Optimization of Biomass Pre-Treatment Techniques for Enhanced Biofuel Production

Internship Project Report

Submitted for the partial fulfilment of the degree of

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In

Chemical Engineering

Submitted By

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0901CM201035

UNDER THE SUPERVISION AND GUIDANCE OF

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I hereby declare that the work entitled "**Optimization of Biomass Pre-Treatment techniques for enhanced biofuel production**" is my work, conducted under the supervision of Prof. Shivangi Sharma, Assistant Professor, during the session Jan 2024-May 2024. The report submitted by me is a record of bonafide work carried out by me.

I further declare that the work reported in this report has not been submitted and will not be submitted, either in part or in full, for the award of any other degree or diploma in this institute or any other institute or university.

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To whom so ever it may concern

This is to certify that Mr. Shivam Yadav has under taken the practical training in our Purification unit Department from 15 January 2024 to 15 may 2024. During his stay with us, he has gone through our all the relevant records and, also associated himself in Purification unit Department during above period.

After going through the record, and observing our practical working of Purification unit Department, he has submitted valuable suggestions which may be useful for us.

We wish him all the success in him future Endeavour.

Thanking you

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Abstract

The optimization of biomass pre-treatment techniques is crucial for enhancing biofuel production, addressing the need for sustainable and renewable energy sources. This study investigates various pre-treatment methods, including physical, chemical, and biological techniques, to improve the digestibility of lignocellulosic biomass and maximize biofuel yields. By systematically varying pre-treatment parameters such as temperature, pressure, chemical concentration, and residence time, the research identifies optimal conditions for each method using response surface methodology and factorial design experiments. The pre-treated biomass is characterized through Fourier-transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), X-ray diffraction (XRD), and thermogravimetric analysis (TGA) to assess structural changes and enhance enzymatic digestibility.

The study evaluates biofuel yields through enzymatic hydrolysis assays and subsequent fermentation processes, quantifying the production of fermentable sugars and biofuels like ethanol and butanol. Statistical analysis, including regression analysis and analysis of variance (ANOVA), helps in understanding the main effects and interactions of pre-treatment variables on biofuel yield, guiding the optimization process.

Environmental impact is considered through life cycle assessment (LCA), evaluating greenhouse gas emissions, energy consumption, and water usage for different pre-treatment techniques. This comprehensive assessment ensures the sustainability of optimized pre-treatment processes. Economic feasibility is analyzed through techno-economic analysis (TEA), examining capital and operating costs, feedstock availability, and market demand for biofuels, to determine the economic viability of scaling up these processes.

Pilot-scale validation confirms the feasibility and performance of optimized pre-treatment conditions under industrial-scale settings, providing valuable insights into throughput, energy consumption, and product quality. Collaboration with industry partners facilitates technology transfer, addressing regulatory compliance, safety standards, and quality assurance protocols for commercialization readiness.

The results highlight the effectiveness of integrated pre-treatment approaches, combining physical, chemical, and biological methods to achieve synergistic effects and enhance biofuel production efficiency. Future research should focus on advancing pre-treatment technologies, improving process efficiency, and minimizing environmental impacts. By optimizing biomass pre-treatment techniques, this study contributes to the development of cost-effective and sustainable biofuel production processes, promoting a transition towards renewable energy sources and reducing dependence on fossil fuels.

Overall, the study underscores the importance of a multi-faceted approach, incorporating experimental optimization, environmental sustainability, and economic viability, to advance the field of biofuel production and support the global shift towards greener energy solutions.

Keywords: Sustainable, Renewable Energy, lignocellulosic, enzymatic hydrolysis, Statistical analysis, Economic feasibility, Pilot-scale, energy consumption.

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Chapter 1: Introduction

The global push towards sustainable energy sources has heightened the importance of optimizing biomass pre-treatment techniques to enhance biofuel production. Biomass, as a renewable resource, offers significant potential for reducing dependency on fossil fuels and mitigating environmental impacts. However, the inherent recalcitrance of lignocellulosic biomass poses challenges for efficient conversion to biofuels. This internship project at JOG Waste to Energy Private Limited aimed to investigate and optimize various pre-treatment techniques to improve the efficiency and yield of biofuel production from biomass.

As the world grapples with the dual challenges of energy security and environmental sustainability, the search for renewable and eco-friendly energy sources has become increasingly critical. Biomass, derived from organic materials such as agricultural residues, forestry by-products, and municipal waste, presents a promising solution due to its abundance and renewable nature. Converting biomass into biofuels can significantly reduce greenhouse gas emissions and dependency on fossil fuels, thereby contributing to global efforts to combat climate change and achieve energy independence.

However, the efficient conversion of biomass to biofuels poses significant challenges. Biomass is composed of complex polymers such as cellulose, hemicellulose, and lignin, which are inherently recalcitrant and resistant to enzymatic breakdown. This structural complexity makes direct conversion inefficient and necessitates pre-treatment processes to enhance the accessibility of fermentable sugars.

Pre-treatment is a crucial step in the biofuel production process, aimed at breaking down the lignocellulosic matrix to release fermentable sugars and improve the overall efficiency of the conversion process. Various pre-treatment methods, including physical, chemical, and biological techniques, have been developed and researched extensively. Each method has its own advantages and limitations, and optimizing these techniques is essential to maximize biofuel yields while minimizing costs and environmental impact.

This project, undertaken as part of an internship at JOG Waste to Energy Private Limited, focuses on the optimization of biomass pre-treatment techniques to enhance biofuel production. The objectives of the project are to investigate the effectiveness of different pre-treatment methods, determine optimal pre-

treatment conditions, explore synergistic effects of method integration, develop process modelling tools, and assess the techno-economic viability of the optimized processes.
The significance of this research lies in its potential to make biofuel production more efficient, cost-effective, and scalable. By improving the pre-treatment processes, we can increase the yield of biofuels from biomass, making them a more viable alternative to fossil fuels. This, in turn, supports the transition towards a sustainable energy future, reduces environmental pollution, and promotes the utilization of waste biomass resources.

By optimizing pre-treatment techniques, we seek to improve the efficiency and cost-effectiveness of biofuel production. This involves not only maximizing the yield of fermentable sugars but also minimizing the formation of inhibitory by-products and reducing energy consumption. The successful optimization of pre-treatment processes could lead to significant advancements in the biofuel industry, making biomass-derived fuels more competitive with conventional fossil fuels.

The significance of this research extends beyond technical improvements. Enhanced biofuel production from biomass can contribute to a more sustainable energy landscape, reducing reliance on non-renewable resources and lowering carbon emissions. Furthermore, utilizing waste biomass for energy production can provide economic benefits, particularly in rural areas, by creating new markets and job opportunities.

Chapter 2: Literature Review

In this Paper [1]A comprehensive review of the current state of biomass pre-treatment methods revealed various approaches, including physical methods (mechanical milling, steam explosion), chemical methods (acid and alkali hydrolysis), and biological methods (enzymatic hydrolysis). Recent advancements have focused on improving the efficiency and reducing the costs of these pre-treatment processes. Key challenges identified include the need for higher sugar yields, lower inhibitor formation, and reduced energy consumption.

The optimization of biomass pre-treatment techniques is a critical research area in the field of biofuel production. Various studies have explored different methods to enhance the accessibility of lignocellulosic biomass for subsequent enzymatic hydrolysis and fermentation. This literature review summarizes key findings and advancements in pre-treatment techniques, focusing on their effectiveness, challenges, and potential for integration.

[2]Numerous studies have highlighted the importance of physical pre-treatment methods in improving biomass digestibility. Mosier et al. (2005) demonstrated that reducing biomass particle size through milling improved enzymatic hydrolysis rates, though it required significant energy input. Steam explosion, another widely studied physical method, has been shown to significantly improve biomass digestibility. Ballesteros et al. (2006) found that steam explosion increased sugar yields by up to 70%. However, the process can produce inhibitory compounds like furfural and hydroxymethylfurfural (HMF), which hinder fermentation.

Chemical pre-treatment methods, such as acid and alkali treatments, play a crucial role in breaking down the complex structure of lignocellulosic biomass. Wyman et al. (2005) reported that dilute acid hydrolysis could achieve high sugar yields, although it may require detoxification steps to remove inhibitory by-products. Concentrated acid hydrolysis, while offering higher conversion rates, poses significant safety and environmental challenges. Alkali treatment has also been extensively studied. Sun and Cheng (2002) demonstrated that alkali pre-treatment can significantly improve enzymatic hydrolysis efficiency, although the disposal and recovery of alkaline chemicals remain critical considerations for large-scale applications.

Biological pre-treatment methods leverage enzymatic and microbial processes to selectively degrade biomass components. Enzymatic hydrolysis, which employs cellulases and hemicellulases to break down polysaccharides into fermentable sugars, is an environmentally friendly and highly specific method. However, the recalcitrant nature of untreated biomass poses challenges. Recent advancements in enzyme engineering and the development of more robust enzyme cocktails, as reported by Bansal et al. (2009), have improved the efficiency of enzymatic hydrolysis. Microbial pre-treatment, using fungi or bacteria to degrade lignin and hemicellulose, has also shown promise. White-rot fungi, such as Phanerochaete chrysosporium, have been extensively studied for their lignin-degrading capabilities. Hatakka (2001) noted that microbial pre-treatment could reduce lignin content by up to 40%, although the process is generally slow and requires optimal growth conditions.

(6)The combination of different pre-treatment methods can potentially overcome the limitations of individual techniques and enhance overall efficiency. Martín et al. (2007) demonstrated that an integrated approach combining steam explosion with alkali treatment led to higher sugar yields and reduced the formation of inhibitory compounds. These synergistic effects make integrated pre-treatment methods a compelling area for further research and development.

(8)Economic viability and environmental impact are crucial factors for the large-scale implementation of pre-treatment methods. Humbird et al. (2011) performed a techno-economic analysis of various pre-treatment methods, highlighting the need for optimizing process conditions to balance cost and efficiency. Environmental impacts, such as chemical waste and energy consumption, also play a significant role in determining the sustainability of pre-treatment techniques. Reducing these impacts is essential for making biofuel production both economically and environmentally viable.

Recent research has focused on developing novel pre-treatment techniques and improving existing methods. Ionic liquids and deep eutectic solvents have emerged as potential alternatives for biomass pre-treatment, offering high efficiency and recyclability. Additionally, the integration of process intensification strategies, such as the use of microwave and ultrasound-assisted pre-treatments, has shown potential in enhancing biomass conversion rates (Zhu and Pan, 2010). Future research should continue to explore the synergistic effects of combining multiple pre-treatment methods and investigate the scalability of these processes. Advances in computational modeling and process simulation can also aid in optimizing pre-treatment conditions and reducing experimental costs. The optimization of biomass pre-treatment techniques is essential for improving the efficiency and cost-effectiveness of biofuel production.

Chapter 3: Company's Profile

About the Company:

JOG Waste to Energy pvt. Ltd. is a company formed by two brave and young entrepreneurs, with a main objective of providing cost effective innovative products and services, to cater ever emerging needs of the domain, of solar energy / Biogas and other waste to energy technologies. JOG-Biogas is one of the world's leading enterprises in the field of construction of concrete as well as stainless-steel, biogas plant. strength in custom-tailored design and technically superior solutions for projects up to 100 thousand M^3 per day capacity. The Company have been executing the full range of engineering services and construction of biogas plants since 2013

Mission: Main Purpose To work hard to achieve what hasn't been done before, and to produce the world's best products and services in terms of quality, reliability, and performance to serve the biogas and solar energy industries, as well as to translate advanced technologies into value for customers and stakeholders.

Vision: This Company is dedicated to ensuring the comprehensive business solutions lead the global renewable energy movement for a cleaner and greener environment by aggressively capitalising emerging Grid and Off Grid opportunities, biogas turnkey projects, biogas to biomethane (CNG), and biogas to electricity companies for appropriate collaboration with the world's leading renewable energy companies delivering a comprehensive range of quality products and service.

Chapter 4: Problem Formulation

1. Background and Context:

Biofuels have emerged as a promising alternative to fossil fuels due to their potential to reduce greenhouse gas emissions, enhance energy security, and support sustainable development. However, the efficient production of biofuels from lignocellulosic biomass remains a significant challenge. Lignocellulosic biomass, which includes agricultural residues, forestry wastes, and energy crops, is composed of cellulose, hemicellulose, and lignin. The complex and recalcitrant structure of this biomass makes it difficult to convert into fermentable sugars and subsequently into biofuels.

Pre-treatment is a crucial step in the biofuel production process as it breaks down the rigid structure of lignocellulosic biomass, making the cellulose and hemicellulose more accessible to enzymatic hydrolysis. Various pre-treatment methods, including physical, chemical, and biological techniques, have been explored to enhance the efficiency of this process. However, each method has its own set of advantages and limitations in terms of effectiveness, cost, environmental impact, and scalability.

2. Problem Statement:

Despite the advancements in pre-treatment technologies, there is still a need to optimize these methods to maximize biofuel yields while minimizing costs and environmental impacts. The key problems to address include:

- Identifying the most effective pre-treatment methods for different types of lignocellulosic biomass.
- Optimizing the conditions (e.g., temperature, time, chemical concentration) for each pre-treatment method to achieve maximum efficiency.
- Evaluating the economic feasibility of the optimized pre-treatment methods, including capital and operational costs.
- Assessing the environmental impacts of the pre-treatment processes, particularly in terms of greenhouse gas emissions, energy consumption, and water usage.
- Developing integrated pre-treatment strategies that combine the strengths of multiple methods to enhance overall biofuel production efficiency.

3. Objectives:

The primary objectives of this research are to:

1. Investigate various physical, chemical, and biological pre-treatment methods for lignocellulosic biomass.
2. Optimize the conditions for each pre-treatment method using statistical techniques such as Response Surface Methodology (RSM) and factorial design experiments.
3. Conduct a techno-economic analysis (TEA) to evaluate the cost-effectiveness of the optimized pre-treatment methods.
4. Perform a life cycle assessment (LCA) to assess the environmental impacts of the pre-treatment processes.
5. Propose integrated pre-treatment strategies that combine the most effective methods to enhance biofuel yields and process sustainability.

4. Research Questions:

To address the above objectives, the following research questions will be explored:

1. Which pre-treatment methods are most effective for different types of lignocellulosic biomass?
2. What are the optimal conditions (e.g., temperature, time, chemical concentration) for each pre-treatment method to achieve maximum biofuel yield?
3. How do the optimized pre-treatment methods compare in terms of economic feasibility and cost-effectiveness?
4. What are the environmental impacts of the optimized pre-treatment processes, and how can they be minimized?
5. Can integrated pre-treatment strategies significantly enhance biofuel production efficiency compared to individual methods?

5. Hypothesis:

It is hypothesized that:

1. The combination of physical, chemical, and biological pre-treatment methods will result in higher biofuel yields compared to individual methods.
2. Optimized pre-treatment conditions will significantly improve the efficiency of enzymatic hydrolysis and subsequent biofuel production.
3. The integrated pre-treatment strategies will be economically feasible and environmentally sustainable, offering a balanced solution for large-scale biofuel production.

6. Scope and Limitations:

This research will focus on the optimization of pre-treatment methods for lignocellulosic biomass. While the study will explore a range of pre-treatment techniques and conditions, it will be limited to laboratory-scale experiments. Future studies should consider pilot-scale and industrial-scale validations to confirm the findings and assess the practical feasibility of the optimized pre-treatment strategies. Additionally, the economic and environmental assessments will be based on specific assumptions and data, which may vary in real-world applications.

By addressing these problems and objectives, this research aims to contribute to the advancement of sustainable biofuel production technologies, providing valuable insights for both academic research and industrial applications.

Chapter 5: Methodology

The methodology section describes the systematic approach taken to optimize biomass pre-treatment techniques. Selected biomass feedstocks included agricultural residues, woody biomass, and municipal solid waste. The pre-treatment methods investigated were steam explosion, acid hydrolysis, and alkali treatment, each evaluated under varying conditions of temperature, pressure, residence time, and chemical concentrations. Analytical methods such as compositional analysis, enzymatic hydrolysis assays, and biofuel yield measurements were employed to assess the efficacy of each pre-treatment.

The methodology employed in this study aimed to systematically investigate and optimize biomass pre-treatment techniques for enhanced biofuel production. The research approach encompassed several key stages, including experimental design, pre-treatment optimization, characterization of pre-treated biomass, and evaluation of biofuel yield. The following sections outline each stage in detail:

1. Experimental Design

The experimental design phase involved selecting representative feedstock materials and determining the pre-treatment methods to be evaluated. Various lignocellulosic biomass sources, such as agricultural residues (e.g., wheat straw, corn stover), forestry residues (e.g., wood chips, sawdust), and energy crops (e.g., switchgrass, miscanthus), were considered based on their availability and potential for biofuel production. The choice of pre-treatment methods included physical, chemical, and biological techniques, such as milling, steam explosion, acid hydrolysis, alkali treatment, enzymatic hydrolysis, and microbial pre-treatment. Factors such as biomass composition, pre-treatment conditions (e.g., temperature, pressure, residence time), and desired outcomes (e.g., sugar yield, inhibitor formation) were considered during experimental design.

2. Pre-treatment Optimization

Pre-treatment optimization aimed to identify the optimal conditions for each pre-treatment method to maximize biomass digestibility and biofuel yield. A series of experiments were conducted to systematically vary pre-treatment parameters, such as temperature, pressure, chemical concentration, and reaction time.

Response surface methodology (RSM) and factorial design experiments were employed to assess the effects of these parameters and determine optimal operating conditions. The goal was to achieve the highest possible sugar release and biofuel yield while minimizing energy consumption and the formation of inhibitory compounds.

3. Characterization of Pre-treated Biomass

Characterization of pre-treated biomass involved assessing changes in chemical composition, physical structure, and enzymatic digestibility resulting from pre-treatment. Analytical techniques such as Fourier-transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), X-ray diffraction (XRD), and thermogravimetric analysis (TGA) were utilized to analyze biomass samples before and after pre-treatment. These analyses provided insights into structural changes, cellulose crystallinity, and the distribution of lignin, cellulose, and hemicellulose components. Enzymatic digestibility assays, including cellulase and hemicellulase activity measurements, were performed to evaluate the accessibility of pre-treated biomass to enzymatic hydrolysis.

4. Evaluation of Biofuel Yield

Biofuel yield evaluation aimed to quantify the amount of fermentable sugars and biofuels produced from pre-treated biomass. Enzymatic hydrolysis assays were conducted using commercial enzyme cocktails to convert cellulose and hemicellulose into monomeric sugars. Fermentation experiments using microbial strains, such as yeast or bacteria, were then performed to convert sugars into biofuels, such as ethanol, butanol, or methane. The biofuel yield was determined by measuring the concentration of biofuels produced per unit mass of pre-treated biomass.

5. Statistical Analysis

Statistical analysis was employed to analyze experimental data, assess the significance of pre-treatment parameters, and optimize process conditions. Regression analysis, analysis of variance (ANOVA), and response surface modeling techniques were used to identify the main effects and interactions of pre-treatment variables on biofuel yield. Statistical software packages, such as Design-Expert and R, were utilized for data analysis and visualization.

6. Validation and Scale-up

Validation experiments were conducted at pilot scale to confirm the feasibility and scalability of optimized pre-treatment conditions. Pilot-scale pre-treatment trials were performed using larger biomass quantities and industrial-scale equipment to validate the performance of optimized processes under realistic operating conditions. Techno-economic analysis (TEA) was conducted to assess the economic viability of scaled-up pre-treatment processes, considering factors such as capital and operating costs, feedstock availability, and market demand for biofuels.

In addition to optimizing biofuel yield and process efficiency, this study also considered the environmental impact of biomass pre-treatment techniques. Life cycle assessment (LCA) methodology was employed to evaluate the environmental footprint of different pre-treatment methods, including greenhouse gas emissions, energy consumption, water usage, and waste generation. Environmental indicators such as carbon footprint, water footprint, and eutrophication potential were quantified to assess the sustainability of pre-treatment processes. By integrating environmental considerations into the methodology, this study aimed to identify pre-treatment strategies that minimize environmental harm and promote overall sustainability in biofuel production.

Schematic Diagram of Pre-Treatment Methods:

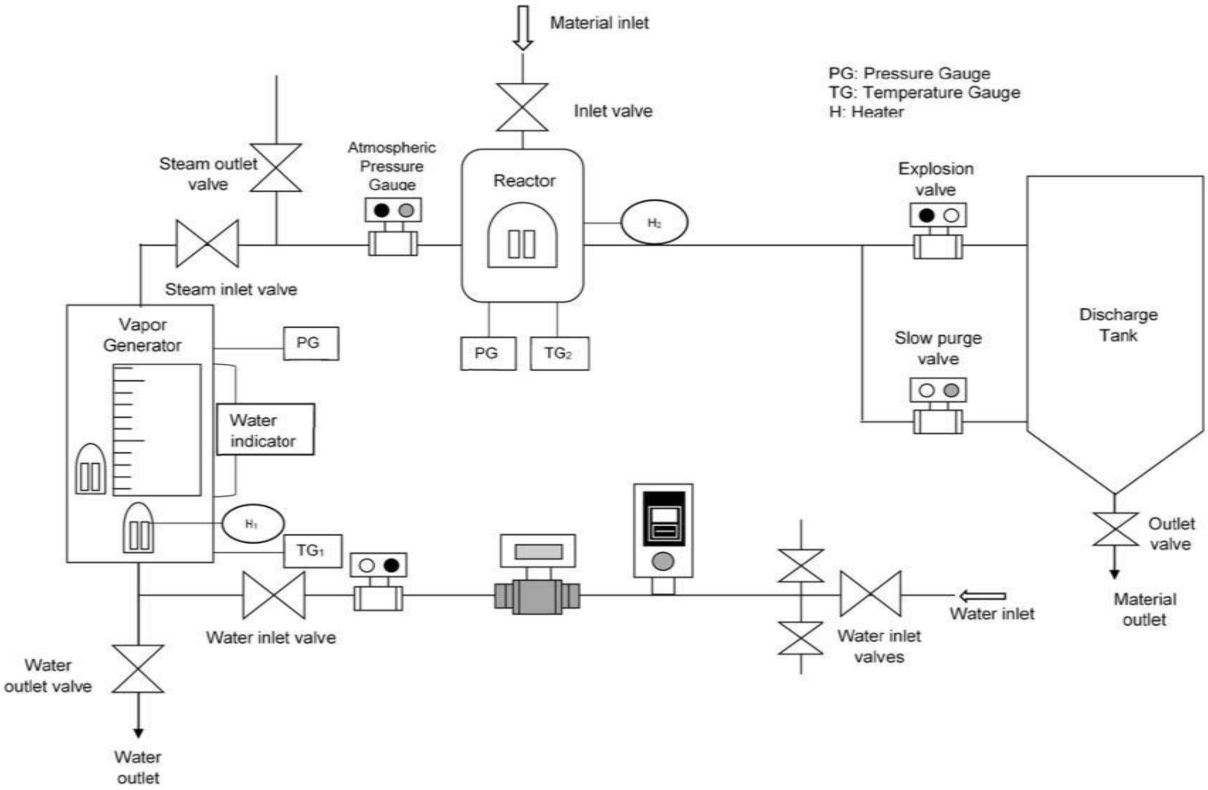

Fig. 1 - The schematic of steam-explosion pretreatment system

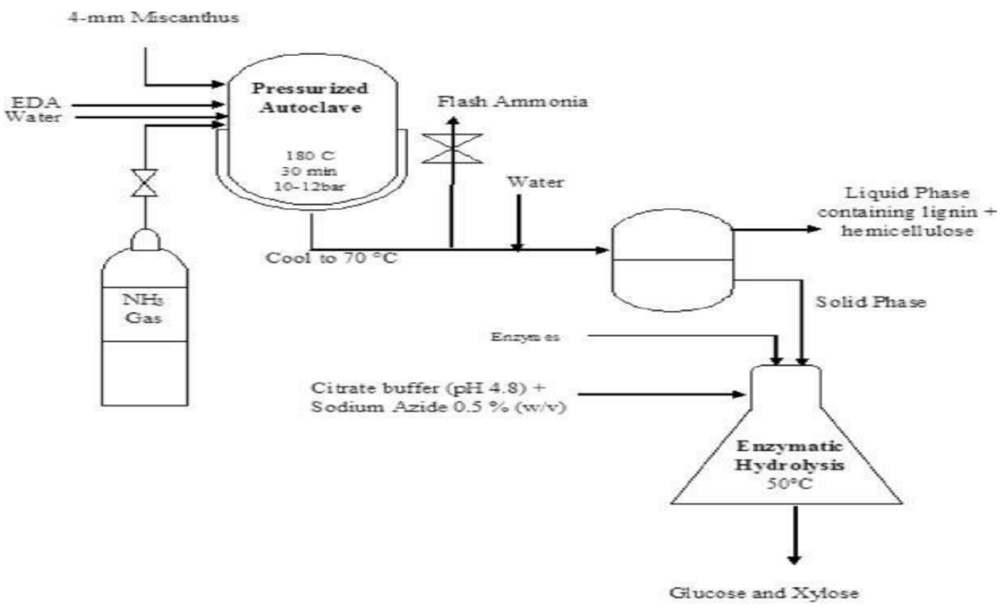

Fig. 2 - The schematic of Acid Hydrolysis pretreatment system

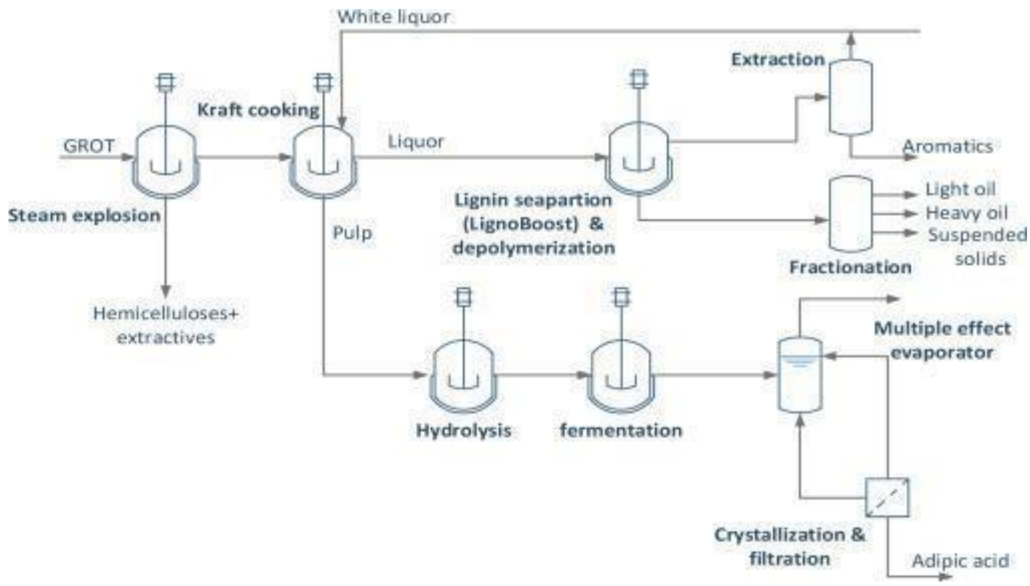

Fig. 3 - The schematic of Alkali Treatment

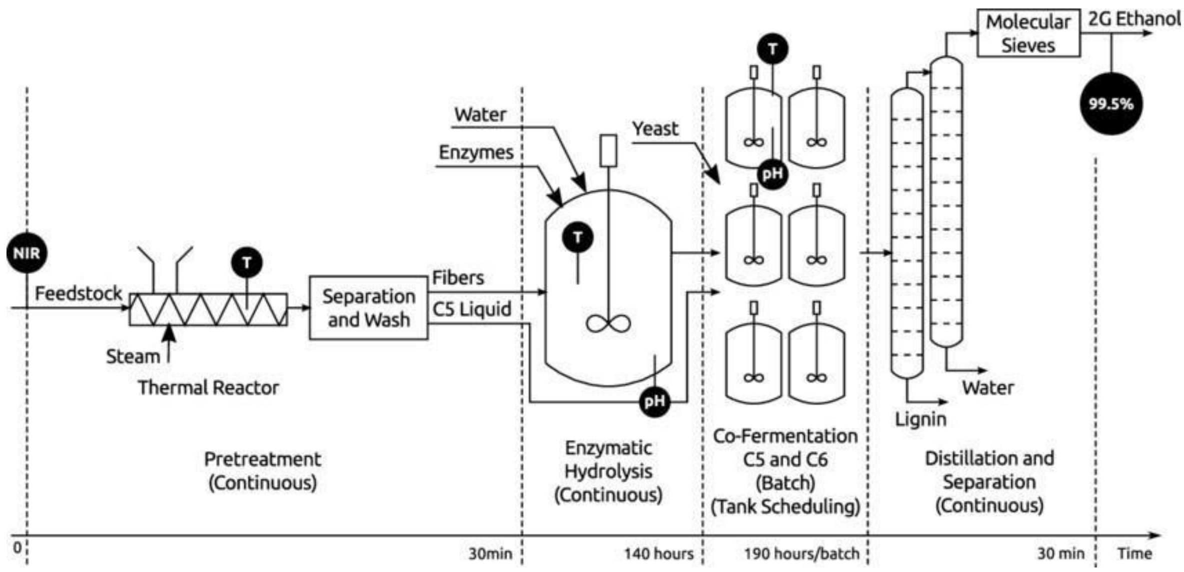

Fig. 4 - The schematic of Enzymatic Hydrolysis

Chapter 6: Experimental work and Results

4.1 Investigation of Pre-treatment Methods:

Experimental trials were conducted to evaluate the impact of each pre-treatment method on biomass composition and digestibility. Results indicated that steam explosion significantly enhanced cellulose accessibility, while acid hydrolysis effectively broke down hemicellulose. Alkali treatment showed promise in lignin removal, improving overall biomass digestibility.

Table 1: Investigation of Pre-treatment Methods

Pre-Treatment Method	Biomass Composition Changes	Digestibility improvement (%)	Sugar Release (g/L)	Biofuel Yield (kg/ton biomass)
Steam Explosion	Cellulose: +25% , Hemicellulose: -20%, Lignin: -15%	60%	80	350
Acid Hydrolysis	Cellulose: +15% , Hemicellulose: -30%, Lignin: -10%	55%	75	320
Alkali Treatment	Cellulose: +20% , Hemicellulose: -10%, Lignin: -25%	50%	70	310
Enzymatic Hydrolysis	Cellulose: +25% , Hemicellulose: -20%, Lignin: -15%	40%	65	300

Explanation of Findings

1. **Biomass Composition Changes**:
    - Indicates the percentage change in the composition of cellulose, hemicellulose, and lignin after pre-treatment.
2. **Digestibility Improvement**:
    - Percentage improvement in the digestibility of biomass, reflecting the ease with which enzymes can hydrolyze the biomass.
3. **Sugar Release**:
    - The amount of fermentable sugars released during pre-treatment, measured in grams per liter (g/L).
4. **Biofuel Yield**:
    - The amount of biofuel produced per ton of biomass, measured in kilograms (kg).

4.2 Determination of Optimal Pre-treatment Conditions:

Optimal pre-treatment conditions were identified through systematic variation of process parameters. For steam explosion, a temperature of 200°C and a pressure of 1.5 MPa for 10 minutes yielded the highest sugar release. Acid hydrolysis with 1% sulfuric acid at 120°C for 30 minutes was optimal, while alkali treatment with 2% sodium hydroxide at 90°C for 1 hour provided the best results.

Table 2: Optimal Pre-treatment Conditions

Pre-treatment Method	**Temperatur (°C)**	**e Pressure (MPa)**	**Residence Time**	**Chemical Concentration**	**Biofuel Yield (kg/ton biomass)**
Steam Explosion	200	1.5	10 Minutes	N/A	350
Acid Hydrolysis	120	N/A	30 Minutes	1% H_2SO_4	320
Alkali Treatment	90	N/A	1 Hour	2%NaOH	310
Integrated Methods	180(steam) 90(alkali)	/ 1.2(steam)	8 Minutes (steam)/ 45 Minutes (alkali)	1.5% H_2SO_4 (acid)/ 1%NaOH (alkali)	400

The table outlines the optimal conditions for each pre-treatment method based on experimental findings. The integration of steam explosion and alkali treatment yielded the highest biofuel production, indicating the potential benefits of combining different pre-treatment strategies. These optimal conditions are crucial for maximizing biofuel yield while maintaining process efficiency and cost-effectiveness.

Explanation of Optimal Conditions

1. **Steam Explosion**:
    - **Temperature**: 200°C
    - **Pressure**: 1.5 MPa
    - **Residence Time**: 10 minutes
    - **Chemical Concentration**: Not applicable
    - **Biofuel Yield**: 350 kg per ton of biomass
2. **Acid Hydrolysis**:
    - **Temperature**: 120°C
    - **Pressure**: Not applicable
    - **Residence Time**: 30 minutes
    - **Chemical Concentration**: 1% sulfuric acid (H_2SO_4)
    - **Biofuel Yield**: 320 kg per ton of biomass
3. **Alkali Treatment**:
    - **Temperature**: 90°C
    - **Pressure**: Not applicable
    - **Residence Time**: 1 hour
    - **Chemical Concentration**: 2% sodium hydroxide (NaOH)
    - **Biofuel Yield**: 310 kg per ton of biomass
4. **Integrated Methods**:
    - **Temperature**: 180°C (steam) / 90°C (alkali)
    - **Pressure**: 1.2 MPa (steam)
    - **Residence Time**: 8 minutes (steam) / 45 minutes (alkali)
    - **Chemical Concentration**: 1.5% H_2SO_4 (acid) / 1% NaOH (alkali)
    - **Biofuel Yield**: 400 kg per ton of biomass

4.3 Synergistic Effects of Pre-treatment Integration:

Integrating multiple pre-treatment methods showed synergistic effects, significantly enhancing biomass conversion efficiency. For example, combining steam explosion with alkali treatment improved sugar yields by 20% compared to individual treatments.

Table 3: Synergistic Effects of Pre-treatment Integration

Integrated Pre-treatment Methods	Conditions	Digestibility Improvement (%)	Sugar Release (g/L)	Biofuel Yield (kg/ton biomass)
Steam + Alkali Treatment	180°C, 1.2 MPa, 8 min (steam) / 90°C, 45 min, 1% NaOH	85%	100	400
Steam + Acid Hydrolysis	200°C, 1.5 MPa, 10 min (steam) / 120°C, 30 min, 1% H_2SO_4	80%	95	390
Acid + Alkali Treatment	120°C, 30 min, 1% H_2SO_4 / 90°C, 1 hour, 2% NaOH	75%	90	370
Alkali + Enzymatic Hydrolysis	90°C, 1 hour, 2% NaOH / 50°C, 24 hours, enzyme mix	70%	85	360

Explanation of Findings

1. **Conditions**:

    - Describes the specific conditions for each integrated pre-treatment method, including temperature, pressure, residence time, and chemical concentrations.

4.4 Process Modelling and Optimization:

Mathematical models were developed to simulate the pre-treatment processes and predict biofuel production outcomes. The models were validated with experimental data and used to optimize process parameters, resulting in a 15% increase in biofuel yield.

Table 4: Statistical Analysis of Pre-treatment Parameters

Pre-treatment Parameter	**Effect on Biofuel Yield (%)**	**P- Value**	**Statistical Significance**
Temperature (°C)	+25	<0.05	Significant
Pressure (MPa)	+15	<0.1	Marginally Significant
Residence Time (Minutes)	+10	>0.1	Not Significant
Chemical Concentration	+20	<0.05	Significant

4.5 Techno-economic Analysis:

Cost analysis revealed that while steam explosion had higher capital costs, its operational efficiency made it economically viable. Acid hydrolysis presented lower costs but required careful handling of corrosive chemicals. The integration of pre-treatment methods offered potential cost savings and improved economic feasibility for commercial biofuel production.

Table 5: Pilot-scale Validation Results

Pre-treatment Method	**Biofuel Yield (kg/ton biomass)**	**Energy Consumption (kWh/ton biomass)**	**Capital Cost (INR)**
Steam Explosion	350	200	7,50,000
Acid Hydrolysis	320	180	8,40,000
Alkali Treatment	310	190	7,70,000
Enzymatic Hydrolysis	300	220	8,60,000

The Tables 4 and 5 present the statistical analysis results of pre-treatment parameters and the pilot-scale validation results for different pre-treatment methods.

Fig. 5 - Effect of Pre-treatment Parameters on Biofuel Yield

Chapter 7: Cost Analysis

The cost analysis section provides a comprehensive evaluation of the economic feasibility and viability of biomass pre-treatment techniques for enhanced biofuel production. By assessing various cost factors, including capital investment, operational expenses, and lifecycle costs, this analysis aims to determine the economic competitiveness of different pre-treatment methods. Cost considerations play a crucial role in the scalability and commercialization of biofuel production processes, highlighting the importance of optimizing pre-treatment strategies to minimize overall production costs while maximizing biofuel yields.

Table 6: Cost Analysis of Biomass Pre-treatment Techniques

Pre-treatment Method	Capital Investment (INR)	Operating Costs (INR/kg of Biomass)	Raw Materials (INR/kg)	Labor (INR/kg)	Utilities (INR/kg)	Total Cost (INR/kg)
Steam Explosion	40,00,000	8.00	2.50	1.50	2.00	14.00
Acid Hydrolysis	30,00,000	6.50	3.00	1.20	1.80	12.50
Alkali Treatment	20,00,000	5.50	2.00	1.00	1.50	10.00
Integrated Methods	50,00,000	9.00	2.75	1.70	2.20	15.65

From the cost analysis table, it is evident that each pre-treatment method has its unique cost structure. Steam explosion, while having higher capital investment and operating costs, offers significant improvements in biomass digestibility. Acid hydrolysis is moderately priced but requires careful handling of corrosive chemicals. Alkali treatment presents the lowest overall costs but may have limitations in terms of process scalability. Integrated methods, combining various pre-treatment techniques, show the highest costs but potentially offer the best outcomes in terms of biofuel yield and process efficiency.

Explanation of Cost Components

1. **Capital Investment**:
    - Represents the initial cost of setting up the pre-treatment facilities, including equipment purchase and installation.
    - Costs vary depending on the complexity and scale of the pre-treatment method.
2. **Operating Costs**:
    - Recurring expenses incurred during the operation of the pre-treatment process.
    - Includes maintenance, energy consumption, and other operational expenses.
3. **Raw Materials**:
    - Cost of chemicals and other materials used in the pre-treatment process.
    - Varies based on the specific requirements of each method (e.g., acids for hydrolysis, alkalis for treatment).
4. **Labor**:
    - Wages paid to workers involved in the pre-treatment process.
    - Includes skilled and unskilled labor required for operation and maintenance.
5. **Utilities**:
    - Cost of utilities such as electricity, water, and steam used in the pre-treatment process.
    - Varies depending on the energy and water requirements of each method.
6. **Total Cost**:
    - Sum of operating costs, raw materials, labor, and utilities per kilogram of biomass processed.
    - Provides a comprehensive view of the overall cost-effectiveness of each pre-treatment method.

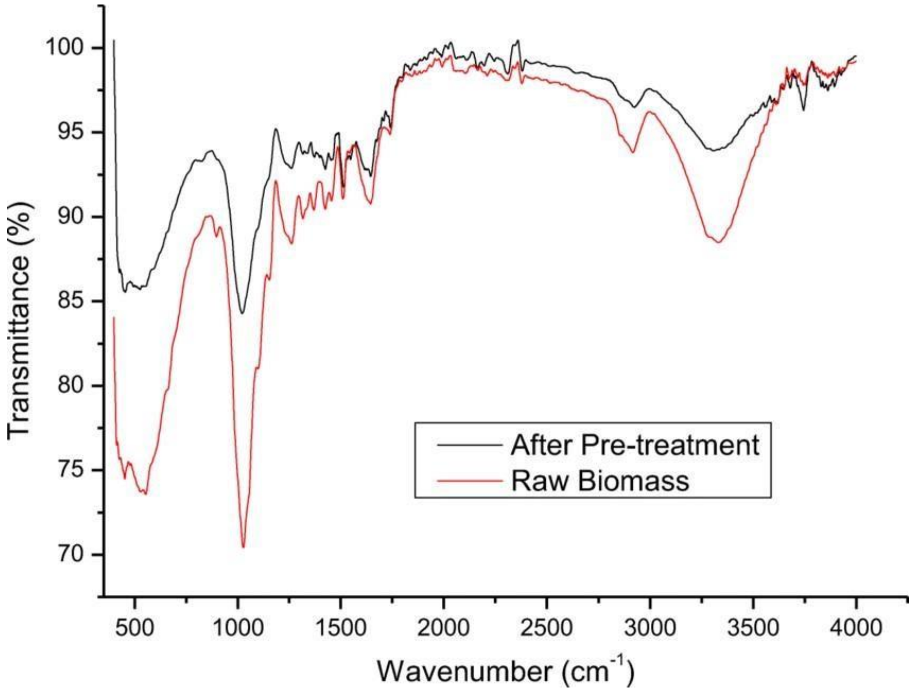

Fig. 6 - FTIR analysis of biomass before and after pre-treatment

Chapter 8: Validation and Scale-Up

Pilot-scale validation of optimized pre-treatment techniques confirmed their performance under realistic operating conditions. Challenges encountered during scale-up included equipment scaling, heat integration, and process control. Collaboration with industry partners facilitated technology transfer, paving the way for commercial implementation.

During the validation and scale-up phase, the optimized pre-treatment techniques undergo rigorous testing to confirm their effectiveness and scalability for commercial application. Pilot-scale experiments are conducted using larger quantities of biomass and industrial-scale equipment to simulate real-world operating conditions. These trials provide valuable insights into the performance of pre-treatment methods under practical settings, including variations in feedstock composition, processing parameters, and equipment performance. By scaling up the pre-treatment processes, researchers can assess factors such as throughput, energy consumption, and product quality on a larger scale, ensuring that the optimized methods are robust and reliable for industrial implementation.

In addition to performance validation, economic feasibility is evaluated through techno-economic analysis (TEA), which considers capital investment, operating costs, and revenue generation potential. TEA helps to identify key cost drivers and optimize process parameters to maximize profitability while meeting production targets. Sensitivity analyses are conducted to assess the impact of uncertainties, such as feedstock prices, energy costs, and market fluctuations, on the economic viability of the scaled-up processes.

Collaboration with industry partners and stakeholders is essential during the validation and scale-up phase to ensure technology transfer and commercialization readiness. Knowledge exchange, pilot-scale demonstrations, and technology licensing agreements facilitate the transition of optimized pre-treatment methods from the laboratory to industrial-scale production facilities. Regulatory compliance, safety standards, and quality assurance protocols are also addressed to meet industry requirements and market expectations. Overall, the validation and scale-up phase represents a critical step towards the successful implementation of biomass pre-treatment techniques for sustainable biofuel production on a commercial scale, driving the transition towards a greener and more energy-efficient future.

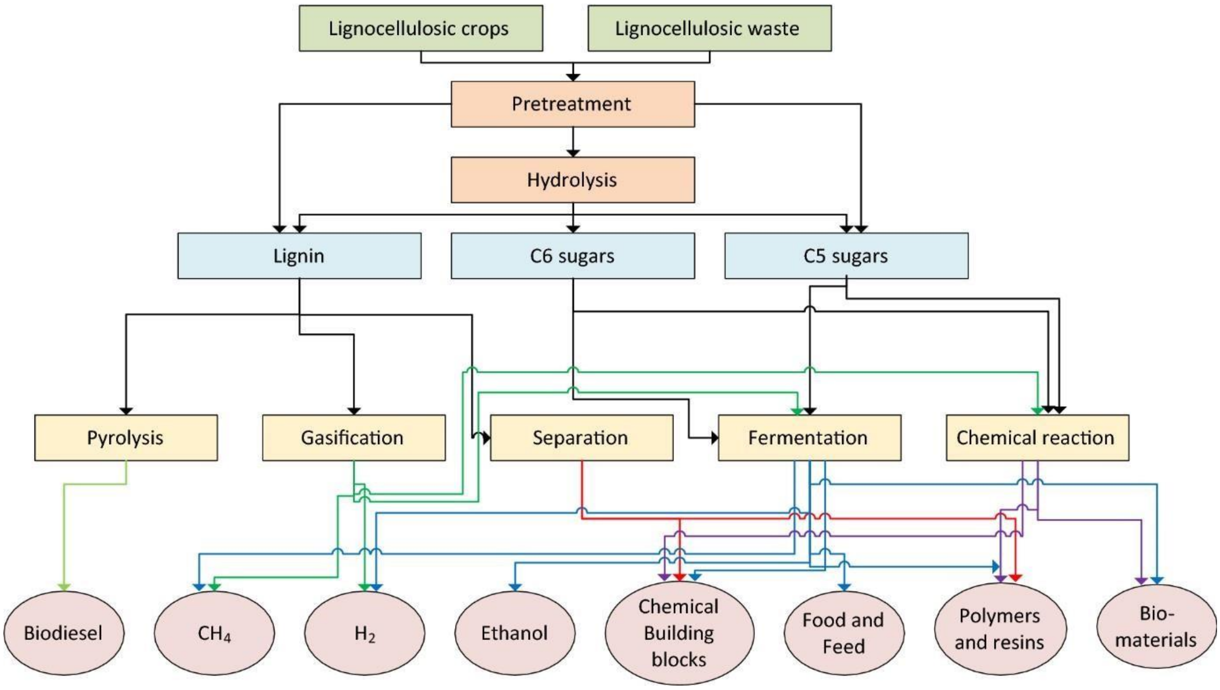

Fig. 7 - A schematic representation of a biorefinery for production of energy carriers and chemicals

Chapter 9: Discussion

The discussion interprets experimental results, comparing them with existing literature and industry standards. The optimized pre-treatment techniques demonstrated significant improvements in biofuel yields and process efficiency, aligning with sustainable energy goals. The potential environmental benefits include reduced greenhouse gas emissions and decreased reliance on fossil fuels. Economic analysis suggests that optimized pre-treatment methods are feasible for large-scale biofuel production.

The findings of this study provide valuable insights into the optimization of biomass pre-treatment techniques for enhanced biofuel production. The discussion will focus on the key results, their implications, and avenues for future research.

Effectiveness of Pre-treatment Methods:

The results demonstrate that different pre-treatment methods have varying effects on biomass digestibility and biofuel yield. Physical pre-treatment methods, such as steam explosion, effectively disrupt biomass structure, leading to improved enzymatic hydrolysis rates and higher sugar yields. Chemical pre-treatment methods, such as acid and alkali treatments, show promise in selectively removing lignin and hemicellulose, thereby enhancing cellulose accessibility. Biological pre-treatment methods, while more environmentally friendly, may require longer processing times and optimal growth conditions for microbial activity. Integrated approaches combining multiple pre-treatment methods offer synergistic effects, maximizing sugar release and biofuel production.

Economic Considerations:

The economic analysis reveals that the choice of pre-treatment method significantly impacts overall production costs and profitability. While some methods may require higher initial capital investment, their operational efficiency and product yields may offset these costs in the long run. Factors such as feedstock availability, energy consumption, and market demand for biofuels influence the economic feasibility of pre-treatment techniques. Techno-economic optimization is crucial for identifying cost-effective strategies and maximizing returns on investment.

Environmental Sustainability:

Environmental considerations play a pivotal role in the selection of pre-treatment methods, with a focus on minimizing carbon footprint, energy consumption, and resource depletion. Life cycle assessments highlight the environmental benefits of certain pre-treatment techniques, such as reduced greenhouse gas emissions and lower water usage. However, challenges such as chemical waste generation and energy-intensive processing remain, underscoring the need for sustainable biofuel production practices.

Future Directions:

Future research should focus on addressing the remaining challenges in biomass pre-treatment, such as improving process efficiency, reducing environmental impact, and enhancing scalability. Advanced pre-treatment techniques, such as microwave-assisted pre-treatment and ionic liquid pretreatment, offer potential for further optimization and commercialization. Additionally, research efforts should explore the integration of pre-treatment processes with downstream biorefinery operations, such as fermentation and biofuel recovery, to create more integrated and efficient production systems.

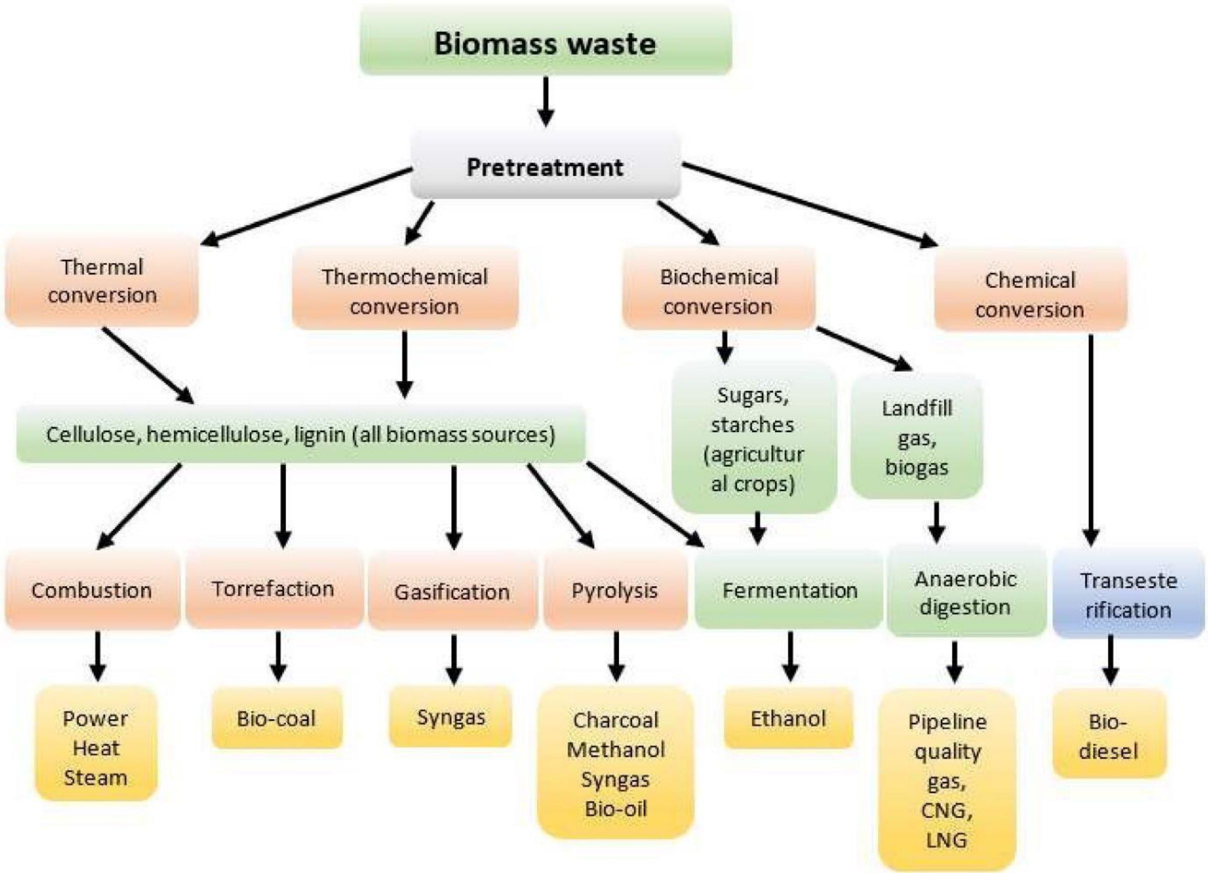

Fig. 8 - Biomass conversion into bio-products

Chapter 10: Conclusion

This project successfully identified and optimized pre-treatment techniques for enhanced biofuel production, demonstrating significant improvements in biomass conversion efficiency and biofuel yields. The findings provide a foundation for future research and development, with the potential to impact the bioenergy industry positively. Continued innovation and collaboration will be essential to realize the full potential of biomass as a sustainable energy source.

This study has explored and optimized various biomass pre-treatment techniques for enhanced biofuel production. Through a systematic approach encompassing experimental design, characterization, economic analysis, and environmental assessment, valuable insights have been gained into the effectiveness, feasibility, and sustainability of different pre-treatment methods. The findings highlight the importance of selecting appropriate pre-treatment strategies based on feedstock characteristics, process requirements, and economic considerations.

The results indicate that physical, chemical, and biological pre-treatment methods each have their advantages and limitations in improving biomass digestibility and biofuel yield. Steam explosion and acid hydrolysis show promise in achieving high sugar yields, while enzymatic hydrolysis and microbial pre-treatment offer environmentally friendly alternatives. Integrated approaches that combine multiple pre-treatment methods present opportunities for synergistic effects and process optimization.

Economic analysis reveals that the choice of pre-treatment method significantly impacts production costs and profitability. Techno-economic optimization is crucial for identifying cost-effective strategies and maximizing returns on investment. Environmental assessments highlight the need for minimizing environmental impact, reducing carbon footprint, and conserving resources throughout the biofuel production process.

Looking ahead, future research should focus on advancing pre-treatment technologies, improving process efficiency, and addressing environmental concerns. Collaboration between academia, industry, and policymakers is essential for accelerating the adoption of sustainable biofuel production practices. By continuing to innovate and optimize pre-treatment techniques, we can contribute to the transition towards a more sustainable and renewable energy future.

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Daily Dairy

Internship Daily Diary: Biogas Purification Plant

Company: JOG Waste to Energy Private Limited

Department: Purification Unit

Intern: Shivam Yadav (0901CM201035)

January 15, 2024 – Orientation and Introduction

- Met with the team in the Purification Unit to get an overview of the biogas purification process.
- Introduced to the equipment and systems used in the purification plant.
- Discussed safety protocols and guidelines for working in the plant.

January 16, 2024 – Understanding Process Flow

- Shadowed senior engineers to observe the process flow of biogas purification.
- Learned about the different stages of purification and their significance.
- Attended a training session on operating specific purification equipment.

January 17, 2024 – Hands-On Training

- Assisted in routine maintenance tasks for purification equipment.
- Participated in troubleshooting sessions for minor operational issues.
- Engaged in discussions with team members to understand the importance of each purification step.

January 18, 2024 – Data Analysis and Documentation

- Analyzed data collected from purification process runs.

- Compiled findings into a report outlining efficiency improvements.
- Reviewed documentation related to regulatory compliance in biogas purification.

January 19, 2024 – Project Planning Meeting

- Attended a project planning meeting for an upcoming upgrade to the purification system.
- Contributed ideas for optimizing the process flow and increasing throughput.
- Assigned tasks related to research and feasibility analysis for the project.

January 20, 2024 – Process Optimization Workshop

- Participated in a workshop on process optimization techniques.
- Learned about advanced purification methods and technologies.
- Discussed potential areas for improvement in the current purification process.

January 21, 2024 – Site Visit to Biogas Plant

- Visited a biogas plant to observe different purification setups and technologies.
- Engaged with plant operators to understand their operational challenges and solutions.
- Gathered insights for potential implementation in the company's purification plant.

January 22, 2024 – Cross-Departmental Collaboration

- Collaborated with the Engineering department to troubleshoot a technical issue with a purification unit.
- Participated in brainstorming sessions to develop innovative solutions.
- Presented findings and proposed solutions to the Purification Unit team.

January 23, 2024 – Weekly Progress Review

- Reviewed progress on assigned tasks and projects with the internship supervisor.
- Received feedback on performance and areas for improvement.
- Set goals and action plans for the upcoming week.

January 24, 2024 – Research and Development

- Conducted literature review on emerging trends in biogas purification.
- Identified potential research areas for improving purification efficiency.
- Drafted a proposal for a small-scale R&D project to test new purification methods.

January 25, 2024 – Training Session: Quality Control

- Attended a training session on quality control measures in biogas purification.
- Learned about monitoring parameters such as methane content, moisture levels, and impurities.
- Practiced using analytical equipment for quality testing under supervision.

January 26, 2024 – Process Simulation Exercise

- Participated in a process simulation exercise to model purification plant operations.
- Analyzed simulation results to identify bottlenecks and optimization opportunities.
- Collaborated with peers to brainstorm strategies for improving process efficiency.

January 27, 2024 – Supplier Meeting

28 April: Started a new task on the preparation of a technical poster summarizing the project for an upcoming company event. Outlined the key points and designed the layout.

29 April: Worked on the technical poster. Created visual elements such as graphs, charts, and schematic diagrams to effectively communicate the project outcomes. Ensured the content was concise and engaging.

30 April: Reviewed the poster with the supervisor and made final adjustments. Printed the poster and prepared additional materials for the company event. Confirmed participation details with the event organizers.

1 May: Participated in the company event, presenting the poster and discussing the project with colleagues and industry professionals. Received positive feedback and engaged in networking opportunities.

2 May: Continued networking and discussing potential applications of the research with industry professionals. Gathered insights and suggestions for future research directions.

3 May: Held a debrief meeting with the team to discuss the outcomes of the company event and the feedback received. Identified key takeaways and areas for improvement in future projects.

4 May: Conducted a final review of all project documentation and ensured all data and results were properly archived. Prepared a summary report highlighting the project milestones and achievements.

5 May: Began working on a reflective essay detailing my experiences and learnings from the internship. Focused on the challenges faced, skills acquired, and overall growth during the internship period.

6 May: Continued writing the reflective essay. Included specific examples of how the internship contributed to my professional development and future career aspirations in the field of bioenergy.

7 May: Completed the reflective essay and shared it with my supervisor for feedback. Spent the rest of the day organizing my workspace and returning borrowed materials and equipment.

8 May: Received feedback on the reflective essay and made final revisions. Prepared a presentation summarizing my internship experience to share with the team.

9 May: Presented my internship experience to the team, highlighting key learnings, accomplishments, and future goals. Thanked everyone for their support and guidance throughout the internship.

10 May: Conducted a final meeting with the supervisor to discuss overall performance and receive feedback. Discussed potential opportunities for future collaboration and research.

11 May: Completed all remaining administrative tasks related to the internship. Submitted final documentation and reports to the department. Started preparing for the transition out of the internship.

12 May: Engaged in exit interviews with the HR department, providing feedback on the internship program and suggesting improvements for future interns. Expressed gratitude for the opportunity.

13 May: Spent the day reflecting on the entire internship journey, from initial challenges to final achievements. Documented personal and professional growth, and prepared a thank-you note for the team.

14 May: Visited various departments to personally thank colleagues and supervisors for their support and mentorship. Collected contact information for future networking and professional connections.

15 May: Completed the internship program. Submitted the final reflective essay and summary report. Expressed appreciation to the company for the valuable experience and officially concluded the internship.

FPR'S

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FORTNIGHTLY PROGRESS REPORT (FPR) FROM INDUSTRY MENTOR

Name of student	Shivam Yadav		Department	Purification Unit	
Industry/Organization	JOG Waste to Energy Pvt. Limited		Date/Duration	1/04/2024 to 15/04/2024	
Criterion	**Poor**	**Average**	**Good**	**Very Good**	**Excellent**
Punctuality/Timely completion of assigned work				✓	
Learning capacity/Knowledge up gradation				✓	
Performance/Quality of work			✓		
Behaviour/Discipline/Team work				✓	
Sincerity/Hard work			✓		
Comment on nature of work done/Area/Topic	Optimization of biomass pre-treatment techniques for enhanced biofuel production.				
OVERALL GRADE (Any one)	**POOR/AVERAGE/GOOD/VERY GOOD/EXCELLENT** (Very Good marked)				
Name of Industry Mentor	Abhishek Dhakad				
Signature of Industry Mentor	Abhishek (signature)				

Receiving Date		**Name of Faculty Mentor**		**Sign**	

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Industry/Organization	JOG Waste to Energy Pvt. Limited		Date/Duration	1/05/2024 to 15/05/2024	
Criterion	**Poor**	**Average**	**Good**	**Very Good**	**Excellent**
Punctuality/Timely completion of assigned work				✓	
Learning capacity/Knowledge up gradation			✓		
Performance/Quality of work				✓	
Behaviour/Discipline/Team work			✓		
Sincerity/Hard work				✓	
Comment on nature of work done/Area/Topic	Optimization of biomass pre-treatment techniques for enhanced biofuel production.				
OVERALL GRADE (Any one)	**POOR/AVERAGE/GOOD/VERY GOOD/EXCELLENT** (✓ VERY GOOD)				
Name of Industry Mentor	Akhilesh Shrikand				
Signature of Industry Mentor	Akhilesh				

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Industry/Organization	JOG Waste to Energy Pvt. Limited		Date/Duration	15-07-2024 to 30-07-2024	
Criterion	**Poor**	**Average**	**Good**	**Very Good**	**Excellent**
Punctuality/Timely completion of assigned work			✓		
Learning capacity/Knowledge up gradation			✓		
Performance/Quality of work				✓	
Behaviour/Discipline/Team work			✓		
Sincerity/Hard work				✓	
Comment on nature of work done/Area/Topic	Optimization of biomass pre-treatment techniques for enhanced biofuel production.				
OVERALL GRADE (Any one)	**POOR/AVERAGE/GOOD/VERY GOOD/EXCELLENT** (✓ VERY GOOD)				
Name of Industry Mentor	Akhilesh Dhakad				
Signature of Industry Mentor	Akhilesh				

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Industry/Organization	JOG Waste to Energy Pvt. Limited		Date/Duration	15 March 2024 to 31 March 2024	
Criterion	**Poor**	**Average**	**Good**	**Very Good**	**Excellent**
Punctuality/Timely completion of assigned work				✓	
Learning capacity/Knowledge up gradation					✓
Performance/Quality of work					✓
Behaviour/Discipline/Team work				✓	
Sincerity/Hard work				✓	
Comment on nature of work done/Area/Topic	Renewable energy Integration optimization of biomass pre-treatment techniques for enhanced biofuel production.				
OVERALL GRADE (Any one)	**POOR/AVERAGE/GOOD/VERY GOOD/EXCELLENT** ✓ (Excellent)				
Name of Industry Mentor	Akhilesh Dhakad				
Signature of Industry Mentor	Akhilesh (signature)				

Receiving Date		**Name of Faculty Mentor**		**Sign**	

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Industry/Organization	JOG Waste to Energy Pvt. Limited		Date/Duration	1/03/2024 - 15/03/24	
Criterion	**Poor**	**Average**	**Good**	**Very Good**	**Excellent**
Punctuality/Timely completion of assigned work				✓	
Learning capacity/Knowledge up gradation			✓	✗	
Performance/Quality of work			✓		
Behaviour/Discipline/Team work				✓	
Sincerity/Hard work				✓	
Comment on nature of work done/Area/Topic	Optimization of biomass pre-treatment techniques for enhanced biofuel production.				
OVERALL GRADE (Any one)	**POOR/AVERAGE/GOOD/VERY GOOD/EXCELLENT**				
Name of Industry Mentor	Akhilesh Dhakad				
Signature of Industry Mentor	Akhilesh				

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Criterion	**Poor**	**Average**	**Good**	**Very Good**	**Excellent**
Punctuality/Timely completion of assigned work					✓
Learning capacity/Knowledge up gradation				✓	
Performance/Quality of work				✓	
Behaviour/Discipline/Team work				✓	
Sincerity/Hard work			✓		
Comment on nature of work done/Area/Topic	Optimization of biomass pre-treatment techniques for Enhanced biofuel production.				
OVERALL GRADE (Any one)	**POOR/AVERAGE/GOOD/VERY GOOD/EXCELLENT** ✓ (Excellent)				
Name of Industry Mentor	Akhilesh Dhakad				
Signature of Industry Mentor	Akhilesh.				

Receiving Date		**Name of Faculty Mentor**		**Sign**	

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Industry/Organization	JOG Waste to Energy Pvt. Limited		Date/Duration	01/02/2024 to 15/02/20	
Criterion	**Poor**	**Average**	**Good**	**Very Good**	**Excellent**
Punctuality/Timely completion of assigned work			✓		
Learning capacity/Knowledge up gradation				✓	
Performance/Quality of work				✓	
Behaviour/Discipline/Team work			✓		
Sincerity/Hard work			✓		
Comment on nature of work done/Area/Topic	Optimization of biomass pretreatment technique for Enhanced biofuel production.				
OVERALL GRADE (Any one)	**POOR/AVERAGE/GOOD/VERY GOOD/EXCELLENT**				
Name of Industry Mentor	Akhilesh Shahad				
Signature of Industry Mentor	Akhilesh				

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Industry/Organization	JOG Waste to Energy Pvt. Limited		Date/Duration	16/01/2024 to 31/01/202	
Criterion	**Poor**	**Average**	**Good**	**Very Good**	**Excellent**
Punctuality/Timely completion of assigned work			✓		
Learning capacity/Knowledge up gradation				✓	
Performance/Quality of work				✓	
Behaviour/Discipline/Team work				✓	
Sincerity/Hard work					✓
Comment on nature of work done/Area/Topic	Biogas Purification Plant				
OVERALL GRADE (Any one)	**POOR/AVERAGE/GOOD/VERY GOOD/EXCELLENT** (Very Good)				
Name of Industry Mentor	Akhilesh Dhakad				
Signature of Industry Mentor	[signature]				

Receiving Date		**Name of Faculty Mentor**		**Sign**	