Biomass Pretreatment Technique For Enhanced Biofuel Production in Biogas Plant

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In

Chemical Engineering

Submitted By

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UNDER THE SUPERVISION AND GUIDANCE OF

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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.

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ABSTRACT

This study explores the optimization of biomass pretreatment techniques to increase biogas output in biogas plants.. The impacts of many pretreatment techniques, such as mechanical, thermal, chemical, and biological ones, on methane concentration and biogas output were methodically assessed. It was discovered through a thorough experimental design that enzymatic hydrolysis combined with alkaline pretreatment, followed by heat treatment, greatly increased biomass digestibility. Combutilizing recently or live plant and animal remains, biomass is a renewable energysourc e that may be burned for fuel. Polymers include cellulose, lignin, fat, protein, and carbohydrates make up the majority of bio mass. When microorganisms break down biomass anaerobically, biogas is created. The four st ages of anaerobic digestion (AD) are methanogenesis, acetogenesis, hydrolysis, and acidogen esis. Because biomass contains complex polymers, the hydrolysis process is rate- limiting. The process of pretreatment prepares the biomass to be attacked by microbes. Physical methods like irradiation, ustion, etc.; chemical methods like wet oxidation, alkali, or acid treatment; biological methods like fungal or enzyme pretreatment; or a mix of these methods can be used as this pretreatment.

Keywords: anaerobic digestion, biomass, biogas generation, pretreatment

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Anurag Gautam

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CONTENT

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ACRONYMS

AD :	Anaerobic digestion
COD :	Chemical oxygen demand
NPK :	Potassium, phosphorus, and nitrogen
GHG :	Greenhouse gas
NNI :	N nutrition index
CO_2 :	Carbon dioxide
H_2 :	Hydrogen
CH_4 :	Methane
CO :	Carbon monoxide
CNG :	Compressed natural gas
H_2S :	Hydrogen sulphide
H_2O :	Water
NH_3 :	Ammonia

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CHAPTER 1: INTRODUCTION

The world's fossil fuel supplies are being significantly depleted as a result of its fast growing energy demands. Finding alternative energy sources that reduce environmental impact is therefore essential. Biogas is one such renewable energy source that may be made from a variety of biomass sources, including garbage. Because it can convert many kinds of biomass into methane-rich biogas and provide a carbon-neutral alternative to fossil fuels, anaerobic digestion (AD) technology is particularly promising.

Additionally, AD technology has a number of benefits over conventional waste treatment methods. These include less odor, lower solids content, fewer greenhouse gas emissions, and more income from non-market advantages. More than 50% of the biogas potential in Germany, which leads the globe in this field, comes from energy crops that are processed in more than 7,000 biogas facilities. AD's low cost, advantages for energy recovery, and decreased production of biosolids make it a popular choice for sludge stabilization.

Anaerobic microorganisms are used in the AD process to break down the organic matter in biomass into biogas in an oxygen-free environment. The main output is biogas, which has a methane content of around 60% by volume. One byproduct that may be treated and used as fertilizer in agriculture is digestate. AD is a three-phase biological process that begins with the hydrolysis of complex organic compounds into smaller molecules, followed by acidogenesis, which turns these molecules into organic acids and hydrogen, and methanogens, which use hydrogen and organic acids to produce methane and carbon dioxide. Biogas may be transformed into energy and heat and used in pipelines in place of natural gas because of its high methane concentration.

Because some anaerobic bacteria develop slowly, AD usually needs extensive residence durations, necessitating the use of large tanks. In order to improve the effectiveness of digestion, it is necessary to break chemical bonds in materials that are hydrolyzable. Slow hydrolysis, limited biodegradability, inhibition from toxic chemicals, and inadequate methanogenesis are some of the factors limiting AD efficiency. Pretreatment is used before of the AD process in order to get over these obstacles and expedite deterioration.

Pretreatments aim to modify the substrate's structure to make it more accessible to enzymes, thereby increasing biogas output. The impact of pretreatments varies depending on the type and characteristics of the substrates. Recently, techniques for dissolving and solubilizing biomass have gained attention as a way to overcome the biological limitations of anaerobic digestion.

CHAPTER 2 – LITERATURE SURVEY

Biomass pretreatment is a crucial step in optimizing biogas production in biogas plants. Effective pretreatment enhances the digestibility of biomass, leading to increased biogas yield and improved process stability. This literature review explores various pretreatment techniques, including mechanical, thermal, chemical, biological, and combined methods, assessing their effectiveness, advantages, and challenges.

Mechanical pretreatment techniques such as grinding and milling reduce the particle size of biomass, thereby increasing the surface area available for microbial attack. Studies indicate that these processes enhance the hydrolysis of biomass, improving the overall biogas yield [10]. By reducing the structural integrity of the biomass, mechanical pretreatment facilitates the breakdown of complex polymers, making them more accessible to enzymatic action.

Shredding and chopping are also commonly used mechanical pretreatment methods. These techniques break down larger pieces of biomass into smaller, more manageable sizes, which can significantly enhance the efficiency of subsequent biological and chemical treatments.

According to Mosier et al. [7], these methods improve the contact between biomass and microorganisms, accelerating the digestion process.

Mechanical pretreatment increases the surface area of biomass and reduces its structural integrity, thereby enhancing microbial hydrolysis and biogas production. High energy consumption and equipment wear and tear are significant drawbacks of mechanical pretreatment method [11] .

Thermal pretreatment techniques involve the application of heat to disrupt the complex structure of biomass. Steam explosion, where biomass is treated with high-pressure steam and then rapidly decompressed, is an effective method for enhancing biomass digestibility [4]. The sudden pressure release causes the biomass to explode into a more digestib le form, making cellulose and hemicellulose more accessible for microbial digestion.

Hot water treatment, where biomass is immersed in hot water, helps to solubilize hemicellulose and disrupt lignin structures [3]. This method increases the availability of fermentable sugars, which are essential for efficient biogas production. Chemical pretreatment involves the use of chemicals to break down biomass components. Acid pretreatment, using acids like sulfuric acid, hydrolyzes hemicelluloses into fermentable .

This method effectively disrupts the lignocellulosic matrix, making the cellulose more accessible to enzymatic action .Alkaline pretreatment uses alkalis such as sodium hydroxide to saponify lignin and disrupt cell wall structures[1]. This method enhances enzyme accessibility and improves the digestibility of biomass.

Oxidizing agents like hydrogen peroxide break down lignin and increase the porosity of biomass, facilitating microbial digestion[2].Chemical pretreatment effectively disrupts the lignocellulosic matrix, enhancing biomass digestibility and biogas yields. Chemical pretreatment can be costly and may require neutralization steps to prevent toxicity to microorganisms [12].

Biological pretreatment uses microorganisms or enzymes to degrade complex biomass components. Fungal pretreatment involves the use of fungi to degrade lignin and hemicellulose, leaving cellulose more accessible for microbial digestion[1].Enzymatic hydrolysis employs specific enzymes like cellulases and hemicellulases to break down cellulose Biological pretreatment is environmentally friendly and highly specific in targeting biomass components for degradation. The slow degradation rate and high cost of enzymes are significant limitations [13].

Combining different pretreatment techniques can often yield better results than using a single method. Thermo-chemical pretreatment combines thermal and chemical methods to enhance biomass degradation [10]. Mechanical-biological pretreatment integrates mechanical size reduction with biological degradation to maximize the availability of fermentable sugars [8]Combined pretreatment techniques can produce synergistic effects, significantly improving the efficiency of biomass conversion and biogas production. The complexity and cost of implementing combined pretreatment methods can be higher than single techniques [14].

CHAPTER 3 – COMPANY PROFILE

JOG Waste to Energy was established by two courageous and young entrepreneurs. Their main objective is to provide innovative and cost-effective products and services to satisfy the ever-evolving needs of the waste-to-energy, biogas, and solar energy sectors. JOG-Biogas is among the best firms in the world for developing biogas plants out of concrete and stainless steel. Our specialty is offering technically superior solutions with specially designed layouts for projects with capacities up to 100,000 m3 per day. We have been developing biogas plants and offering full engineering services since 2013. We have developed into specialists in a multitude of technologies, such as the best device technology available, steel or concrete reactors, mesophilic and thermophilic processes, and so on.

Our Main Objective To assist the solar energy and biogas industries by producing the best products and services in the world in terms of quality, reliability, and performance. To transform our cutting-edge innovations into value for our stakeholders and customers by relentlessly striving to achieve the unattainable

With our all-inclusive corporate solutions, we hope to spearhead the worldwide renewable energy movement for a healthier and more environmentally friendly world. In order to do this, we will actively pursue new prospects in the Grid and Off Grid domains, as well as turnkey projects including the conversion of biogas into biomethane (CNG) and biogas to energy companies. We intend to establish appropriate collaborations with leading global providers of renewable energy, offering an extensive array of superior products and services.

Methane and carbon dioxide are the main components of biogas. Trace levels of siloxanes and hydrogen sulfide moisture are possible. When exposed to oxygen, gases like methane, hydrogen, and carbon monoxide may all burn or oxidize. Biogas may be used as a fuel for cooking and other heating purposes because of this energy release. It may also be utilized to transform the energy in gas into power and heat in a gas engine. Many elements, such as organic wastes like cow dung and other biodegradable materials like biomass from kitchens, gardens, and farms, as well as wastes from night soil, may be used to create biogas in a residential biogas plant. Anaerobic digestion (AD) is the process that produces biogas.

CHAPTER 4:PROBLEM STATEMENT

Despite its potential as a renewable energy source, biomass conversion into biofuels is hampered by inefficient pretreatment methods. Current technologies frequently provide low yields and considerable energy usage, limiting the economic sustainability of biofuel production. Therefore, there is a vital need to optimize biomass pretreatment procedures to maximize the efficiency of biofuel production, minimize energy input, and improve overall sustainability.

CHAPTER 5 : METHODOLOGY

5.1: MICROBIOLOGY

The four main mechanisms that propel anaerobic digestion (AD) are acidogenesis, acetogenesis, methanogenesis, and hydrolysis. The groups of microorganisms referred to as acidogenic, acetogenic, and methanogenic bacteria aid in these activities. Two prokaryotic kingdoms—Archaea and Bacteria—have a strong association with the very complicated microbial ecology of the anaerobic process. Hydrolysis, the initial stage, is the process of dissolving complex organic components into smaller molecules. In the second stage, these chemicals proceed through acidogenesis, which results in the production of organic acids and hydrogen. The last step involves the production of methane and carbon dioxide from organic acids and hydrogen by archaea methanogens.

A summary of the AD procedure is shown in Figure 1. Particulate, water-insoluble polymers like proteins, lipids, and carbohydrates make up organic matter. Bacteria are unable to directly access these insoluble polymers because they are unable to pass through biological membranes. Certain types of hydrolytic bacteria provide the enzymes needed for hydrolysis, which changes insoluble polymers into soluble monomers and oligomers. Amino acids are produced from proteins, long-chain fatty acids are produced from lipids, and sugars are produced from carbs. These soluble molecules are converted into acetic acid, other longer volatile fatty acids, alcohols, CO2, and hydrogen by acidogenic bacteria during the process of acidogenesis. Ethanol (C2H5OH), propionic acid (CH3CH2COOH), butyric acid (CH3CH2CH2COOH), and acetic acid (CH3COOH) are the main acids that are created. Clostridium, Peptococcus, Lactobacillus, and Actinomyces are among other bacteria that may create acids.

In acetogenesis, proton-reducing acetogens convert longer volatile alcohols and fatty acids into acetic acid and hydrogen. The acetogenesis reaction is depicted below.

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 \qquad (1)$$

Methanogens employ hydrogen and acetic acid, or carbon dioxide and carbon dioxide, in the last stage of the process to generate methane and carbon dioxide. The ideal temperature range for methane generation in mesophilic bacteria is typically 35–37°C. The greatest methanogenic activity of thermophilic methanogens is achieved at around 55°C, which sets them apart from mesophilic ones. Compared to a mesophilic digestion process, a thermophilic digestion process can withstand a larger organic loading. However, the gas produced by the thermophilic process has less methane in it and is more susceptible to toxins.

Because methanogens develop more slowly in the reactor environment than other species, they are also more susceptible to temperature fluctuations. Although the ideal pH range for methanogenesis is 7.0–7.2, it can occur at neutral pH- in the range of 6.5–7.5 VFAs, or volatile fatty acids, may accumulate if the methanogens are badly impacted by a temperature change, for instance. This decreases the pH, which has a detrimental impact on the methanogens and creates a vicious cycle of negative feedback. The following expression for the methanogenesis reactions may be found in Eqs. (2)–(4):

$$CH_3\,COOH \rightarrow CH_4 + CO_2 \qquad (2)$$

$$2C_2H_5OH + CO_2 \rightarrow CH_3 + 2CH3COOH \qquad (3)$$

$$CO_2 + 4H_2 \rightarrow CH_4\ \ 2H_2O \qquad (4)$$

The features of wastewater, as well as the kind and layout of the treatment system, may all have a substantial impact on the digesting efficiency and stability. A substrate will degrade more thoroughly the longer it is maintained under ideal reaction conditions. For a given amount of substrate to be treated, a larger reactor capacity must be provided for a longer retention period.

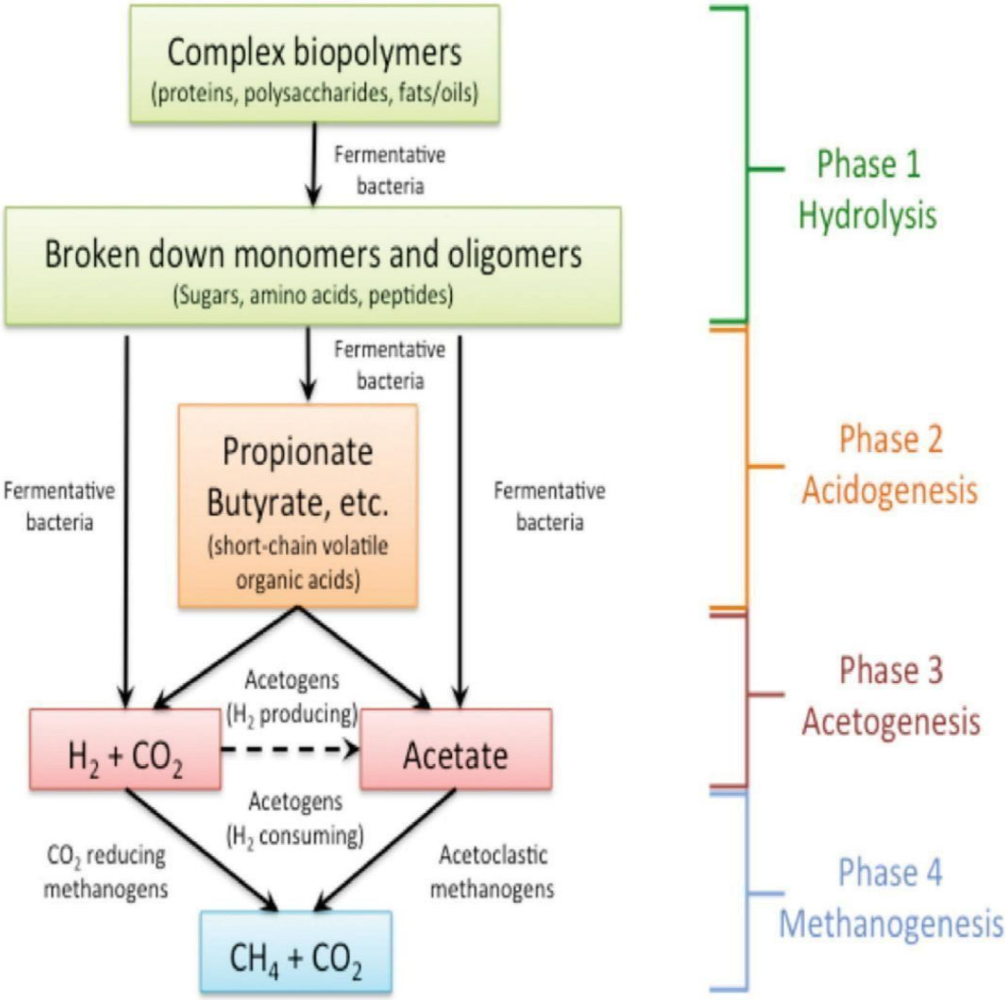

Figure 1. Schematic representation of anaerobic digestion (dutton institute)

Washout of the microbe occurs with less overall degradation with shorter retention duration Thus, for the full-scale reactor to operate effectively and correctly, these two impacts must be balanced in the AD design.

5.2 : Need for pretreatment

Renewable resources that have been attempted for biogas generation include energy crops such as sunflower, rape, and jatropha, agricultural wastes such as banana stems, barley straws, rice straws, softwood spruce, and unconventional biomass such as glycerol and microalgae. Crop biomass consists of organic wastes such as animal manure, wastewater sludge, and municipal solid waste, as well as crops such as maize, wheat, barley, and sweet sorghum. Figures 2-4 show how pretreatment affects the biomass of sludge ,macroalgae, and lignocellulosic material.

Because of the various interactions between its constituent elements and its diverse composition, lignocellulosic biomass has a highly decomposed and complex structure. Simple sugars are formed when polysaccharides such as cellulose and hemicellulose are hydrolyzed. Lignin prevents microbial attack during the hydrolysis process by anchoring cellulose and hemicellulose and preserving cell integrity. Pretreatment boosts the biomass's digestibility by dissolving the lignin layer that covers the cellulose and hemicellulose. Pretreatment also helps to reduce cellulose crystallinity while boosting porosity.

Furthermore, because of inhibitors, biomass—such as fruit wastes—degrades fast but generates little. Feathers and horns include keratin, an insoluble protein. Its polypeptide chain is hydrophobic, disulfide- and hydrogen-bonded, tightly packed, and firmly cross-linked. This insoluble protein's high resistance to proteolytic enzyme activity severely hinders the biological digestion of these wastes. This type of crosslinking of the polypeptide e chain makes the keratin easier to digest and more obtainable. Conversely, however,

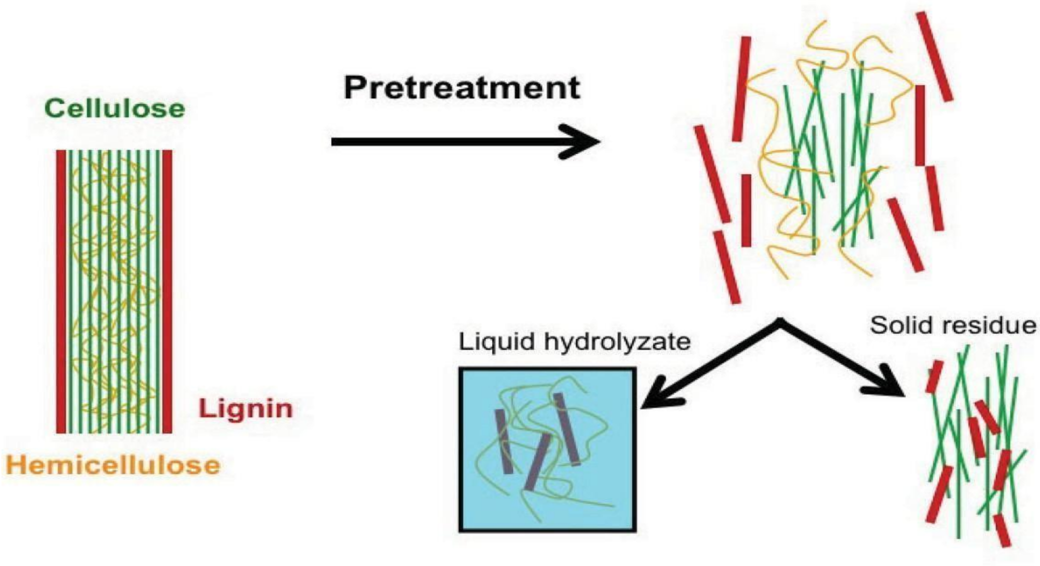

Figure 2: Pretreatment's impact on lignocellulosic biomass (dutton institute)

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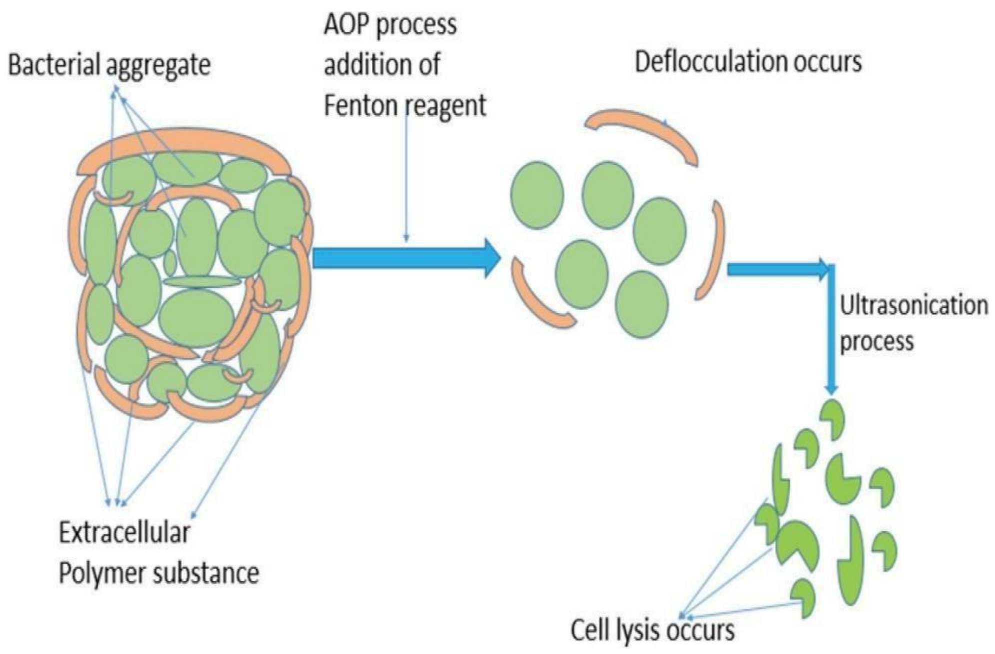

Figure 3: Effect of pretreatment on sludge biomass (dutton institute)

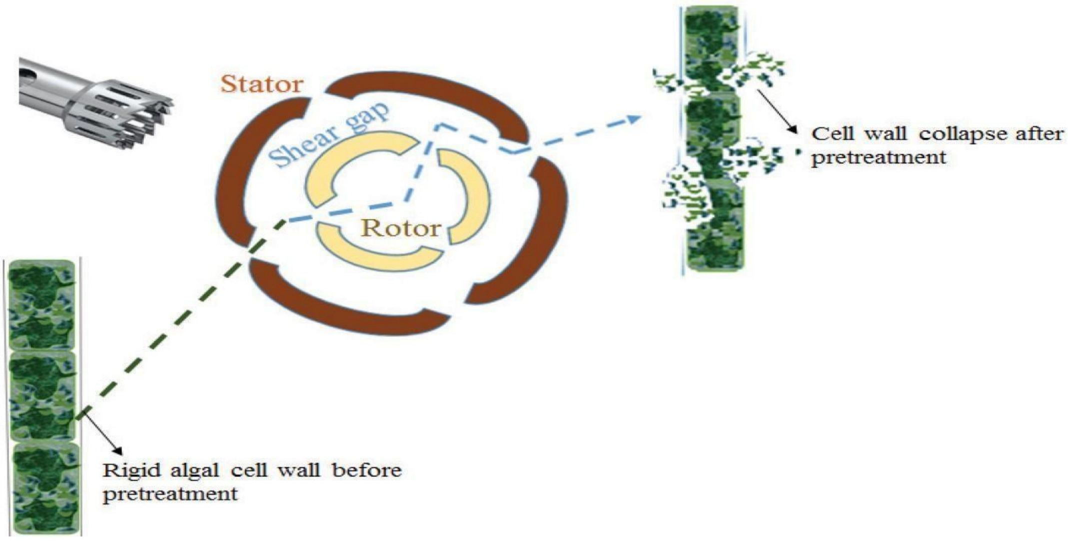

Figure 4: Effect of pretreatment of macroalgal biomass.

Because of its high organic content, activated sludge—a byproduct of aerobic wastewater treatment—becomes a suitable raw material for energy production. Different kinds of microbial cells may be found in secondary wastewater sludge, and their cell walls function as barriers to stop exo-enzymes from breaking them down. In activated sludge, exocellular polymeric substances (EPS) make up a substantial amount of the organic matter in addition to microbial cells.

Two important factors that affect the digestibility of activated sludge are the floc structure and the EPS binding mechanisms to cations. Therefore, in a typical anaerobic sludge treatment, hydrolysis becomes the rate-limiting phase, limiting the degradation to a 30–35% reduction in chemical oxygen demand (COD). The sludge has to be treated to break down the cell walls and release intracellular components into the aqueous phase in order to improve the process.

As a result, anaerobic digestion (AD) becomes more efficient, with shorter retention times and increased biogas production. Methanogenic bacteria cannot break down biopolymers during AD due to the tough macroalgal cell envelope, which is composed of complex proteins and carbohydrates that provide high mechanical strength and chemical resistance.

Pretreatment enhances the liquefaction process, facilitating the release of biopolymers. Numerous detailed pretreatment techniques have been developed to increase biogas output and make biomass more suitable for microbial digestion. To prevent excessive sugar breakdown, pretreatment must be conducted under gentle conditions.

It has been demonstrated that a number of pretreatment techniques increase biomass biodegradability by encouraging hydrolysis. Ball milling, microwave radiation, treatment with sodium hydroxide, steam explosion, ultrasonic therapy, biological techniques, and ozonation are some of these techniques. Since most of the articles that are now accessible deal with the pretreatment of lignocellulosic biomass, this chapter concentrates on sludge pretreatment.

5.3 : PRETREATMENT TECHNOLOGIES

One of the primary drawbacks of the conventional anaerobic digestion (AD) process is lower hydrolysis rates, which result in a larger digester capacity and a longer hydraulic retention time (HRT). Sludge breaks down slowly and lacks readily biodegradable, soluble organic components, necessitating preparation. Biomass pretreatment enhances AD by reducing retention times and increasing bio gas production. Advances in various pretreatment techniques—thermal, chemical, mechanical, biological, and physical, as well as combinations such as physicochemical, mechanical-chemical, biological-physicochemical, and thermal-chemical—can significantly increase the biodegradability of sludge. Numerous studies worldwide have sought to identify the optimal pretreatment techniques.

Tables 1 and 2 present data on the specific energy used and methane production achieved with various chemo-mechanical and physico-chemical pretreatments.

Physical

Through the use of physical force, physical pretreatment modifies the biomass's structure and reduces the size of its particles. This increases the particle's surface area and increases its vulnerability to enzymatic and microbial assaults, which improves the AD process for the synthesis of methane. Various techniques such as microwave irradiation, solvent extraction, mechanical pounding, dispersion, deflaking, extrusion, milling, and cavitation can be used for physical preparation .

Milling

Milling pretreatment, particularly for lignocellulose and algal biomass, is employed to enhance the substrate's bioaccessibility to cell tissues and reduce its size, thereby breaking up the cellular structure by increasing the biomass's specific surface area. This particle size reduction accelerates enzymatic breakdown and decreases viscosity in digesters, leading to improved mixing and fewer issues with floating layers.

Table 1. Methane production and specific energy used with different chemo-mechanical pretreatments.

S. No.	Name of the pretreatment	Specific energy consumed (KJ/kg TS)	Solubilization achieved (%)	Biomethane yield	References
1	Disperser + alkali	4543	24	1391 ml	Rani et al.
2	Thermo chemo disperser	5360.94	18.6	0.456 L/g VS	Kavitha et al.
3	Chemo disperser	5012	30	0.521 L/g VS	Poornima Devi et al.
4	Sono alkaline	4172	59	0.109 ml/g VS removed	Rani et al.
5	Thermo chemo sonic	5290.5	27	0.423 g COD/ g COD	Kavitha et al.
6	Citric acid + ultrasonic	171.9	22.8	0.425 L/g VS	Gayathri et al.
7	Fenton + ultrasonic	641	34.4	0.32 g COD/g COD	Kavitha et al.
8	Thermo chemo sonic	5500	35	0.70 g COD/g COD	Kavitha et al.
9	Disperser + microwave	18,600	22	0.28 g COD/g COD	Kavitha et al.
10	Chemo mechanical	7377	38	50 ml/g VS removed	Kavitha et al.
11	Sonic mediated biological	2.44	23	0.18 d1	Kavitha et al.
12	Chemo thermo disperser	174	60	0.81 g COD/g COD	Kavitha et al.
13	Surfactant sonic	5220	24.7	0.23 g/g COD	Ushani et al.
14	Chemo disperser	3212.6	16	0.15 g COD/g COD	Tamilarasan et al.
15	Surfactant + sonic	5400	26	0.6 g/g COD	Santhi et al.
16	Disperser + bacterial	9.6	22.4	0. 269 g COD/ g COD	Banu et al.
17	Ultrasound + microwave	16,705	33.2	0.2 L/g COD	Kavitha et al.

Cavitation

Cavitation techniques commonly used include acoustic cavitation and hydrodynamic cavitation. Acoustic cavitation is generated by passing ultrasonic waves through a liquid medium, causing a recurring sequence of compressions and rarefactions that produce microbubbles known as cavitation. Hydrodynamic cavitation, on the other hand, is produced by hydraulic systems.

Table: Specific Energy Consumption and Biogas Yield with Various Pretreatments

S. No.	Name of the Pretreatment	Specific Energy Consumed (KJ/kg TS)	Solubilization Achieved (%)	Biomethane Yield (ml/g VS)	References
1	Microwave	1843	18.6	0.162	Rani et al.
2	Microwave + citric acid	13,000	32	0.625 L/g	Ebenezer et al. [38]
3	Microwave + surfactant	13,000	28	0.47 L/g	Ebenezer et al. [58]
4	Microwave + H2O2	18,600	56	0.313 L/g	Eswari et al. [59]
5	H2O2 + microwave	18,920	46.6	250 ml/g	Eswari et al. [60]
6	Thermo ozone	151.02	30.4	0.32 g COD/g COD	Kannah et al. [1]

Table 2. Particular amount of energy used for each physicochemical pretreatment

There are temperatures as high as 5000 K and pressures as high as 180 MPa as a result of these cavitation that swiftly collapse after expanding to an unstable size. Microorga nisms' cell walls are harmed by the strong shear stresses created in the surrounding liquid by the quick collapse of many microbubbles . Higher sonication power levels, however, are said to have a negative impact on the pretreatment procedure. Higher power levels cause bubbles to develop close to the ultrasonic transducer's tip, which prevents energy from being transferred to the liquid medium .

In the waste activated sludge (WAS) ultrasonic pretreatment investigation, Apul & Sanin looked into an increase in anaerobic biodegradability after 15 minutes of sonication.

When compared to control conditions, they improved daily biogas output and methane production in semi-continuous reactors by 49% and 74%, respectively, using an organic loading rate of 0.5 kg/m^3•d and a solid retention duration (SRT) of 15 days. Zeynali et al. investigated how well fruit and vegetable waste might be converted into biogas with the use of ultrasonic pretreatment. They conducted tests at 20 kHz and 80 µm amplitude for sonication durations of 9, 18, and 27 minutes.

The highest methane production occurred during an 18-minute sonication period with a specific energy of 2380 kJ/kg of total solids, yielding biogas with double the energy content needed for sonication. Alzate et al. reported that only 20% of the methane was produced by sonicating macroalgae at a specific energy input of 75 MJ/kg TS. However, the methane generation rate increased to 80-90% when the specific energy was raised to 100-200 MJ/kg TS.

Hydrodynamic cavitation (HC) creates cavitation by forcing fluid flow past cavitating objects, significantly reducing pressure and forming numerous microbubbles that collapse, releasing large amounts of energy. This energy helps dissolve biomass, enhancing its suitability for bacterial decomposition in the AD process and increasing biogas output. Researchers investigated HC processing of wheat straw, measuring methane yields of 31.8 ml for untreated wheat straw, 77.9 ml for pre-treated wheat straw, and 172.3 ml for combined pre-treatment (KOH + HC), which was the highest output.

Microwave Irradiation

When cell walls and membranes are exposed to microwave radiation, their chemical (hydrogen) bonds are broken, leading to denaturation because the polarized areas of the macromolecules align with the poles of the electromagnetic field. Athermal effects are not the only effects that microwaves may have. They can also cause dipole orientation, which breaks down the floc matrix and destroys hydrogen bonds. When compared to conventional heating, microbial cells exposed to microwave radiation (MW) displayed more damage at equal applied temperatures. Using 800 W of electricity at 50°C, Rincón et al. investigated the effects of MW pre-treatment on solid waste from olive mills to improve anaerobic digestion.

Extrusion Pretreatment

Extrusion pretreatment applies heat, compression, and shear stress to biomass, causing physical damage and chemical changes as the material moves through the extruder. The extruder system comprises one or two screws rotating within a hermetically sealed, temperature-controlled barrel. As biomass progresses through the barrel, it encounters high shearing and friction, which increases pressure and temperature. Upon exiting the barrel, the pressure release alters the biomass structure, facilitating easier digestion in subsequent processes.

Maroušek optimized various pelleted hay extrusion settings to maximize cumulative biogas output, achieving the highest biogas production under optimal conditions at 405 m^3/ton TS, with a pressure of 1.3 MPa, a reaction time of 7 minutes, and 8% dry matter. This resulted in a 33% improvement over the control, yielding 405 m^3/ton TS (52.3% methane). Similarly, Novarino and Zanetti employed extrusion pretreatment to enhance biogas production from the organic component of municipal solid waste, achieving a biogas yield of 800 L/kg VS at a methane concentration of around 60%.

Thermal Pretreatment

Thermal pretreatment improves hydrolysis and increases methane output in subsequent anaerobic digestion (AD). Various temperatures ranging from 60 to 270°C have been studied, with temperatures above 200°C found to produce resistant soluble organics. Optimal thermal pretreatment temperatures are typically between 160 and 180°C, which have been shown to increase methane production during AD.

Exceeding 200°C can dramatically reduce the biodegradability of sludge hydrolysate due to the formation of toxic or inhibitory intermediates or refractory soluble organics. Borges and Chernicharo studied the effects of heat treatment on anaerobic sludge, finding that at 75°C, protein, glucose, lipid, and chemical oxygen demand (COD) levels increased by 30-35 times, while biogas production increased by 50%. This indicates that the remaining organic component becomes more biodegradable under these conditions.

Chemical Pretreatment

Acid Pretreatment

Acid pretreatment degrades sludge and lyses cells, making intracellular organics more accessible and accelerating the digestion process. For lignocellulosic biomass, acid pretreatment breaks the covalent, hydrogen, and Van der Waals forces that hold the biomass components together, reducing cellulose and breaking down hemicellulose. Devlin and colleagues demonstrated that pretreatment with pH 2 HCl significantly enhanced the digestion of waste activated sludge (WAS). Semi-continuous digestion studies showed that this pretreatment increased methane production by 14.3% compared to untreated WAS after a 12-day hydraulic retention period at 35°C. Taherdanak et al. improved biomethane production from wheat plants during mesophilic anaerobic digestion by treating them with acid.

Alkali Pretreatment

Alkaline pretreatment mainly causes the swelling of particulate organics at high pH, making cellular components of biomass more responsive to enzymatic activity. The hydroxyl anions in alkali break down complex cell structures, promoting protein liquefaction, RNA hydrolysis, and saponification in macroalgae. In lignocellulosic biomass, alkaline pretreatment causes swelling, delignification, and de-esterification of intermolecular ester bonds. This increases the biomass's porosity and internal surface area while reducing polymerization and crystallinity, making it more accessible to bacteria and enzymes. In WAS, higher pH levels degrade microbial cell walls, releasing intracellular chemicals into the liquid phase.

Oxidative

One pretreatment approach that may be used to fully decompose organic molecules into carbon dioxide and water is wet air oxidation, which improves the interaction between molecular oxygen and organic matter. High temperatures—and hence high pressures—are necessary to do this . To maintain the high temperature conditions, a high pressure is required. Wet air oxidation is a pretreatment procedure that improves the interaction of molecular oxygen with organic matter and may be used to totally degrade organic molecules into carbon dioxide and water. To do this, enormous pressures and temperatures are necessary. To keep the high temperatures constant, an equivalent amount of pressure is necessary.

Ozonation

Because ozone is a potent oxidant, it may effectively oxidize substrates. It can break down lignin in a variety of feedstocks. It converts lipids, proteins, polysaccharides, and other refractory substances into molecules that can be broken down naturally. Anaerobic microbes may readily access and absorb more soluble and readily biodegradable organic materials through the effective cell wall rupture that occurs during the ozonation process. As a result,
enhances the AD process .

Goel et al. examined the AD of ozone-pretreated excess sludge by running laboratory-scale reactors over a lengthy period of time. They observed that ozone pretreatment might partially dissolve the sludge solids, increasing anaerobic degradability in the process. The amount of ozone provided impacted the degree of solubilization and the efficacy of digestion. The AD efficiency improved to about 59% at 0.05 g $O3$/g TS, compared to 31% in the control run. Several process indicators, such as particular methane production and ammonia concentration in the reactor, show that ozonated sludge has higher reported solid degradation rates.

Biological

Biological pretreatment relies on various forms of heterotrophic microorganisms to break down complex biopolymers like proteins and carbohydrates into simpler end products. The enzymes produced by these bacteria facilitate the solubilization of organic molecules in biomass with minimal energy input and without significantly altering the substrate environment, highlighting its significance. This process can occur with or without the addition of exogenous enzymes, as some enzymes are endogenously produced by the microbes in the sludge.

Examples of enzymes that can significantly enhance hydrolysis and biopolymer release include protease, lipase, cellulase, alpha-amylase, and dextranase. However, these enzymes can be expensive and challenging to store. Bonilla et al. evaluated the use of B. licheniformis protease for enzymatic pretreatment of pulp mill biosludge, finding that biogas output could be improved by up to 26% following biochemical methane potential (BMP) testing.

Biological pretreatment of microalgae, such as Chlorella vulgaris, using bacteria that secrete cellulase before anaerobic digestion enhances biomass bioavailability and methane production. Studies show that bacterial pretreatment can nearly double methane production compared to control. Fungal pretreatment also improves the digestibility of cellulose by breaking down lignin and hemicellulose, which is essential for the AD process.

CHAPTER 6: RESULT AND DISCUSSION

Result from Table 1:

• Evaluated several pretreatment strategies for converting biomass to biomethane.

• Methods used included alkali dispersers, thermo-chemo dispersers, chemo dispersers, sono alkaline, citric acid + ultrasonic, and Fenton + ultrasonic.

• Energy usage varied significantly between approaches, from 2.45 KJ/kg TS to 18,000 KJ/kg TS.

• Certain approaches can achieve up to 60% solubilization.

• Biomethane production was reported in many units, including ml/kg, L/g VS, and g COD/g COD.

Result from Table 2:

• Studied microwave-based pretreatment techniques, including those using citric acid, surfactants, and H_2O_2.

• Energy consumption varied from 141.02 to 18,910 KJ/kg TS.

• Solubilization rates varied from 18.6% to 56%.

• Biomethane yield varied widely, with metrics such as ml/g VS, L/g VS, and g COD/g COD.

The tables give useful information on several pretreatment strategies for biomass conversion to

biomethane. Future research should concentrate on creating low-cost, energy-efficient, and ecologically friendly pretreatment technologies to help the transition to a bio-based economy.

CHAPTER 7 : FUTURE CHALLENGES AND CONCLUSION

Right now, fossil fuels like coal, natural gas, and crude oil account for a sizable amount of the world's energy supply. It is anticipated that the current energy policy and management would result in a 44% increase in global energy consumption between 2006 and 2030. Simultaneously, atmospheric concentrations of greenhouse gases are increasing at an accelerated rate, with carbon dioxide emissions from fossil fuels being the primary cause. A greater emphasis is currently being placed on various methods for the bioconversion of biomass into methane-rich biogas due to factors such as growing global warming, the need for sustainable waste management, and high energy costs.

When it comes to producing biogas, AD is a highly advantageous method compared to other bioenergy production methods. Since biomass is a living substance that stores sun energy through photosynthesis, AD biogas is perpetually renewable, in contrast to fossil fuels . It has been rated as one of the bioenergy production process's most ecologically friendly and energy-efficient technologies [86]. By employing locally available resources, it may drastically reduce greenhouse gas emissions when compared to fossil fuels.

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Algae, cereals, grasses, leaves, manure, and fruit and vegetable waste are among the items that might be used. The process may be implemented on a local and large scale in a variety of worldwide areas. A prolonged head start time (HRT) of several weeks to a month is required for complete energy crop digestion with significant gas outputs and minimal digestate residual gas potential. More increases in process efficiency and the development of new technologies for mixing, process monitoring, and process control are necessary for the widespread deployment of biogas plants. The inclusion of micronutrients and substrate pretreatment present a significant opportunity to boost the biogas output. As the number of biogas plants rises, there is also a need to enhance the effluent quality to prevent pathogen and nutrie nt pollution of ground water .

Pretreatment selection should take into account not only energy balance and economics, but also a number of environmental issues, including pathogen eradication, chemical usage, potential for sustainable residue utilization, and effects on the environment and human health . Carballa and associates. assessed the environmental effects of various pretreatment techniques using a life cycle assessment to determine the potential for eutrophication, global warming, depletion of abiotic resources, and toxicity to humans and animals.

Low initial and operating costs are necessary for a biogas plant to operate profitably [28]. Physical, thermal, and chemical processes are among the common ways that are currently commercially applied with several patented technologies. However, studies on biological methods are still being conducted, ranging from bench to large-scale implementations.

a lot of pretreatment Techniques are costly or energy- intensive. Any pretreatment method's effectiveness is measured by comparing its cost to the value of increased methane yield, a measure of the method's economic viability. However, the majority of the pretreatment's impact is contingent upon the biomass composition and operation parameters. Because of the high cost of process engineering, investment expenses for pretreatment of resistant substrates are currently considerable. Commercial enzymes are expensive, thus utilizing an enzyme-secreting bacterial consortium for biomass is preferable since biological disintegration removes the requirement for energy inputs and chemical contamination.

However, biological pretreatment is not appropriate for large-scale operations where land expensive due to the requirement for lengthy response periods. A small number of the examined studies calculated the net energy gain or loss resulting from pretreatment, while the majority evaluated the effects of pretreatment procedures on the biogas output in a laboratory setting . The majority of research published in the literature are lab-scale studies that don't provide the same results as large-scale biogas producing plants. Therefore, there is a constant need for more advanced, environmentally friendly techniques of processing biomass that need less energy and produce less waste.

The impact of several biomass pretreatments on improving biogas production is concluded in this chapter, along with future challenges for an environmentally responsible and energy- efficient approach. Consequently, Pretreatment conditions must be optimized to decrease production costs, increase process efficiency, and create fewer residues. A pretreatment plan that is developed based on the aforementioned variables may increase each pretreatment's performance and achieve financial, environmental, and technical viability. To gather relevant data that might result in the required advancements in the AD sector, more study on combination pretreatments is required in the future.

CHAPTER 8: SOCIAL RELEVANCE

1. Energy Security and Access

By optimizing the conversion of organic waste into biogas, pretreatment techniques contribute to a reliable and renewable energy source. This is particularly crucial for rural and remote areas where access to conventional energy infrastructure is limited. Decentralized biogas production reduces dependency on fossil fuels and enhances energy security, providing a stable and local energy supply.

2. Environmental Sustainability

Effective biomass pretreatment reduces the volume of organic waste destined for landfills, mitigating associated environmental hazards such as groundwater contamination and methane emissions. In addition to reducing greenhouse gas emissions as compared to fossil fuels, enhanced biogas production also helps mitigate climate change. The use of biogas as a clean fuel supports global efforts to transition to sustainable energy systems.

3. Economic Development

The application of biogas and biomass pretreatment technology boosts regional economies by generating employment in the building, running, and upkeep of biogas facilities. Additionally, farmers and agricultural communities benefit economically from selling agricultural residues and utilizing the by-products of biogas production, such as biofertilizers, which enhance soil fertility and crop yields.

4. Public Health

Biogas as a clean cooking fuel significantly reduces indoor a ir pollution, which is a major health hazard in many developing regions where traditional biomass fuels are commonly used. Improved air quality leads to better respiratory health and overall well-being. Moreover, integrating biogas plants with sanitation systems, such as biogas toilets, improves hygiene and reduces disease transmission.

5. Empowerment

The adoption of biogas technologies, supported by education and training programs, empowers communities by promoting sustainable practices and self- sufficiency. Local involvement in biogas projects fosters a sense of ownership and responsibility towards environmental stewardship and sustainable development..

CHAPTER 8: COURSE OUTCOMES

CO1: Understand Biomass Composition and Conversion Processes

CO2: Evaluate Various Pretreatment Techniques

CO3: Analyze the Impact of Pretreatment on Biogas Yield

CO4: Examine Environmental and Economic Benefits

CO5: Discuss the Social Implications

CO6: Apply Knowledge in Practical Scenarios

CO7: Promote Sustainable Practices

CO8: Conduct Research and Critical Analysis

CO9: Develop Technical and Communication Skills

CO10: Foster Innovation and Problem-Solving Abilities

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