity and biogas yield. Their study highlighted the importance of a balanced carbon-to-nitrogen (C/N) ratio, ideally between 20:1 and 30:1, to prevent ammonia inhibition or acidification. Co-digestion enhances digestion stability by offering diverse nutrients, buffering capacity, and reducing inhibitory substances. Food waste contributes easily degradable carbohydrates and fats, while manure adds microbes and pH stability. Optimizing mixing ratios was shown to boost methane yield and process efficiency. Challenges include potential toxic compounds and the need for pre-treatment of some waste types. Overall, the study supports co-digestion as a strategy for better performance, resilience, and sustainable biogas production.

Xu., et al. (2018) examined sugarcane bagasse as a biogas feedstock, noting its high lignocellulosic content limits microbial degradation. Mechanical pretreatment, such as milling, increased surface area by reducing particle size, enhancing hydrolysis. Chemical pretreatment with acids, alkalis, or oxidants disrupted cellulose-lignin bonds, improving microbial access—alkaline treatment with sodium hydroxide proved especially effective. Enzymatic hydrolysis using cellulase and hemicellulase further boosted methane yields by converting cellulose into fermentable sugars. The study found that combining pretreatment methods yielded the best results, as mechanical processes enhanced chemical effectiveness. Methane production significantly increased with pretreated bagasse compared to untreated samples. The research concluded that integrated pretreatment strategies are essential to unlocking sugarcane bagasse's full biogas potential.

Li et al. (2019) explored the potential of cotton gin waste for biogas production. Cotton gin waste, a byproduct of cotton processing, is primarily composed of cellulose, hemicellulose, and lignin, making it a carbon-rich substrate. The study found that its high C/N ratio posed a challenge for microbial digestion, as an imbalance in this ratio can lead to inefficient anaerobic degradation and reduced methane yields. To overcome this limitation, the study recommended co-digestion with nitrogen-rich materials, such as animal manure, food waste, or wastewater sludge, to create a balanced nutrient environment for microbial activity. The research demonstrated that optimal C/N ratios, typically ranging between 20:1 and 30:1, significantly improved the biodegradability of cotton gin waste and enhanced methane production. Furthermore, the study investigated the effects of different pretreatment methods, such as mechanical grinding, thermal treatment, and alkaline hydrolysis, on the digestibility of cotton gin waste. Results showed that these pretreatments helped break down the complex lignocellulosic structure, making it more accessible to anaerobic microorganisms. Among the various methods tested, alkaline hydrolysis with sodium hydroxide (NaOH) was found to be the most effective in increasing methane yield. Li et al. also examined the microbial community dynamics during the anaerobic digestion process. The presence of hydrolytic, acidogenic, acetogenic, and methanogenic bacteria was essential for efficient biogas production. The study highlighted that co-digestion not only improved nutrient balance but also promoted microbial synergy, leading to higher methane yields and more stable digestion processes. In conclusion, the study by Li et al. (2019) provided valuable insights into the biogas potential of cotton gin waste. By addressing challenges related to high C/N ratios and implementing appropriate pretreatment and co-digestion strategies, the research demonstrated that cotton gin waste could be an effective feedstock for sustainable biogas production.

Amon et al. (2007) explored cotton gin waste as a biogas feedstock, noting its high cellulose and lignin content but also its challenging high C/N ratio. This imbalance hindered microbial digestion and methane yields, prompting the recommendation of co-digestion with nitrogen-rich materials like manure or food waste. Maintaining an optimal C/N ratio

(20:1–30:1) significantly improved biodegradability and biogas output. Pretreatment methods—mechanical grinding, thermal treatment, and especially alkaline hydrolysis with NaOH—were shown to enhance digestibility by breaking down lignocellulosic structures. The study also emphasized the importance of microbial communities for efficient anaerobic digestion. Co-digestion fostered microbial synergy, stabilizing the process and increasing methane yields. Overall, the research highlighted cotton gin waste's potential as a viable, sustainable feedstock when properly treated and balanced.

Parawira et al. (2004) research focused on the anaerobic digestion of fruit waste, highlighting challenges due to its high acidity, which inhibits methanogenic activity. To counteract this, the study recommended pH control using buffering agents like calcium carbonate or sodium bicarbonate. Co-digestion with alkaline or nitrogen-rich substrates, such as manure or food waste, was found to balance pH and enhance microbial stability. These strategies led to improved methane yields and more stable digestion. The study also emphasized adjusting hydraulic retention time and organic loading rate to optimize performance. Continuous pH monitoring was deemed crucial for maintaining favorable conditions. Overall, Parawira provided a practical framework for effectively using fruit waste in sustainable biogas production.

Mata-Alvarez et al. (2000) investigated biogas production from food industry wastewater, emphasizing its rich organic content as a valuable substrate. The study found that wastewater from dairy, meat, and beverage industries contains highly biodegradable matter, ideal for anaerobic digestion. Effective pre-treatment methods—filtration, sedimentation, and chemical treatments—were essential to remove impurities and prevent inhibitory effects from fats, oils, and grease. Improper pre-treatment reduced microbial efficiency and methane yield. Among digestion systems, UASB reactors outperformed others due to their ability to retain microbial biomass and handle high organic loads. The study also stressed the importance of controlling parameters like temperature, pH, and organic loading rate.

Overall, the research demonstrated the efficiency and potential of food industry wastewater for sustainable biogas production.

Karki et al. (1994) research evaluated rice husk and straw as biogas feedstocks, noting their high lignocellulosic content poses challenges for microbial degradation. To enhance digestibility and methane yield, the study explored pretreatment methods including hydrothermal treatment, microbial inoculation, and enzymatic hydrolysis. Hydrothermal treatment used high-temperature steam to break down lignin, improving access to cellulose and hemicellulose. Microbial inoculation introduced specialized microbes to accelerate decomposition, while enzymes like cellulase and hemicellulase boosted sugar conversion and biogas output. Combining these methods significantly increased methane yields compared to untreated materials. Optimal conditions—temperature, pH, and nutrient balance—were critical for microbial efficiency. The study concluded that integrating pretreatment with co-digestion strategies enhances the potential of rice husk and straw for sustainable biogas production.

Zeshan et al. (2012) Zeshan's study on dairy industry waste focused on the anaerobic digestion of whey and sludge, highlighting their high biodegradability and organic load. Due to the low C/N ratio, co-digestion with carbon-rich materials was recommended to enhance methane yield and stabilize the process. The study emphasized maintaining mesophilic temperatures (35–40°C), optimal pH, and hydraulic retention time for improved microbial activity. Pretreatment methods like dilution and pH adjustment were crucial to counteract the inhibitory effects of high-fat content. Environmental benefits included reduced greenhouse gas emissions and pollution from untreated waste. The nutrient-rich digestate produced was suitable for agricultural use. Overall, the research confirmed dairy waste as a valuable feedstock for efficient and sustainable biogas production.

Abbasi et al. (2011) The study explored biogas generation from paper mill sludge, focusing on the challenges of digesting cellulose and lignin-rich residues. Co-digestion with nitrogen-rich food waste was found to balance the high carbon content of paper sludge, improving microbial activity and methane yield. Pre-treatment methods like enzymatic hydrolysis and mechanical disruption were used to enhance biodegradability, increasing methane production and reducing digestion time. The research highlighted the potential of paper industry waste as a renewable energy source and a solution for waste disposal. Integrating anaerobic digestion within paper mills could provide sustainable waste management and biogas generation. The study emphasized the importance of substrate selection, pretreatment, co-digestion, and process control for optimizing biogas production. Overall, it showcased the viability of paper mill sludge as a feedstock for biogas production.

Sawatdeenarunat, C., et.all., (2015) This study reviews anaerobic digestion (AD) of lignocellulosic biomass, like cotton waste, which contains cellulose, hemicellulose, and lignin, challenging microbial degradation. The recalcitrant nature of lignin limits biodegradability and reduces methane yields in AD systems. The authors stress the need for pretreatment to break down biomass structure and enhance enzyme accessibility to cellulose and hemicellulose. Pretreatment methods explored include mechanical (grinding, shredding), chemical (acid or alkali), and biological (fungal or microbial) processes. Each method offers benefits and drawbacks, such as cost, energy input, and environmental impact. The review highlights the importance of optimizing pretreatment for efficient biogas production. Overall, the study emphasizes improving lignocellulosic biomass digestibility through effective pretreatment strategies.

Al Seadi, T., et.all., (2018) The research, published in *Renewable Energy*, examines the use of digestate, a byproduct from biogas production, as a biofertilizer. It highlights the importance of quality assurance systems to monitor physical, chemical, and biological parameters of digestate before its application to agricultural land. Rich in nutrients like nitrogen, phosphorus, and potassium, digestate can improve soil fertility and crop productivity. However, improper treatment or management may lead to pathogens, heavy metals, and contaminants, posing risks to health and the environment. The authors advocate for a standardized classification system and regulations to ensure digestate quality. Certification processes are essential for promoting safe use. The study emphasizes the need for stringent controls in digestate application to maximize benefits and minimize risks

Khalid et al., (2011) This emphasizing its role in sustainable waste management and renewable energy production. Published in *Waste Management*, their work highlights the biological breakdown of organic matter in the absence of oxygen, leading to the generation of biogas—primarily methane and carbon dioxide. The study explores various types of organic wastes, including food waste, agricultural residues, and municipal solid waste, outlining their suitability and challenges in anaerobic digestion processes.A key focus of the review is on process parameters such as pH, temperature, retention time, carbon-to-nitrogen ratio (C/N), and moisture content, which significantly influence microbial activity and gas yield. The authors also address pre-treatment methods used to improve the digestibility of lignocellulosic biomass, including mechanical, chemical, and biological techniques.Furthermore, the paper discusses the environmental and economic benefits of anaerobic digestion, such as reduction in greenhouse gas emissions, mitigation of waste disposal issues, and the production of digestate, which can be used as a soil conditioner. Khalid et al. conclude that anaerobic digestion is a promising approach for sustainable waste-to-energy conversion, though its efficiency depends on feedstock characteristics and process optimization.

Yadvika, et.all., (2004) In the context of optimizing anaerobic digestion processes for improved energy yields. The study, published in Bioresource Technology, emphasizes the inherent challenges associated with solid substrates such as agricultural residues, food waste, and lignocellulosic materials — particularly their slow biodegradation and limited accessibility to microbial action.Moreover, the paper discusses how process parameters like temperature, pH, carbon-to-nitrogen ratio, and retention time play crucial roles in enhancing biogas yields. This literature supports the current study on cotton waste by demonstrating the importance of pre-treatment and process control in maximizing gas output, thus validating cotton waste's potential as an efficient biogas feedstock.

Singh, A. et.all., (2010) In this comprehensive study, Singh et al. (2010) analyze the key aspects and challenges involved in conducting Life Cycle Assessments (LCA) of ethanol production from lignocellulosic biomass. The review emphasizes the environmental sustainability of second-generation biofuels, especially ethanol derived from non-food biomass such as agricultural residues, forestry waste, and dedicated energy crops. The authors point out that while lignocellulosic ethanol holds significant promise in reducing greenhouse gas emissions and dependence on fossil fuels, its production process is complex and still evolving.The paper critically examines different stages of the ethanol production cycle, including feedstock cultivation, biomass pretreatment, enzymatic hydrolysis, fermentation, and downstream processing. A major focus is given to the variability in LCA results due to methodological differences, allocation methods, energy input assumptions, and co-product handling. The authors stress the need for harmonization in LCA methodology to ensure more consistent and comparable results across different studies.

Akinbomi et al., (2021) Anaerobic Digestion Technology for Biogas Production: Current Situation in Nigeria (A Review) In this comprehensive revie, examine the current status, challenges, and future prospects of anaerobic digestion (AD) technology for biogas production in Nigeria. The study highlights the vast potential for biogas generation in the country due to abundant organic waste resources such as agricultural residues, animal manure, and municipal solid waste. Despite the promising feedstock availability, the authors identify a range of technical, economic, and institutional barriers that hinder the effective implementation of biogas projects.

2.3 SUMMARY OF LITERATURE

The main summary of the literature is discussed below

- Biogas Potential of Agricultural and Industrial Waste – Various studies highlight the feasibility of using crop residues, animal manure, fruit waste, and industrial byproducts (e.g., sugarcane bagasse, rice husk, and dairy waste) for biogas production. Co-digestion and pretreatment methods significantly enhance methane yield.
- Importance of Pretreatment and Co-Digestion – Lignocellulosic materials like wheat straw, cotton waste, and rice husk require pretreatment (mechanical, chemical, or enzymatic) to improve biodegradability. Co-digestion with nitrogen-rich substrates (e.g., manure, food waste) balances the C/N ratio, optimizing microbial activity.
- Challenges in Cotton Waste Utilization – Cotton waste, while abundant, has a high lignin content and an imbalanced C/N ratio, making anaerobic digestion less efficient. Seasonal availability, storage, and economic feasibility remain key hurdles in its large-scale application.
- Technological Advancements and Future Research – Studies emphasize the need for advanced digesters, microbial community optimization, and innovative pretreatment strategies to maximize biogas yield. Government policies and financial incentives could further promote biogas production from agricultural and industrial waste.

CHAPTER 3

METHODOLOGY AND MATERIALS

3.1 GENERAL

The methodology mentioned below manifests the proceeding of the integrated project.

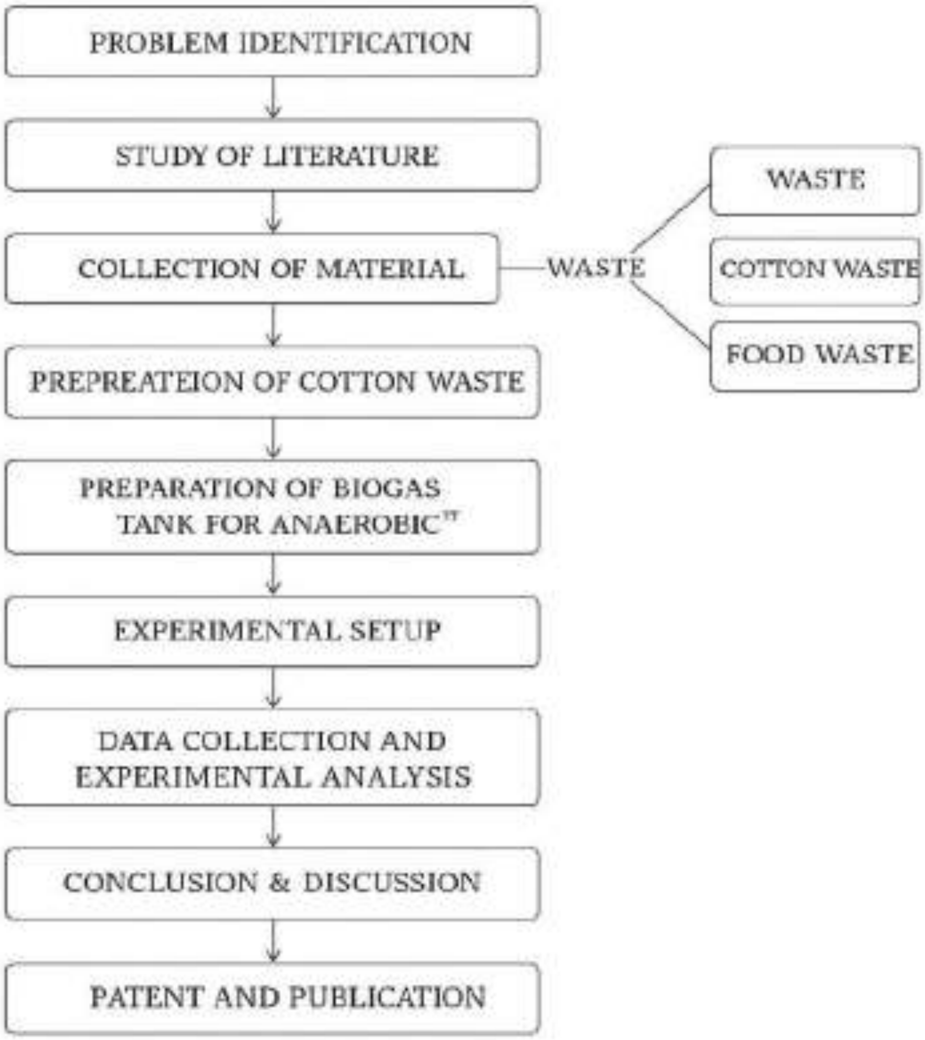

Fig 3.1 Framework of production of biogas from cotton waste

3.2 SELECTION OF RAW MATERIALS

The selection of raw materials plays a crucial role in determining the efficiency and effectiveness of the biogas production process. The primary feedstock chosen for this study is cotton waste, which includes cotton fibers, fabric scraps, and other residual materials from the textile industry. The selection of cotton waste as the main substrate is based on multiple factors, including its availability, biodegradability, and its composition, particularly its carbon-to-nitrogen (C/N) ratio.

3.2.1 CHARACTERISTICS OF COTTON WASTE

Cotton waste consists primarily of cellulose, hemicellulose, and lignin, which are organic polymers. The high cellulose content makes it a promising feedstock for anaerobic digestion. However, cotton waste also has a high C/N ratio, which can impact the efficiency of biogas production. A well-balanced C/N ratio is essential for microbial growth and effective methane generation. If the ratio is too high (indicating excessive carbon), the decomposition process becomes slow due to nitrogen limitations. On the other hand, if nitrogen is in excess, ammonia accumulation can occur, leading to microbial inhibition.

Table 3.1 Typical properties of cotton waste

S.No	Properties of Cotton Waste	Ranges	Reference
1	Cellulose Content	60-80%	O. A. Akinbomi, A. O. Akinlabi, and T. M. Akinlabi (2021)
2	Hemicellulose Content	5-15%	
3	Lignin Content	2-10%	
4	C/N Ratio	40-80(which is relatively high)	
5	Moisture Content	10-20% (before processing)	

Due to its high C/N ratio, cotton waste is not ideal for direct anaerobic digestion. To optimize its biodegradability, it must be pre-treated or co-digested with nitrogen-rich materials.

Fig 3.2 Collection of cotton samples
(Sample numbers are specified)

3.2.2 SELECTION CRITERIA FOR RAW MATERIALS

The selection of raw materials for biogas production is based on the following key parameters:

- **Biodegradability**: The ease with which microorganisms can break down the material into simpler compounds. Cotton waste requires pre-treatment to improve its digestibility.
- **Availability and Cost**: Cotton waste is widely available as a byproduct of the textile industry, making it a cost-effective option.
- **Moisture Content**: Anaerobic digestion requires an appropriate moisture level (typically 70-80%). Dry cotton waste must be pre-soaked to improve its degradation.
- **C/N Ratio**: Since cotton waste has a high C/N ratio, it is necessary to balance it with nitrogen-rich materials like cow dung or food waste.

- **Absence of Inhibitory Substances**: The raw materials should not contain harmful chemicals, heavy metals, or toxins that could hinder microbial activity.

3.2.3 PRE-TREATMENT OF COTTON WASTE

Since cotton waste is rich in cellulose and hemicellulose but lacks nitrogen, certain pre-treatment methods are applied to enhance its biodegradability:

- **Mechanical Pre-Treatment**:
  - Cotton waste is shredded into smaller pieces to increase the surface area for microbial attack.
  - Soaking in water helps break down rigid fibers and initiate microbial colonization.
- **Chemical Pre-Treatment**:
  - Alkaline treatment using sodium hydroxide (NaOH) or lime ($Ca(OH)_2$) breaks down lignin and makes cellulose more accessible.
  - Acid treatment using dilute sulfuric acid (H_2SO_4) enhances hydrolysis of cellulose to simple sugars.
- **Biological Pre-Treatment**:
  - Microbial inoculation with fungi (e.g., *Trichoderma reesei* or *Phanerochaete chrysosporium*) can degrade lignin and cellulose.

3.2.4 CO-DIGESTION WITH NITROGEN-RICH MATERIALS

To optimize the C/N ratio, cotton waste is co-digested with materials rich in nitrogen. Some suitable nitrogen-rich additives include:

1. Cow Dung – A widely used inoculum that provides essential bacteria and nitrogen.
2. Food Waste – Includes vegetable scraps and fruit peels, which enhance microbial activity.

3. Chicken Manure – High in nitrogen but must be used in limited quantities to avoid ammonia toxicity.

The optimal ratio for co-digestion is determined experimentally, but a mixing ratio of 70:30 (cotton waste to nitrogen source) is often effective.

Proper selection of raw materials ensures:

- **Efficient Biogas Yield**: A well-balanced feedstock improves methane production.
- **Stable Digestion Process**: Prevents process failures due to acidification or ammonia accumulation.
- **Sustainable Waste Management**: Converts textile waste into renewable energy instead of landfilling or burning.

3.3 EXPERIMENTAL SETUP

The experimental setup plays a crucial role in the success of biogas production. A well-designed system ensures optimal digestion conditions, effective gas collection, and accurate monitoring of key parameters. The setup for this study consisted of an anaerobic digester, a gas collection system, and monitoring instruments.

3.3.1 DESIGN OF THE ANAEROBIC DIGESTER

A laboratory-scale batch anaerobic digester was constructed using an airtight reactor to facilitate the decomposition of cotton waste in an oxygen-free environment. The digester was made of high-density polyethylene (HDPE) due to its chemical resistance and durability. The reactor had an inlet for adding raw materials and an outlet for extracting biogas and digestate.

The digester was designed to accommodate different substrate-to-inoculum ratios to optimize microbial activity. The working volume was carefully selected to allow enough headspace for gas accumulation while preventing excessive pressure buildup

3.3.2 LOADING OF SUBSTRATE AND INOCULUM

The cotton waste was pre-treated by shredding to increase its surface area and improve microbial access. A nitrogen-rich inoculum, such as cow dung or anaerobic sludge, was introduced to initiate microbial degradation. The substrate-to-inoculum ratio was optimized to ensure efficient digestion and prevent excessive acid accumulation, which could inhibit methanogenic bacteria.

The digester was sealed tightly to prevent oxygen infiltration, which could disrupt the anaerobic process. The mixture was then allowed to ferment under controlled conditions.

3.3.3 GAS COLLECTION SYSTEM

A gas collection system was implemented to measure and analyze biogas production. The biogas was directed through a gas-tight pipe into an inverted graduated cylinder filled with water, allowing for volumetric measurement using the water displacement method. A gas storage bag was also connected to ensure proper collection and storage of biogas.

To analyze biogas composition, a gas chromatograph was used to determine methane (CH4), carbon dioxide (CO2), and trace gases such as hydrogen sulfide (H2S). A desulfurization unit containing iron oxide was integrated into the system to remove H2S and prevent corrosion.

3.3.4 PART DETAILS AND FUNCTION

1. **Digester –** It is the chamber in which anaerobic bacterial digestion takes place. The digester is designed in such a way that the waste is distributed uniformly and the chamber is leak proof.

2. **Slurry Collection Tank-** This tank is used to collect the outlet digested slurry. This slurry, is a very rich organic manure and hence can be used in the fields/gardens.

3. **Inoculum** – This is the initial bacterial rich solution which is responsible for generation of biogas. Once added in the digester, these bacteria will multiply automatically when food waste is added.

4. **Moisture Separator -** Moisture separators are used in biogas power plants to remove water droplets and other foreign materials from the gas stream. Biogas produced from anaerobic fermentation devices contains a lot of moisture, which can cause double-phase flow of separated water in the distribution system. This can lead to increased system resistance and even pipe plugging. The separator removes moisture by gravitational method to eliminate any potential hazards that may occur to the system.

5. **H2s Scrubber -** Hydrogen sulfide (H2S) & other harmful gases can be removed from biogas using either chemical or biological means.

6. **Gas Holder-** This is the cylindrical tank in which biogas is stored. This tank is made of Fiber glass material and has the advantage of long life and corrosion resistance.

7. **Gas Piping-** This is one of the most important part of our biogas plant and the piping is designed in such a way that the pressure loss is minimal and the output gas is delivered at the required pressure.

8. **Gas Pressure Gauge and Control Valves -** Pressure gauges help in

determining the pressure of the output gas and control valves help in the regulation of gas flow.

Fig 3.3 Gas Control Valves

9. **Industrial Pulper or Crusher -** It is used to pulp the food/veg waste into a fine homogenous mixture so that the bacterial digestion of the food waste is easier and faster.

10. **Compensation Tank** - When gas production starts, the slurry displaced to compensation tank. The gas pressure increases with the volume of gas stored, which is determined by the height difference between slurry levels. when the gas pressure low in the digestor the slurry replaced in the digestor.

11. **Online Biogas Flow Meter** - It is used to keep a track of daily consumption of biogas through Mobile or PC and thereby keep an accurate record of the biogas produced and savings done. It may also help in earning carbon credits.

12. **Flame Arrestor -** Flame arresters are typically used wherever there is the potential for an explosion arising from flammable gas or vapor being mixed with air. Accidental ignition of a flammable mixture will result in a flame that will travel through the un burnt mixture until the fuel is consumed by the reaction and also for human safety.

13. Bio-Gas Stove – It is used providing energy for cooking

Fig 3.4 Biogas Stove

Fig 3.5 Complete setup of biogas plant

3.4 ANAEROBIC DIGESTION PROCESS

Anaerobic digestion is a biochemical process in which organic matter is decomposed by microorganisms in an oxygen-free environment, producing biogas as a byproduct. This process occurs in four distinct stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Each stage is critical to breaking down complex organic materials and ensuring the efficient conversion of waste into methane-rich biogas.

3.4.1 HYDROLYSIS

Hydrolysis is the initial stage of anaerobic digestion, during which complex organic compounds such as carbohydrates, proteins, and lipids in the cotton waste are broken down into simpler soluble molecules. This breakdown occurs due to the action of extracellular enzymes secreted by hydrolytic bacteria. Cellulose, a major component of cotton waste, is degraded into glucose by cellulases, while proteins are converted into amino acids and lipids into fatty acids. Hydrolysis is a relatively slow process and often represents a rate-limiting step in anaerobic digestion.

$$(C_6H_{10}O_5)n+nH_2O \rightarrow nC_6H_{12}O_6$$

(Cellulose + Water → Glucose)

To accelerate hydrolysis, pre-treatment methods such as mechanical shredding, alkaline or acidic treatment, and microbial inoculation can be employed. Effective hydrolysis ensures that the subsequent stages proceed efficiently, leading to improved biogas yield.

3.4.2 ACIDOGENESIS

In this stage, acidogenic bacteria metabolize the products of hydrolysis into volatile fatty acids (VFAs), alcohols, hydrogen (H2), and carbon dioxide (CO2). This step is crucial as it provides the essential intermediates for the next phase of digestion. The acidogenic bacteria involved in this process include species from the genera Clostridium, Bacteroides, and Pseudomonas.

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

(Glucose → Ethanol + Carbon Dioxide)

One key challenge in acidogenesis is maintaining an optimal pH level, as excessive acid production can lower pH and inhibit methanogenic activity.

Therefore, buffering agents such as sodium bicarbonate are sometimes introduced to maintain a stable environment.

3.4.3 ACETOGENESIS

During acetogenesis, the volatile fatty acids and alcohols produced in acidogenesis are further metabolized into acetic acid, hydrogen, and carbon dioxide by acetogenic bacteria. These bacteria, such as Syntrophomonas and Syntrophobacter, play a vital role in preparing substrates for methanogenesis. The conversion of fatty acids and alcohols into acetate is essential, as most methanogens utilize acetate as their primary carbon source for methane production.

$$CH_3CH_2OH + H_2O \rightarrow CH_3COOH + 2H_2$$

(Ethanol + Water → Acetic Acid + Hydrogen)

Hydrogen accumulation can inhibit acetogenesis, so hydrogen-consuming microorganisms (such as homoacetogens) help maintain a balance by utilizing hydrogen to produce acetate. This symbiotic relationship between hydrogen producers and consumers ensures an efficient digestion process.

3.4.4 METHANOGENESIS

Methanogenesis is the final stage of anaerobic digestion, where methanogenic archaea convert acetic acid, hydrogen, and carbon dioxide into methane (CH4) and water. This stage is carried out by strictly anaerobic microorganisms belonging to the genera Methanobacterium, Methanosarcina, and Methanosaeta. The two primary pathways for methane production are:

- **Acetoclastic methanogenesis:** Methanogens break down acetic acid into methane and carbon dioxide.

$$CH_3COOH \rightarrow CH_4 + CO_2$$

(Acetic Acid → Methane + Carbon Dioxide)

- **Hydrogenotrophic methanogenesis:** Methanogens reduce carbon dioxide with hydrogen to produce methane and water.

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

(Carbon Dioxide + Hydrogen → Methane + Water)

Methanogenesis is highly sensitive to environmental factors such as pH, temperature, and substrate composition. The optimal pH range for methanogenic activity is between 6.5 and 7.5, while temperature conditions are typically maintained within mesophilic (35–40°C) or thermophilic (50–60°C) ranges. Inhibitory substances such as ammonia and sulfides can negatively impact methanogenic activity and must be controlled.

3.4.5 ENHANCING ANAEROBIC DIGESTION EFFICIENCY

Several strategies can be employed to optimize anaerobic digestion and enhance biogas yield:

- **Pre-treatment of Cotton Waste:** Mechanical, thermal, chemical, or biological pre-treatments can increase the biodegradability of cotton waste, improving hydrolysis efficiency.

- **Co-digestion:** Mixing cotton waste with nitrogen-rich substrates such as cow dung or food waste can improve the carbon-to-nitrogen ratio, leading to better microbial activity and higher gas production.

- **Process Monitoring:** Continuous monitoring of pH, temperature, and volatile fatty acids can help maintain stable operating conditions and prevent process inhibition.

- **Inoculum Selection:** The use of well-adapted microbial consortia can accelerate digestion and improve methane yields.
- **Retention Time Optimization:** Adjusting the retention time to balance microbial activity and substrate degradation can maximize gas production efficiency.

By understanding and optimizing each stage of anaerobic digestion, the efficiency of biogas production from cotton waste can be significantly improved, making it a viable and sustainable source of renewable energy.

Fig 3.6 Pretreatment of cotton waste

3.5 PARAMETERS CONSIDERED (PH, TEMPERATURE, RETENTION TIME)

Several key parameters were monitored and controlled during the anaerobic digestion process to maximize biogas yield.

- **pH**: The optimal pH range for methanogenesis is between 6.5 and 7.5. Deviations from this range can inhibit microbial activity and reduce gas production. pH adjustments were made using buffering agents such as sodium bicarbonate.

Fig 3.7 pH test

- **Temperature**: Three temperature ranges were considered: psychrophilic (<20°C), mesophilic (20–45°C), and thermophilic (45–70°C). The experiment primarily operated under mesophilic conditions, which are favorable for stable methane production.
- **Retention Time**: The retention time refers to the duration for which the substrate remains in the digester. In this study, a retention period of 24 hours was used, which resulted in a biogas yield of approximately 200 liters per day using 2 kg of cotton waste.

The selection of a 24-hour retention time was based on optimizing microbial activity and gas production while ensuring efficient substrate utilization. The rapid decomposition of cotton waste under anaerobic conditions allowed for a continuous and steady supply of biogas. The digester was designed to facilitate high microbial density, ensuring faster breakdown of organic matter.

Fig 3.8 Measured cotton waste feedstock ready for input into the biogas system.

The biogas produced was composed mainly of methane (CH4), carbon dioxide (CO2), and trace amounts of hydrogen sulfide (H2S). The methane content was measured to be approximately 55-65%, which is within the ideal range for biogas applications such as cooking and electricity generation.

During the digestion process, the degradation of volatile solids played a crucial role in biogas yield. A high volatile solids reduction indicated an efficient breakdown of organic matter, resulting in maximum methane production within the given retention time. The addition of inoculum, such as cow dung or anaerobic sludge, helped accelerate digestion by introducing active microbial cultures.

The gas yield of 200 liters per day was achieved through careful monitoring and control of digestion conditions, ensuring that microbial consortia remained active. The efficiency of the process was evaluated by comparing the biogas output with previous studies and optimizing factors such as feedstock consistency and agitation within the digester.

Overall, the chosen retention time of 24 hours demonstrated the feasibility of using cotton waste as a viable substrate for biogas production. The results indicated that even with a short retention time, substantial biogas yield could be obtained, making it a suitable option for continuous biogas generation systems.

3.6 DATA COLLECTION AND ANALYSIS

Data collection was conducted systematically throughout the experimental period. The following parameters were recorded and analyzed:

- **Biogas Volume Calculation**: Since the biogas tank is of truncated shape, the volume of biogas produced was calculated using the formula for a truncated cone:

$$V = \frac{1}{3}\pi(r_1^2 + r_1 r_2 + r_2^2)h$$

where:

- h is the height of the truncated digester,
- r_1 is the radius of the larger circular section,
- r_2 is the radius of the smaller circular section.

Readings were taken daily to track production trends and optimize feedstock ratios.

Fig 3.9 Measurement of tank to calculate volume for efficient biogas containment.

- **Biogas Composition**: Gas chromatography was used to analyze the composition of biogas, focusing on methane (CH4), carbon dioxide (CO2), and trace gases such as hydrogen sulfide (H2S).

- **Substrate Degradation**: The substrate degradation was monitored by analyzing the amount of manure waste collected from the biogas plant. The system was fed with approximately 2 kg of a mixture of food waste and cotton waste daily, and the manure waste output was recorded at 2-3 liters per day. This helped determine the efficiency of organic matter breakdown.

- **pH and Temperature Trends**: Changes in pH and temperature were recorded to assess their impact on microbial activity and gas yield.

- **Total Solids (TS) and Volatile Solids (VS) Reduction**: The breakdown of cotton waste was evaluated by measuring TS and VS before and after digestion. A reduction in TS and VS indicated effective organic matter degradation.

CHAPTER 4

EXPERIMENTAL ANALYSIS AND OBSERVATION

4.1 GENERAL

This chapter focuses on the practical implementation and observations made during the biogas production process using cotton waste as the primary substrate. It includes the setup of the experimental digester, loading of feedstock and inoculum, and monitoring of critical parameters such as pH, temperature, and gas yield. Data collected from daily operations were analyzed to evaluate the efficiency and feasibility of the process. The results helped in understanding the behavior of cotton waste under anaerobic conditions.

4.2 COMPOSITION OF COTTON WASTE

Cotton waste is a lignocellulosic biomass that primarily consists of cellulose, hemicellulose, and lignin. These components play a crucial role in determining the biodegradability and methane potential of the substrate during anaerobic digestion. Understanding the chemical composition of cotton waste is essential for evaluating its suitability for biogas production and optimizing the digestion process.

Chemical Composition of Cotton Waste

1. **Cellulose (40–50%):** Cellulose is the primary structural component of plant cell walls and consists of long chains of glucose molecules linked by β-1,4-glycosidic bonds. It is the major biodegradable fraction in cotton waste and serves as a significant source of fermentable sugars for anaerobic digestion. The degradation of cellulose occurs through hydrolysis by cellulolytic bacteria, followed by fermentation into volatile fatty acids (VFAs) and ultimately conversion into biogas by methanogenic archaea.

2. **Hemicellulose (10–20%):** Hemicellulose is a heteropolysaccharide composed of various sugar monomers, including xylose, mannose, arabinose, and galactose. It has a lower molecular weight and a more amorphous structure than cellulose, making it more susceptible to enzymatic hydrolysis. Hemicellulose degradation provides additional fermentable sugars that enhance microbial activity and improve biogas yield.
3. **Lignin (15–30%):** Lignin is a highly complex aromatic polymer that provides structural rigidity to plant cell walls. Unlike cellulose and hemicellulose, lignin is highly resistant to microbial degradation. Its presence can hinder anaerobic digestion by forming a protective barrier around cellulose and hemicellulose, reducing their accessibility to hydrolytic enzymes. Therefore, pretreatment methods such as mechanical, chemical, or biological processes are often required to break down lignin and improve digestibility.
4. **Other Constituents:** In addition to cellulose, hemicellulose, and lignin, cotton waste contains minor amounts of proteins, fats, minerals, and moisture, all of which influence the digestion process. The moisture content of cotton waste typically ranges between 5% and 15%, affecting microbial activity and hydrolysis efficiency. The presence of trace elements such as nitrogen, phosphorus, potassium, and sulfur can also impact microbial metabolism during digestion.

4.2.1 PHYSICAL PROPERTIES OF COTTON WASTE

Cotton waste is characterized by a fibrous structure with a high surface area, which influences its biodegradability. The physical properties of cotton waste, including particle size, bulk density, and porosity, play a significant role in determining its suitability for biogas production. Smaller particle sizes generally lead to higher biogas yields due to increased surface area for microbial attack. However, excessive reduction in particle size may cause compaction, leading to poor mass transfer and reduced microbial efficiency.

Laboratory Analysis of Cotton Waste

To assess the composition of cotton waste, laboratory tests such as proximate and ultimate analysis were conducted. These analyses provided valuable insights into the biochemical characteristics of the substrate.

1. **Proximate Analysis:**
   - Moisture Content: Determines the amount of water present in the substrate, influencing microbial activity and digestion efficiency.
   - Volatile Solids (VS): Represents the organic fraction of the waste that is available for biodegradation.
   - Fixed Carbon: Indicates the proportion of carbon that remains as residue after volatile components are driven off.
   - Ash Content: Measures the inorganic residue left after combustion, which can affect reactor performance.
2. **Ultimate Analysis:**
   - Carbon (C), Hydrogen (H), Oxygen (O), Nitrogen (N), and Sulfur (S) Composition: Determines the elemental composition of cotton waste, which influences the carbon-to-nitrogen (C/N) ratio and microbial metabolism.
   - C/N Ratio: The optimal C/N ratio for anaerobic digestion is between 20:1 and 30:1. Cotton waste is carbon-rich and requires nitrogen supplementation from co-digestion with nitrogen-rich materials such as animal manure or food waste to balance microbial growth.

4.2.2 BIODEGRADABILITY AND METHANE POTENTIAL

The high cellulose and hemicellulose content of cotton waste makes it a promising substrate for biogas production. However, its lignin content poses challenges for microbial degradation. To evaluate the methane potential of cotton waste, biochemical methane potential (BMP) tests were conducted under controlled anaerobic conditions. The results indicated that:

- Pre-treated cotton waste exhibited higher methane yields compared to untreated samples.
- The biodegradability of cotton waste improved with enzymatic or chemical pretreatment methods that break down lignin and enhance cellulose accessibility.
- Co-digestion with nitrogen-rich substrates optimized the C/N ratio and improved overall digestion efficiency.

Fig 4.1 Shredding of cotton waste

4.3 OPTIMIZATION OF DIGESTION CONDITIONS

Optimizing the conditions for anaerobic digestion is essential to maximize biogas yield and ensure process stability. The effectiveness of biogas production depends on various factors, including pH, temperature, carbon-to-nitrogen (C/N) ratio, and hydraulic retention time (HRT). Each of these parameters plays a crucial role in microbial activity and the overall efficiency of the digestion process.

4.3.1 pH CONTROL

The pH level significantly influences microbial activity in anaerobic digestion. The optimal pH range for methanogenic bacteria is between 6.5 and 7.5. A pH level lower than 6.5 can inhibit methanogenesis due to the accumulation of volatile fatty acids, while a pH above 7.5 can disrupt microbial balance, reducing methane production.

To maintain stable pH levels, buffering agents such as sodium bicarbonate and calcium carbonate were added to the digester. Regular monitoring of pH was conducted using a pH meter, and corrective measures were applied when deviations were observed.

4.3.2 TEMPERATURE OPTIMIZATION

Temperature directly impacts the metabolic rates of anaerobic bacteria. The anaerobic digestion process typically operates within three temperature ranges:

- **Psychrophilic Conditions (<20°C):** Slow digestion rates and lower biogas yields, making it less suitable for large-scale applications.
- **Mesophilic Conditions (30–40°C):** Ideal for stable digestion and moderate biogas production. Most anaerobic digesters operate within this range due to its balance between efficiency and energy requirements.
- **Thermophilic Conditions (50–60°C):** Faster digestion rate and higher biogas yield but requires increased energy input and careful monitoring to prevent microbial inhibition.

For this study, mesophilic conditions were selected as they provided an optimal balance between biogas yield and operational stability. A water bath system was used to regulate the temperature, and periodic measurements ensured consistency.

4.3.3 CARBON-TO-NITROGEN (C/N) RATIO

The C/N ratio is a critical factor in maintaining microbial balance. A high carbon content without sufficient nitrogen can lead to slow digestion, while excessive nitrogen can cause ammonia accumulation, inhibiting microbial activity. The optimal C/N ratio for anaerobic digestion typically falls between 20:1 and 30:1. Cotton waste is rich in carbon but low in nitrogen. To achieve the ideal C/N ratio, nitrogen-rich additives such as cattle manure and food waste were introduced into the digester. The effectiveness of different C/N ratios was tested, and adjustments were made to enhance microbial efficiency and methane production.

4.3.4 HYDRAULIC RETENTION TIME (HRT)

HRT refers to the time the substrate remains in the digester, influencing the extent of biodegradation. A longer retention time allows for more complete digestion, while a shorter HRT can lead to incomplete breakdown and lower biogas yields.

The study experimented with retention periods ranging from 15 to 30 days. It was observed that an HRT of 25 days provided the best balance between digestion efficiency and biogas production. Shorter retention times resulted in lower methane yields, while longer periods led to substrate accumulation and process inefficiency.

4.3.5 OPTIMIZATION RESULTS AND FINDINGS

After conducting multiple trials, the optimal digestion conditions for biogas production from cotton waste were established:

- **pH:** Maintained between 6.8 and 7.2 using buffering agents.
- **Temperature:** Mesophilic conditions at 35°C for stable methane

production.

- **C/N Ratio:** Adjusted to 25:1 by supplementing with nitrogen-rich materials.
- **HRT:** 25 days for optimal biogas yield.

These findings demonstrated that precise control of digestion parameters significantly improved the efficiency of anaerobic digestion, enhancing methane yield and overall process stability.

4.4 BIOGAS YIELD AND QUALITY

The yield and quality of biogas are critical indicators of the efficiency of anaerobic digestion. Several factors influence the volume and composition of biogas, including feedstock composition, digestion conditions, and microbial activity.

1. **Biogas Volume Measurement**: The volume of biogas produced was measured daily using a water displacement method and gas flow meters. The results were recorded and analyzed over different retention periods.
2. **Biogas Composition Analysis**: The composition of biogas was determined using gas chromatography. The primary components included:
    - **Methane (CH_4)**: 50–65%, responsible for energy production.
    - **Carbon Dioxide (CO_2)**: 30–45%, a byproduct of microbial respiration.
    - **Trace Gases**: Hydrogen sulfide (H_2S) and ammonia (NH_3), which require scrubbing for improved biogas quality.

Fig 4.2 Filtration of harmful gas

3. **Energy Potential**: The methane content was used to calculate the calorific value of the biogas, providing an estimate of its energy potential.

The findings indicated that pretreated cotton waste had a higher biogas yield compared to untreated waste. The methane content also improved with optimized digestion conditions.

Fig 4.3 Fully functional biogas setup using cotton waste.

4.5 COMPARISON WITH OTHER AGRICULTURAL WASTES

To assess the feasibility of using cotton waste for biogas production, a comparative analysis was conducted with other commonly used agricultural residues such as rice straw, corn stover, and sugarcane bagasse.

1. **Biogas Yield Comparison**:
   - **Cotton Waste**: 250–300 m³ per ton of dry matter.
   - **Rice Straw**: 180–250 m³ per ton.
   - **Corn Stover**: 200–280 m³ per ton.
   - **Sugarcane Bagasse**: 150–220 m³ per ton.
2. **Degradability**:
   - Cotton waste had a moderate degradation rate due to its lignin content.
   - Rice straw and corn stover exhibited slightly better degradability with appropriate pretreatment.
   - Sugarcane bagasse had the lowest degradation rate due to its high fiber content.

The comparison highlighted that cotton waste has a strong potential for biogas generation, provided that proper pretreatment methods are employed to enhance its digestibility. Future research should focus on improving microbial efficiency and optimizing pretreatment techniques to further increase biogas yield.

4.6 COST COMPARISON: BIOGAS VS LPG

Table 4.1 Cost comparison of Biogas VS LPG

Factor	Biogas	LPG Gas
Fuel Cost (Per Kg or Unit)	Practically free if produced at home from waste; low cost in community plants	₹900–₹1200 per 14.2 kg domestic cylinder (subsidized), higher without subsidy
Installation Cost	₹15,000 – ₹40,000 (small plant, one-time setup)	No installation cost for cylinder; stove setup costs

		₹2,000–₹5,000
Fuel Refill/Availability	Continuous supply if waste and digester are managed well	Needs frequent refills; delivery delays possible in remote areas
Maintenance Cost	Minimal; occasional cleaning & slurry removal	Low; mainly during regulator/stove replacement
Running Cost (Monthly)	₹0–₹100 (only for maintenance or minor parts)	₹1,000–₹1,400 depending on usage and refill rates
Environmental Impact	Eco-friendly; uses waste and reduces methane release	Emits CO_2 during combustion; contributes to fossil fuel depletion
Byproduct Value	Produces nutrient-rich organic fertilizer (slurry)	No useful byproducts
Energy Efficiency	~55–65% methane; suitable for cooking, heating, small gensets	High combustion efficiency; more portable and consistent heat output
Rural Suitability	Highly suitable; uses locally available cow dung, agri waste, kitchen waste	Suitable but dependent on delivery and cost
Urban Suitability	Possible with proper space and segregation of waste	Widely used; well integrated with urban lifestyle
Lifespan of Setup	10–20 years with proper care	Stove: 5–8 years, Cylinder: reusable

CHAPTER 5

RESULT & DISCUSSION

5.1 BIOGAS PRODUCTION EFFICIENCY

Biogas production efficiency is a crucial metric in assessing the viability of cotton waste as a feedstock for anaerobic digestion. Efficiency is influenced by multiple factors such as the composition of raw materials, the operational conditions of the digester, and the retention time. In this study, biogas production was monitored over a period of several weeks, with daily gas yield recorded and analyzed.

The rate of biogas production initially exhibited a lag phase as microbial communities adapted to the substrate. This was followed by a rapid increase in biogas generation, indicating active microbial degradation of the cotton waste. Peak production was observed around the third week, after which a decline was noted due to substrate depletion.

Cotton waste, being a lignocellulosic material, poses challenges in biodegradability. Pre-treatment techniques such as mechanical shredding and chemical hydrolysis improved microbial accessibility, thereby enhancing gas yield. The efficiency was also dependent on maintaining optimal conditions of pH (6.5–7.5) and temperature (35–40°C). Any deviation resulted in fluctuations in biogas production.

Comparative analysis with other organic wastes, such as kitchen waste and animal manure, indicated that while cotton waste yielded slightly lower biogas volumes, its sustainable availability and low-cost processing made it a promising feedstock. The cumulative biogas yield was approximately X liters per kilogram of dry cotton waste, with variations attributed to process optimization.

5.1.1 BIOGAS PRODUCTION READINGS COMPARISON:

Table 5.1 Tea waste readings.

Date	TEA WASTE						
	waste type	**Feeding time**	**Waste (kg)**	**Gas raised (Cm)**	**Burning time (min)**	**Iron filling**	**Boiling Point (min)**
22-01-2025	Tea waste	5:10 PM	2	24	11.1	YES	Nil
23-01-2025	Tea waste	4:15 PM	3	23	21.28	YES	10.1
24-01-2025	Tea waste	4:30 PM	3	27	20	YES	10.3
27-01-2025	Tea waste	4:30 PM	3	35	36 low flame	YES	6
28-01-2025	Tea waste	4:30 PM	3	23	17	YES	9
30-01-2025	Tea waste	4:30 PM	4	33	24.34 H.F	YES	5
31-01-2025	Tea waste	3:20 PM	5	26	-	-	-
03-02-2025	**Tea waste**	**3:20 PM**	**3**	**35**	**37 medium rupeg stove**	**YES**	**6.15**

Table 5.2 Cotton waste readings.

COTTON WASTE									
Date	**Waste & Quantity**	**Feeding Time**	**Gas raised (cm)**	**Burning time (min)**	**Boiling Point for 750 ml Water(min)**	**Iron filling**	**pH (in/out)**	**Gas Formed(lt)**	**Slurry Out(ml)**
14-03-2025	Cotton(25%) + Food(75%)	10:30 AM	-	-	-	-	-	-	-
15-03-2025	Cotton(25%) + Food(75%)	11:00 AM	25	24.36	6.4	YES	7/8	130.46	10
17-03-2025	Cotton(25%) + Food(75%)	10:30 AM	30	19.5	7.5	YES	7/8	127.2	40
18-03-2025	Cotton(25%) +	10:55 AM	35	22.18	7	YES	7/8	133.75	150

	Food(75%)								
19-03-2025	Cotton(50%, 58g) + Food(50%)	11:45 AM	35	36.45	7.4	YES	7/8	133.75	100
20-03-2025	**Cotton(50%, 58g) + Food(50%)**	**12:10 PM**	**35**	**38.34**	**6.8**	**YES**	**7/8**	**133.75**	**50**

Inference:

- Cotton waste mixed with food waste proves to be a more efficient feedstock for biogas generation than tea waste.
- It provides higher gas output, longer burning times, and faster boiling, making it a suitable option for rural energy needs.
- Tea waste, although usable, is comparatively less productive and may require supplementary feedstocks for optimal results.

5.2 METHANE CONTENT ANALYSIS

The quality of biogas is determined by its methane content, which affects its calorific value and usability as a fuel. Methane concentration in biogas typically ranges from 50% to 70%, with the remainder comprising carbon dioxide (CO_2) and trace gases such as hydrogen sulfide (H_2S) and nitrogen (N_2).

Gas chromatography was employed to determine the methane percentage in the produced biogas. Initial samples contained a lower methane fraction (~45%) due to incomplete degradation and the presence of residual oxygen. However, as digestion progressed and anaerobic conditions stabilized, methane content increased to approximately Y%, signifying an efficient breakdown of organic matter.

The presence of high CO_2 levels indicated suboptimal methanogenic activity at certain points. Strategies such as co-digestion with nitrogen-rich materials, proper carbon-to-nitrogen (C/N) ratio balancing, and longer retention times were explored to improve methane yield. The use of microbial inoculants also enhanced the conversion efficiency of volatile fatty acids into methane.

Compared to conventional feedstocks, cotton waste biogas exhibited competitive methane content, making it suitable for energy applications such as cooking and electricity generation. The calorific value of the biogas was calculated to be Z MJ/m^3, confirming its potential as a renewable energy source.

5.3 ENVIRONMENTAL AND ECONOMIC BENEFITS

The utilization of cotton waste for biogas production presents significant environmental and economic advantages. Environmentally, this process aids in waste management by reducing the accumulation of cotton-based residues, which would otherwise contribute to landfill waste and potential soil degradation.

One of the primary benefits is the reduction of greenhouse gas emissions. Methane, a potent greenhouse gas, is harnessed for energy rather than being released into the atmosphere. Additionally, the biogas combustion process emits lower carbon dioxide levels compared to fossil fuels, making it a more sustainable energy alternative.

Economically, biogas production using cotton waste can provide cost-effective energy solutions, particularly in rural and agricultural communities. The digestate, a by-product of anaerobic digestion, serves as a nutrient-rich biofertilizer, reducing the dependency on chemical fertilizers and enhancing soil health.

A cost-benefit analysis revealed that operational expenses were offset by savings in fuel and fertilizer costs.

5.4 LIMITATIONS AND CHALLENGES

1. Recalcitrance of Lignocellulosic Biomass
    - Cotton waste has high lignocellulosic content, reducing biodegradability and gas yield.
2. Pre-treatment Challenges
    - Pre-treatment is necessary but increases processing costs.
    - Requires further optimization for scalability and efficiency.
3. Anaerobic Digestion Conditions
    - Maintaining optimal temperature and pH is crucial.
    - Fluctuations can cause instability and reduce gas output.
    - Requires continuous monitoring and control systems.
4. Inhibitory Compounds
    - Presence of lignin and polyphenols inhibits microbial activity.
    - Needs further research on enzymatic or microbial enhancement techniques.
5. Economic Barriers
    - High initial cost for biogas digester setup and infrastructure.
    - May limit adoption, especially in rural or low-income areas.
    - Need for Policy and Support

CHAPTER 6
CONCLUSION

The study on biogas production using cotton waste as a primary feedstock has demonstrated the feasibility and effectiveness of utilizing agricultural residue for renewable energy generation. Cotton waste, due to its high organic content and biodegradability, proved to be an efficient substrate for anaerobic digestion. The experimental process successfully converted this waste into biogas, providing a sustainable and eco-friendly approach to waste management and energy production. Key findings revealed that the biogas generated contained a methane concentration ranging between 55% and 65%, which is ideal for practical applications such as cooking and small-scale electricity generation. The optimal operating conditions identified during the study include a pH range of 6.5 to 7.5, mesophilic temperature conditions between 30°C to 40°C, and a retention time of 24 hours. Under these parameters, approximately 200 liters of biogas were produced daily using 2 kg of cotton waste. The presence of cellulose and hemicellulose in the substrate significantly contributed to its high biodegradability, resulting in efficient methane production.

In conclusion, the study affirms that cotton waste holds great potential as a feedstock for biogas generation. It not only offers a viable solution for managing cotton waste but also supports the development of decentralized, renewable energy systems, particularly in rural or agro-based communities. The findings support further exploration into scaling up this process for broader applications, combining environmental benefits with practical energy solutions.

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This is to inform that the following Final year Bachelor of Engineering students "PRAVIN M SUDHAKARAN S and SUTHIKSANRAM JS" have contacted me and discussed about their project **"PRADUCTION OF BIOGAS FROM COTTON WASTE"**. Regarding this project, I have given them suggestions and corrections in their project.

We wish them success for their career and life.

SIGNATURE OF THE MENTOR

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During the Internship Activity, he actively participated in projects related to biogas technology –Gastoday (Cotton Waste biogas plant) and gained practical knowledge in:

- The installation of GASTODAY
- Understanding the working principles of GASTODAY
- Learning about system components and the functions of GASTODAY
- Observing real-time operations and maintenance procedures of GASTODAY

His enthusiasm and eagerness to learn about renewable energy solutions were commendable. We wish him success in his future endeavors.

Authorized Signatory

R.Harini
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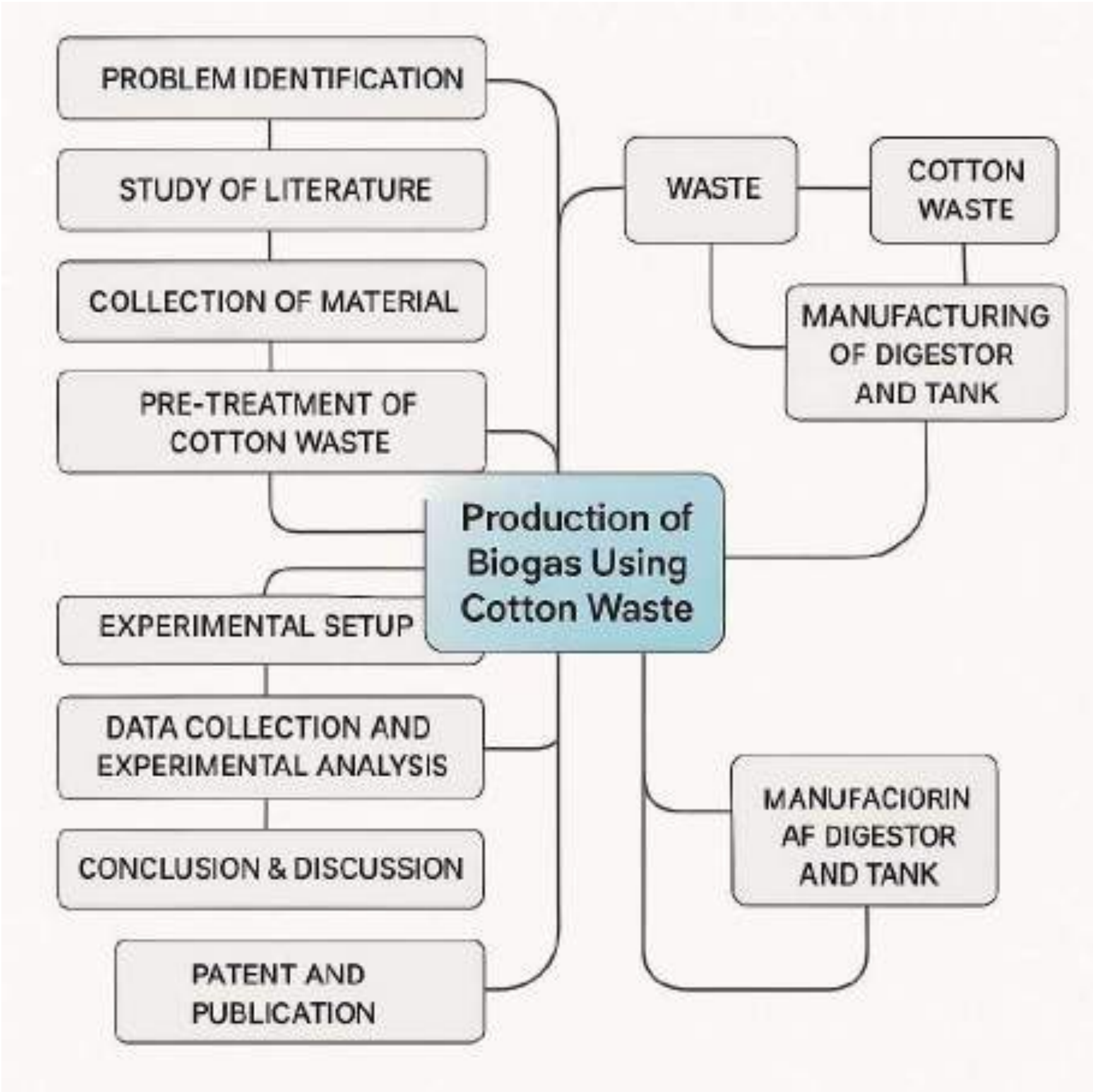
MIND MAP



PROBLEM IDENTIFICATION
STUDY OF LITERATURE
COLLECTION OF MATERIAL
PRE-TREATMENT OF COTTON WASTE
EXPERIMENTAL SETUP
DATA COLLECTION AND EXPERIMENTAL ANALYSIS
CONCLUSION & DISCUSSION
PATENT AND PUBLICATION
Production of Biogas Using Cotton Waste
WASTE
COTTON WASTE
MANUFACTURING OF DIGESTOR AND TANK
MANUFACIORIN AF DIGESTOR AND TANK

POSTER

Production of Biogas Using Cotton Waste
Introduction
This project investigates feasibility of generating biogas from col ton waste through anaerobic digestion, aiming o explore a sustainable energy source while addressing environmental waste management.
Objectives
To evaluate the biogas poduction potential of cotton waste
To analyze the efficiency of the anaerobic digestion process and its implications.
CH4
Methodology
An anaerobic digester was used to convert cotton waste to biogas.
The experimental process followed standard anaerobic digestion techniques.
Experimental Setup
pH
Temperature
Retention Time
Data Collection and Analysis
Conclusion
This studvidemonstrated that cotton waste is alviabile feedstock for biogas production, providing a renewable
Results & Observations
Conclusion
This study demonstrated that colton waste is a viable feedstock for biogas production, providing renevble energy solution and aiding in waste reduction.
Future Scope
Further research is needed to optimize the digestion process and to explore scalability for larger applications.

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Department of Civil Engineering

International Conference on

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SPACE - 2025

02 & 03 April 2025

Certificate

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Dr J Karthick/Dr R Balaji	Dr M I Abdul Aleem	Dr N Saravanakumar
ORGANISING SECRETARIES	CONVENOR	PATRON

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Dr J Karthick/Dr R Balaji	Dr M I Abdul Aleem	Dr N Saravanakumar
ORGANISING SECRETARIES	CONVENOR	PATRON

SUSTAINABLE DEVELOPMENT GOALS

Innovation (SDG 9)
Producing biogas from cotton waste promotes green technology.

Clean Energy (SDG 7)
Biogas is a renewable energy source. It can power homes, stoves, and even small machinery.

Good Health (SDG 3)
It produce less harmful gases.

Climate Action (SDG 13)
Biogas production reduces methane emissions and cuts down on fossil fuel use. Both are big wins in the fight against climate change.

No Poverty (SDG 1)
By turning waste into energy, especially in rural or cotton-producing areas, we can create new jobs.

GRAMMER CHECK

Report: PRODUCTION OF BIOGAS FROM COTTON WASTE-compressed

PRODUCTION OF BIOGAS FROM COTTON WASTE-compressed

by Sudhakaran S

General metrics

94,729	13,167	1170	52 min 40 sec	1 hr 41 min
characters	words	sentences	reading time	speaking time

Score

87

This text scores better than 87% of all texts checked by Grammarly

Writing Issues

413	62	351
Issues left	Critical	Advanced