

**WASTE TO ENERGY: FERMENTATION OF MUNICIPAL SOLID WASTE  
TO PRODUCE BIOETHANOL**Shreya Kundu<sup>1</sup>, Shefali Chokshi<sup>2</sup>, Twinkal Kahar<sup>3</sup>, Kunal Majmudar<sup>4</sup><sup>1</sup>Environmental Science & Technology, Shroff S. R. Rotary Institute of Chemical Technology, Vataria - 393135, Bharuch.<sup>2</sup>Environmental Science & Technology, Shroff S. R. Rotary Institute of Chemical Technology, Vataria - 393135, Bharuch.<sup>3</sup>Environmental Science & Technology, Shroff S. R. Rotary Institute of Chemical Technology, Vataria - 393135, Bharuch.<sup>4</sup>Environmental Science & Technology, Shroff S. R. Rotary Institute of Chemical Technology, Vataria - 393135, Bharuch.

**Abstract** — Recent focus on energy sector has been switched from non-renewable fossil fuels to renewable biofuels due to former's harmful impact on environment. There are various biofuels and each has its own production methodology but all these eco-friendly fuels have similar contribution towards growing energy demand and sustainable development. The growing awareness about utilization of fossil fuels and their impact on atmosphere, leads to the use of fuels derived from biodegradable organic waste which results in lowering carbon footprints, reducing greenhouse gas emission, reducing dependency on fossil fuels, providing economic security and lowering level of pollution compared to the non-renewable fossil fuels. Some of these green fuels are bioethanol, biogasoline, bio-diesel, biohydrogen, biogas, etc., derived from agricultural waste, food waste, algae, etc. Our work mainly focuses on bioethanol as a biofuel as it has some significant advantages such as its capability to replace gasoline and to achieve the carbon emission goals under Kyoto Protocol. Another reason for use of bioethanol over other biofuels is that it can be potentially used as transportation fuel with minimal or no modifications in the existing vehicular engines. Bioethanol as a biofuel is an alcohol produced by the fermentation of biomass such as agricultural, food and municipal solid waste and can also be effectively blended with petrol or gasoline. Bioethanol has similar properties to that of ethanol and therefore, it can be also used as solvent in various industrial and laboratory applications. It has been found that after significant fermentation and treatment 41-46% of bioethanol can be produced and can resolve the mentioned problem of supply. Thus, this paper primarily focuses on the production of bioethanol by comparing different types of feedstocks and properties of each sample of bioethanol produced from these available feedstocks.

**Keywords**—Bioethanol, Fermentation, Waste to energy, Municipal solid waste.

**I. INTRODUCTION**

The rapid expansion of urban areas and prosperity of industries suppresses the fossil fuel reserves in order to meet the growing energy and fuel demand. These fossil fuels like gasoline, petrol, diesel, etc., help to generate electricity, serve as transport fuel, and other goods. The degree of reliability on these non-renewable sources is leading oil reserves on the edge of exhaustion. The exponential rate of development and progress of urban areas has caused major concerns like pollution, increase in greenhouse gas emissions, increase in global warming, and climate change. Each of these problems can be resolved by generating a green, clean and reliable fuel via non-conventional method and resources. This idea has led to the initiation to produce biofuels like biogas, bioethanol, biogasoline, biodiesel, etc. Among many of these biofuels, production of bioethanol has drawn attention of researchers because of its potential to be blended with gasoline, petrol and diesel with or without any major modifications in the vehicular engines.

In India it has been made mandatory under Ethanol Blended Petrol Program launched by Government of India in January 2003, to blend ethanol upto 5% (E5) with the gasoline used to drive automobiles <sup>[1, 2]</sup>. It has been projected to blend upto 20% of bioethanol and biodiesel with petrol by 2017 in India. All over the globe, India collectively with China, and Thailand produces and contributes 5% of bioethanol production <sup>[3]</sup>. Around the globe most common blend is 10% of ethanol with 90% of petrol known as E10 but it has been found that vehicles having flexible and modified engines can run on the blends upto 85% of ethanol and 15% petrol known as E85 <sup>[4]</sup>. When bioethanol is blended with petrol in less amount results in increase of octane of the fuel and increase in the oxygen content of overall fuel thereby initiates clean burning of the fuel with lesser emissions <sup>[5]</sup>.

Bioethanol is produced from plants that harness the power of sun and thus it is considered to be a renewable fuel. It has great potential as transportation fuel because it is an oxygenated fuel containing 35% of oxygen. This is the reason of low NO<sub>x</sub> and particulate matter emission after combustion of bioethanol. If nearly pure ethanol i.e., 95% ethanol and 5% water is used as fuel it mitigates the problems of air pollution by reducing the emission due to clean combustion characteristics and provides numerous environmental benefits due to low pressure of bioethanol <sup>[2]</sup>. As a clean fuel burning with neat emission, bioethanol is far better than gasoline but has drawbacks like cold start problem and low energy density <sup>[5]</sup>. It can help reduce the rate of formation of carbon monoxide in older car engines and can be introduced to the existing road transport fuel system easily.

In US the major raw material for the production of bioethanol has been corn while in Brazil it has been sugarcane and molasses. Although these crops yielded large amount of ethanol, it gave rise to another controversy relating to the food

vs. fuel debate due to major concerns like land exploitation to grow these crops and increasing food insecurity <sup>[1]</sup>. Therefore, after extensive research in the field of economical and renewable feedstocks for bioethanol production, it has been found that plant residues and agricultural waste like corn stover, rice straw, wheat straw, etc., has the potential to produce bioethanol <sup>[3]</sup>. Lignocellulosic feedstock can increase the cost of the process as it requires appropriate pre-treatment, and high capital cost for production of bioethanol <sup>[3]</sup>. But these feedstocks have various advantages like low cost, abundantly and easily available, and renewable source <sup>[2]</sup>. Lignocellulosic feedstocks include paper, grasses, wood chips, cotton, saw dust, municipal solid waste, herbaceous waste, marine algae, crop residues like corn straw, rice straw, sugarcane bagasse, and wheat straw <sup>[2, 3, 6]</sup>.

The major concern limiting the expansion of this biofuel at larger scale is cost. The economy of production of bioethanol also depends on the market for its by products which is distillers' dried grain solubles which serves as animal food <sup>[2]</sup>. Hence, to make green gold fuel viable and feasible extensive research in the field of pretreatment of various available lignocellulosic feedstock and enzymatic hydrolysis is being carried on. After all replacing gasoline with bioethanol will release only that much amount of carbon dioxide as that absorbed by the biomass that will be replanted <sup>[5]</sup>.

Our work is thus focused on bioethanol as its production is a source for low cost biofuel generation. Bioethanol can also be potentially blended with fossil fuels with or without modifications in vehicular engines <sup>[7]</sup>. It has various advantages like higher octane no, complete combustion, carbon neutral, etc. Bioethanol can be produced using different feed stocks classified as first generation (Starch and sugar based), second generation (Cellulose based) and third generation bioethanol (Microorganisms based). However we have carried out experiment using different second generation bioethanol feed stocks.

The aim of study is to find the prospective to produce bioethanol at laboratory scale through fermentation of locally available municipal solid waste and comparing percent conversion of each feedstock sugar to bioethanol and different properties of the bioethanol produced.

The objective of the study is mentioned as follows:

1. To compare the potential of mixed solid waste and segregated solid waste available locally to produce bioethanol.
2. To find a suitable feedstock to produce bioethanol in prevailing climatic conditions.

The scope of the study is production of bioethanol in the prevailing climatic and geographical conditions.

To produce bioethanol through fermentation of following mentioned feedstock:

1. Municipal solid waste i.e., mixed waste
2. Kitchen waste
3. Canteen Waste

The production of bioethanol will be carried out using a laboratory scale model.

Appropriate pretreatment, microbial strain, and operating parameters will be studied for available feedstock.

## II. LITERATURE SURVEY

Table 1: Literature survey

Sr No	Author	Substrate	Pretreatment	Microbial Strain	Reaction Parameters	% Yield or % Conversion	Ref.
1.	Uduak George AKPAN et al.	Old newspaper and food waste	Acid and microbial hydrolysis	Saccharomyces cerevisiae	pH 5.0, 28±2°C	95	[11]
2.	Anil Singh, Alok Singh	Potatoes peel Banana peels Rice straw Corn cob	Alkali Pretreatment	Saccharomyces cerevisiae	N.A.	46.8 44.3 41.4 46.0	[12]
3.	Ajay Kumar Singh et al.	Banana peels	Comminution	Aspergillus Niger	30°C, pH 6, 7 days fermentation period.	6.540	[13]
4.	Leonidas Matsakas et al.	Household food wastes (45% dry material)	Enzymatic liquefaction & saccharification & hydrothermal pretreatment	Saccharomyces cerevisiae (cellulases and $\beta$ -glucosidase for Enzymatic saccharification)	30°C, 100 RPM agitation, 15 hours	40.81	[14]

5.	C. Moukamnerd et al.	Potato chips	Comminution	Commercial dry yeast	32°C, pH 4.5 - 5.0, 5 rpm Fermentation period 32 hours	80.7 ± 4.7	[15]
6.	Park et al.	Waste newspaper	Defibration	Saccharomyces cerevisiae KNU5377	40°C, Fermentation period 72 h	8.4	[2]
7.	Sujit et al	Mahula (Madhuca latifolia L.) flowers	N.A.	Saccharomyces cerevisiae	Moisture 70%, pH 6.0, 30°C	58.44	[2]
8.	Pallavi Sharma et al.	Banana Peels	Microwave oven irradiation	Aspergillus niger (3% (w/v)) and Saccharomyces cerevisiae (4% (v/v))	30°C, pH 6.0, Fermentation period 7 days	6.289	[16]
9.	Thongdumyu et al.	Food waste	N.A.	Z. mobilis and C. shehatae	35°C, 180 rpm, 72 h, pH 5.0	96	[17]
10.	Ramesh et al.	Lantana camara (red sage)	Acid hydrolysis	Saccharomyces cerevisiae	50°C, pH 5 Fermentation period 16 h,	48	[17]

### 1. Study of effect of temperature on bioethanol production

It is reviewed in the literature <sup>[13]</sup> that maximum bioethanol production from fermentation of banana peels was found at 30°C temperature using microbial strain of Aspergillus Niger. This is followed by 40°C, 20°C and 50°C in which bioethanol production was decrease from 5.691% to 1.957%. At optimum temperature of 30°C, household food wastes can be fermented using Saccharomyces cerevisiae to produce bioethanol in 15 hours of fermentation period <sup>[14]</sup>. It was reported in literature <sup>[13]</sup> that production of bioethanol from corn flour using Saccharomyces Cerevisiae and Aspergillus Niger was maximum at 30°C temperature. In literature <sup>[2]</sup> bioethanol yields of 8.4% has been achieved by fermenting waste newspaper using Saccharomyces cerevisiae at 40°C temperature. In another literature, optimum temperature for maximum bioethanol yield from agricultural waste using Saccharomyces Cerevisiae and Aspergillus Niger microbial strains was reported to be 30°C. Findings in literature <sup>[13]</sup> suggest range between 25 and 30°C to be optimum temperature thermophilic bacteria Saccharomyces Cerevisiae to produce bioethanol from sweet sorghum, and apple pomace.

### 2. Study of effect of pH on bioethanol production

It was studied from the literature that production of bioethanol from cellulosic food waste like banana peels was maximum at pH 6 which was followed by pH 5 and pH value 4. Literature <sup>[17]</sup> suggests that fermentation of Lantana Camara can produce 48% bioethanol using Saccharomyces cerevisiae at pH value 5. Findings in literature <sup>[13]</sup> suggest that pH value of 5.6 is optimum for bioethanol production from molasses using Saccharomyces Cerevisiae and yield of bioethanol was achieved maximum using combined cultures of Saccharomyces Cerevisiae and Aspergillus Niger<sup>[8]</sup> from potato waste at pH value ranging between 5 and 6. Using grape fruit waste as feedstock to produce bioethanol literature suggests optimum pH value to be 5.4 using cultures of Saccharomyces Cerevisiae. Another experiment suggested maximum production yield of bioethanol from lignocellulosic waste like corn cobs using co-culture of Aspergillus Niger and Saccharomyces Cerevisiae at optimum pH value of 5 <sup>[13]</sup>.

### 3. Study of effect of different microbial strain for bioethanol production

It was found in literature <sup>[13]</sup> that to decrease the fermentation time to produce bioethanol from food waste like banana peels it is necessary to increase the concentration of Saccharomyces Cerevisiae microbial culture. Experiment conducted in literature <sup>[13]</sup> also suggest that increase in bioethanol yield can achieved by increasing the concentration of Saccharomyces Cerevisiae from 4% to 12% in the combined cultures of Aspergillus Niger and Saccharomyces Cerevisiae while using starch rich food waste like potatoes. Z. Mobilis and C. Shehatae has been found to be efficient in maximizing bioethanol yield using food waste as feedstock at an optimum pH value 5 <sup>[17]</sup>. Hence, studies suggest that to increase the bioethanol yield and to decrease the fermentation time it is necessary to increase the concentration of suitable yeast strain in the system <sup>[13]</sup>.

### III. PRETREATMENT METHODS

The most important processing challenge in the production of biofuel is pre-treatment of the biomass. Biomass wastes contain a complex mixture of carbohydrate polymers known as cellulose, hemicellulose and lignin<sup>[9]</sup>. Producing sugars from the biomass, requires pretreatment with acids or enzymes, to reduce the size of the feedstock and to open up the cell structure. The cellulose and hemicellulose portions are hydrolyzed to sugar using dilute acids or enzymes which is then fermented into bio-ethanol. The lignin available in biomass is generally used as a fuel for the ethanol production plant boilers. Pre-treatment methods are used to separate and solubilize one or more of these components present in biomass and to make the biomass more compatible for further biological or chemical treatment. The pre-treatment is done to break the matrix for reducing crystallinity of the cellulosic content and increase the fraction of amorphous cellulose, the most suitable form for enzymatic attack<sup>[18]</sup>. Goals of an effective pre-treatment process are

- (i) To form sugar via hydrolysis
- (ii) to avoid loss and/ or degradation of sugars formed
- (iii) to limit formation of repressive products
- (iv) to reduce energy demands
- (v) to minimize costs.

Physical, chemical, physicochemical and biological treatments are the four basic types of pre-treatment techniques employed.

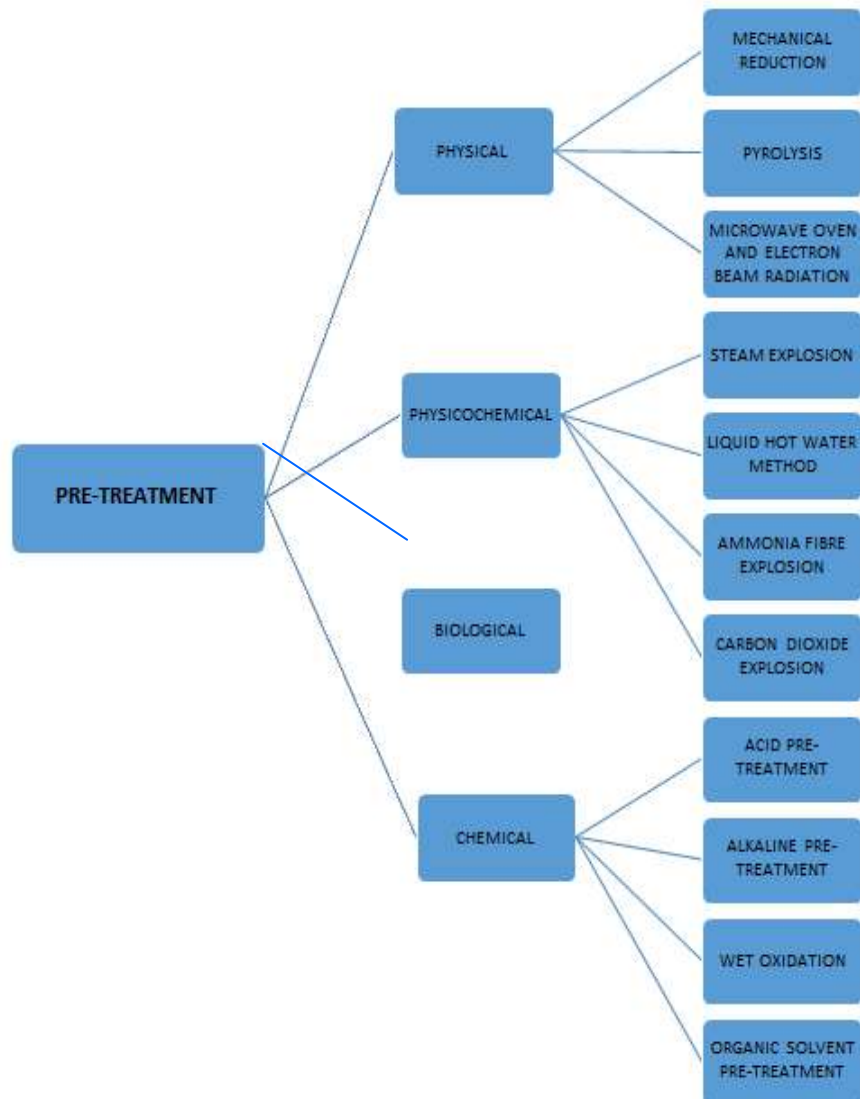


Figure 1: Various pretreatment technologies for bioethanol production.

➤ **Physical pre-treatment:**

1. *Mechanical reduction:*

The first step taken under production of bio-ethanol should be milling, grinding, chipping, etc., to increase the surface area and efficiency of downstream processing. For milling the raw material wet milling, compression milling, dry milling, vibratory ball milling etc., are usually preferred<sup>[10,20]</sup>. The power input for mechanical reduction of agricultural materials depends on different parameters like initial and final particle sizes of raw material, moisture content, the nature of raw material being handled. Size reduction increases efficiency of process but very fine particle size may impose adverse effects on the subsequent processing such as pre-treatment and enzymatic hydrolysis. It may generate lumps during the subsequent steps involving liquid and may lead to channeling. Specific energy consumption may also increase. For the raw material, we are using shredder and grinder is must.

2. *Pyrolysis:*

Pyrolysis is an endothermic process requiring less energy input. In this process the feedstock is treated at temperature more than 300°C, and cellulose is rapidly decomposed to produce gaseous products such as hydrogen and carbon-monoxide and residual char. This decomposition process is very slower and less volatile products are formed at lower temperatures. The residual char is treated with leaching by water or mild acid. The water leachate contains enough carbon sources to support essential microbial growth for bioethanol production and glucose is its main component. An average of 55% of total weight of biomass is lost during water leaching. An experiment has shown 80 to 85% conversion of cellulose (more than 50% glucose) to sugars through mild acid leaching (1 N H<sub>2</sub>SO<sub>4</sub>, 95 °C, 1 h)<sup>[20]</sup>.

3. *Microwave oven and electron beam irradiation pre-treatment:*

Specifically, lignocellulosic biomass can also be pre-treated in a microwave oven, which is also feasible and easy method, using high heating efficiency. Microwave treatment utilizes thermal and non-thermal effects.

In the thermal method, internal heat is generated in the biomass by microwave radiation, which results due to the vibrations of the polar bonds in it and the surrounding aqueous medium. Thus, a hotspot is created within the material. This heating feature results in an explosion effect among the particles and improves the obstruction of refractory structures of lignocellulosic material. Thermal pre-treatment provides an acidic environment for auto-hydrolysis by releasing acetic acid from the lignocelluloses materials.

In the non-thermal method, i.e., the electron beam irradiation method, the polar bonds are aligned with a continuously changing magnetic field and the disruption which makes them vibrates and shock to the polar bonds accelerates the processes. Due to high energy radiation, changes in cellulosic feedstock results in increase of specific surface area, decrease of degree of polymerization and crystallization of cellulose, hydrolysis of hemicelluloses and partial depolymerisation of lignin. Microwave pre-treatment of raw materials by lignin extraction has been reported to give a yield of 45-52% of total available reducing sugars<sup>[11]</sup>.

➤ **Physicochemical pre-treatment**

1. *Steam explosion or auto-hydrolysis:*

Steam explosion makes biomass more accessible to cellulose attack. This method of pre-treatment does not require any catalyst and the biomass dissociates to yield xylitol, levulinic acid, and alcohols. In this method, the biomass is heated at high pressure steam (20-50 bar, 160-290 °C) for a few minutes; then reaction is stopped by sudden decompression to atmospheric pressure. When steam is allowed to expand the lignocelluloses matrix, it separates individual fibers in it. steam-explosion pre-treatment is economically attractive due to high recovery of xylose (around 50%).

2. *Liquid hot water method:*

This method uses hot liquid water compressed at pressure above saturation point to hydrolyze the hemicelluloses. It is a hydrothermal pre-treatment method releasing high fraction of oligomers (form of hemicellulosic sugars). The treatment generally requires temperatures between 170-230 °C and pressures above 5 MPa for 20 min. However, it also contributes to the production of small amounts of undesired degrading compounds like furfural, carboxylic acid, etc., that are very toxic to bio-ethanol fermentation as they inhibit microbial growth. As xylose recovery is relatively high, and no acid or chemical is required, it becomes an environmentally safe and economically feasible method.

3. *Ammonia fibre explosion:*

Ammonia fiber explosion (AFEX) pre-treatment involves both liquid ammonia and steam explosion. It is an alkaline thermal pre-treatment, exposing the lignocellulosic materials at high temperature and pressure, which is then followed by rapid pressure release. This method is attractive as it is simple in operation and requires short process time. It is more effective for the substrates having less lignin content compared to sugarcane. This does not directly liberate any sugars, but allows the polymers (hemicellulose and cellulose) to be attacked with enzyme which breaks it down to sugars. To be economical due to the high cost of ammonia, it requires efficient ammonia recovery generally by evaporation. The major parameters that affect the AFEX process are as follows



1. Ammonia loading
2. Temperature
3. High pressure
4. Amount of moisture present in biomass, and
5. Residence time.

4. *Carbon dioxide explosion:*

Carbon dioxide explosion acts in a manner similar to that of the ammonia and steam explosion techniques. However, Carbon dioxide explosion is less expensive than ammonia explosion. It does not cause the formation of inhibitors and conversion yields achieved are higher compared to steam explosion.

➤ **Chemical pre-treatment:**

Chemical pre-treatment methods involve the usage of different chemicals like dilute acid, alkali, ammonia, organic solvent, Sulphur dioxide, carbon dioxide or other chemicals. These methods are easy in operation and possess good conversion yields in short span of time.

1. *Acid pre-treatment:*

Acid pre-treatment is considered as one of the most important techniques and aims for high yields of sugars from lignocellulosic. It is usually carried out by using concentrated or diluted acids (usually between 0.2% and 2.5% w/w) at temperatures between 130 °C and 210 °C. Sulphuric acid is widely used for acid pre-treatment among various types of acid such as hydrochloric acid, nitric acid and phosphoric acid. Acid pre-treatment improves cellulose hydrolysis by utilizing dilute or concentrated acids. The acid medium attacks the polysaccharides, especially hemicelluloses which are easier to hydrolyze than cellulose. However, acid pre-treatment results in the production of various inhibitors like furfural, 5-hydroxymethylfurfural and acetic acid. These products are growth inhibitors of microorganisms. Hydrolysates should be detoxified as to be used for fermentation.

2. *Alkaline pre-treatment:*

Alkaline pre-treatment of lignocellulosic matter digests the lignin matrix and converts it to cellulose and hemicellulose which is readily available for enzymatic degradation. Alkali treatment of lignocellulosic material breaks the cell wall by dissolving hemicelluloses, lignin, and silica, by hydrolyzing acetic esters and uronic, and by swelling cellulose. Crystallinity of cellulose is affected due to swelling and results to decrease. By this process, the substrates are fractionated into alkali-soluble lignin, hemicelluloses and residue, which make it easy to utilize them for more valuable products. The remaining end residue (mainly cellulose) can be used to produce cellulose derivatives. This process uses hydroxides of sodium, potassium, calcium and ammonium.

3. *Wet oxidation:*

In wet oxidation, the material is treated with water and either by air or oxygen at temperatures more than 120 °C. The water is added to the biomass at a defined ratio. This technique promotes transfer of hemicelluloses from solid phase to the liquid phase. The liberated hemicellulose molecules are not hydrolyzed. The products formed during hemicellulose hydrolysis formed during wet oxidation are oligomers of sugar.

4. *Organic solvent pre-treatment:*

Organic solvent pulping processes are alternative methods for the delignification of lignocellulosic materials. Utilizing the organic solvent/water mixtures cancels or eliminate the need to burn the liquor and allows the lignin isolation by distillation of the organic solvent or water. Different organic solvents which can be used for delignification are methanol, ethanol, acetic acid, acetone, etc. According to a study, combining ammonia and ionic liquid pre-treatments of feedstock (mainly rice straw) results around 97% conversion of cellulose to glucose<sup>[23]</sup>.

➤ **Biological pre-treatment:**

Degradation of the complex lignocellulosic material, liberating cellulose can be achieved with the help of different microorganisms like white rot and soft rot fungi, etc. Biological pre-treatment contributes to the degradation of lignin and hemicellulose and as per a study, white rot fungi seem to be the most effective microorganism for biological pretreatment. Biological pretreatment of waste with white rot fungi should be performed at low temperature (around 25 °C)<sup>[19]</sup>. Bio-delignification generally needs longer time periods. Main objective of biological pre-treatment is to take out sugar from lignocellulosic material using suitable microorganism.

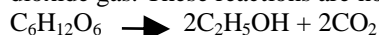
➤ **Enzymatic hydrolysis:**

Saccharification is the most critical and important step for bioethanol production, in which complex carbohydrates are converted to simple monomers. Enzymatic hydrolysis requires clement environment and less energy conditions compared to acid hydrolysis. It requires 40-50°C temperature and pH around 4-5 for cellulose to convert<sup>[21]</sup>. Enzymatic hydrolysis is having various advantages like low corrosion, low toxicity, and low utility cost compared to acid or alkaline

hydrolysis, no inhibitory by-product formation takes place. But, enzymatic hydrolysis is carried out by highly substrate specific cellulase enzymes. Cellulose is hydrolyzed to glucose whereas hemicellulose gives rise to several pentose and hexose. Various factors influencing yields of monomer sugars from lignocellulosic material are temperature, pH and mixing rate, and factors affecting yield are substrate concentration, cellulase enzyme loading, and surfactant addition. High concentration of substrate leads to substrate hindrance. The major cost of the lignocellulosic ethanol technology is contributed by Cellulase. Therefore, selection of an efficient pre-treatment reduces degree of cellulose crystallinity and eliminates maximum content of lignin, thus hydrolysis time and cellulase loading will be reduced. The cellulose is modified using surfactants, by adsorbing lignin onto the surfactant and thus prevents unproductive binding of enzyme with lignin and reduces enzyme loading.

➤ **Fermentation** <sup>[19, 20]</sup>:

The chemistry behind the process of fermentation is simply, to convert glucose sugar to alcohol (ethanol) and carbon dioxide gas. These reactions are not very simple in presence of yeast but can be shown as:



i.e., sugar (glucose) in presence of yeast ferments and produces ethyl alcohol and CO<sub>2</sub> gas.

For fermentation process, the saccharified biomass is used. But in industrial application, utilization of lignocellulosic material for production of bioethanol is restricted by the lack of appropriate microorganisms which can efficiently ferment sugar (pentose as well as hexose). For a commercially viable bio-ethanol production, an ideal microorganism should have characteristics like broad substrate utilization, high ethanol yields and productivity, ability to withstand high concentrations of bio-ethanol and high temperature, tolerant to inhibitors present in Hydrolysates and should possess cellulolytic activity. Modified or engineered microorganisms are therefore, used to achieve complete utilization of the sugars in the Hydrolysates and better production benefits. The processes usually employed in the fermentation of lignocellulosic Hydrolysates are simultaneous saccharified and fermented (SSF) and separately hydrolyzed and fermented (SHF). SSF is superior for ethanol production as it can improve bioethanol yields by removing end product inhibition and eliminates the need for many reactors, also it is cost effective too. The limitations of SSF can be removed by using thermo-tolerant microorganisms, which has been developed to withstand the higher temperatures needed for enzymatic hydrolysis. Apart from SSF or SHF, the alternative methods are Consolidated Bio-Processing (CBP) and simultaneous saccharification and co-fermentation (SSCF). In CBP, there is a single reactor in which cellulase production, biomass hydrolysis and ethanol fermentation is carried out. The process is also known as direct microbial conversion (DMC). To process and ferment cellulose directly to bio-ethanol single culture or mixed culture of microorganisms are mostly used. No capital investment is required to produce or purchase enzyme for application of CBP, which is one of its major advantages, but it requires long fermentation period and gives poor yield. In SSCF the co-fermenting microorganisms need to be compatible with respect to operating pH and temperature. Sequential fermentation using two different microorganisms in different time periods of the fermentation process is for better utilization of sugar can also be employed.

Fermentation by-product formation <sup>[20]</sup>:

Bioethanol is mainly produced by yeast fermentation, but by-products formation also takes place. These by-products should be removed to obtain purified bio-ethanol. Starch and lignin are mainly two kinds of by-product sources. By-products derived from starch include esters, organic acids, and higher alcohols whereas by-products derived from lignin include cyclic and heterocyclic compounds. Distillation process can remove most of these by-products.

## **IV. MATERIALS AND METHOD**

### **4.1 Material and Apparatus:**

Following are the materials and apparatus used for this purpose.

1. Food waste containing corn cob, corn stover, rice water, peels of potato, banana, and beetroot.
2. Distilled water
3. Baker's Yeast
4. Measuring Cylinder
5. Analytical Balance
6. Porcelain bowl
7. Spatula
8. 500 ml reagent bottles
9. Sample Bottle
10. Filter Paper
11. Funnel
12. Distillation Apparatus

### **4.2 Experimental Procedure:**

Following is detailed procedure in which the experimental work was carried out:

1. The waste was segregated (like potato peels, banana peels, corn cobs and stalk, rice water, mixed waste, etc) collected from canteen and kitchen which was divided in 6 mixtures were formed as shown below.
  - i. Mixed waste (slurry)
  - ii. Mixed waste (powdered form)
  - iii. Corn cobs + Rice water
  - iv. Corn cobs + Corn Stover
  - v. Potato peels
  - vi. Banana peels
2. The collected waste is classified as different mixtures or is used alone, it is then sun dried and its size is reduced by crushing, milling or grinding and pre-treatment may be provided if necessary.
3. The crushed waste is then prepared for fermentation, by considering the ratio of solid to liquid as 1:10 i.e., for example 1 g of waste is added to 10 ml of distilled water.
4. Once the waste is prepared for fermentation, Inoculum of baker's yeast is prepared to carry out fermentation.
5. Inoculum of yeast is added to prepared waste in a 500 ml reagent bottle and is kept for fermentation in a dark place for a period of 7 days without disturbing it.
6. Once fermentation is done it is filtered and distilled at 78.04°C i.e., the boiling point of ethanol.
7. The presence of bioethanol is tested by qualitative analysis like addition of sodium and observing effervescences or addition of acetic acid and getting a fruity smell, etc.
8. Various tests were performed to check density, viscosity, boiling point, etc. Also the samples were analysed with Gas Chromatography.

## V. OBSERVATION

Table 2: Observation table for lab scale work

Sr. No	Waste composition	Volume of solution prepared(ml)	Volume of sample obtained(ml)	Density (kg/ m <sup>3</sup> )	Viscosity (cP)
1.	Mixed waste Slurry	100	71	860.12	1.467
2.	Potato peels	100	72	837.48	1.436
3.	Banana peels	100	79.2	864.64	1.474
4.	Corn cobs & Rice water	100	48	854.56	1.460
5.	Corn cobs & Corn Stover	100	64.4	849.12	1.452
6.	Mixed waste (sundried)	100	60	850.48	1.454

The analysis of the sample was done using Gas Chromatography with AOC-20i Autoinjector for quantitative analysis of bioethanol sample. Some components detected through chromatography in the bioethanol sample produced from peels of potato are as follows:

1. Water
2. Bioethanol & rest are traces of alcohol like methanol, etc.
3. Organic acids like Acetic Acid, etc.

## VI. CALCULATION

The calculation formulae of this work are given as follows.

$$\text{Density, } \rho = \frac{\text{Weight of the sample (gm)} \times 1000 \left( \frac{\text{kg}}{\text{m}^3} \right)}{\text{Volume of sample (ml)}}$$

$$\text{Kinematic Viscosity (centistokes), } \gamma = \frac{A - B}{t}, \text{ where } A = 0.26 \text{ and } B = 171$$

$$\text{Absolute Viscosity (centipoise), } \mu = \text{Kinematic Viscosity} \times \text{Density (gm/cm}^3\text{)}$$

$$\text{Conversion of cellulose to ethanol (\%)} = \frac{[\text{EtOH}]}{(f \times \text{biomass} \times 1.111 \times 0.51)} \times 100$$

Where, [EtOH] is ethanol concentration at the end of the fermentation (g/L)



f is cellulose fraction of dry biomass (g/g)

Biomass is dry biomass concentration at the beginning of the fermentation (g/L);

0.51 is conversion factor for glucose to ethanol based on stoichiometric biochemistry of yeast;

1.111 is conversion factor of cellulose to equivalent glucose <sup>[22]</sup>

## VII. RESULT

Table 3: Percent conversion of sugar to bioethanol in different feedstocks

Sr. No.	Feedstock	Volume of sample obtained (ml)	Percent Purity	Percent Conversion
1.	Mixed Waste (slurry)	71	-	-
2.	Corn Cob and Rice Water	48	45	30
3.	Potato peels	72	47	46
4.	Mixed Waste (after drying)	60	-	-
5.	Corn cob and stalk	64.4	40	36.8
6.	Banana Peels	79.2	44	48.4

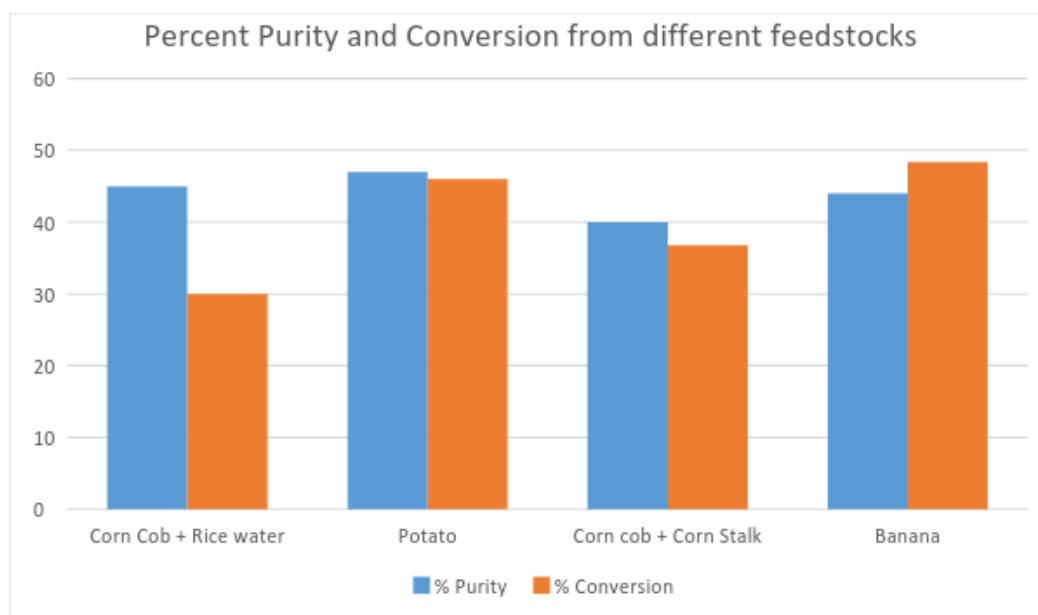


Figure 2: Graph representing percent purity and conversion from different feedstocks.

## VIII. CONCLUSION

Bioethanol is a fuel made with renewable resources and on blending it with petrol it can meet the future needs for fuel. Production of bioethanol from waste like potato peels, corn cobs, etc., can be the solution to food to fuel debate, also the residue can be used for generation of biogas and compost.

After carrying out the experiment we observed that potato peels yield relatively better quality of bioethanol resulting in 47% purity and 46% conversion to ethanol than other mixtures.

Still the bioethanol produced through the experiment needs further purification such as dehydration, etc.

The work suggests that segregated waste yields better percent of sugar to bioethanol conversion than the mixed wastes.

This work also suggests that Bioethanol produced by fermentation of Municipal Solid Waste (MSW) produces low quality of ethanol for utilization as fuel, solvent, etc., and needs further enrichment of quality.

## IX. REFERENCES

1. Pragati Awasthi, Smriti Shrivastava, Amit C Kharkwal and Ajit Varma; Biofuel from agricultural waste: A review, 2015; International Journal of Current Microbiology and Applied Science 4(1): 470-477
2. Zuber Khan, Anjani K. Dwivedi; Fermentation of Biomass for Production of Ethanol: A Review, 2013; Universal Journal of Environmental Research and Technology, Volume 3, Issue 1: 1-13
3. Alya Limayema, Steven C. Ricke; Lignocellulosic biomass for bioethanol production: Current perspectives, potential issues and future prospects, 2012; Progress in Energy and Combustion Science 38: 449-467
4. Mustafa Balat, Havva Balat; Recent trends in global production and utilization of bio-ethanol fuel, 2009; Applied Energy 86:2273–2282
5. James D Mcmillan; Bioethanol Production: Status and Prospects, 1997; Renewable Energy 10: 295-302
6. C.N. Ibeto, C.U. Afoefule, K.E. Agbo; A Global Overview of biomass potentials for Bioethanol Production: A renewable alternative fuel, 2011; Trends in Applied Sciences Research 6(5): 410-425
7. Kevin A Gray<sup>1</sup>, Lishan Zhao, Mark Emptage; Bioethanol, 2006; Current Opinion in Chemical Biology, 10:141–146
8. S.N. Naik, Vaibhav V. Goud, Prasant K. Rout, Ajay K. Dalai; Production of first and second generation biofuels: A comprehensive review, 2010; Renewable and Sustainable Energy Reviews 14: 578–597
9. Seungdo Kim, Bruce E. Dale; Global potential bioethanol production from wasted crops and crop residues, 2004, Biomass and Bioenergy 26:361 – 375
10. Sean Michael Scully, Johann Orlygsson; Recent Advances in Second Generation Ethanol Production by Thermophilic Bacteria, 2015; Energies 8:1-30
11. Uduak George AKPAN, Adamu Ali ALHAKIM, and Udem Joshua Josiah IJAH; Production of Ethanol Fuel from Organic and Food Wastes, 2008; Leonardo Electronic Journal of Practices and Technologies Issue 13:1-11
12. Anil Singh, Alok Singh; A comparative overview of Bio-ethanol production from Organic Residues of Agro waste Materials, 2015; European Journal of Biotechnology and Bioscience, Volume: 3, Issue: 3, 11-14
13. Ajay Kumar Singh, Sanat Rath, Yashab Kumar, Harison Masih, Jyotsna K. Peter, Jane C. Benjamin, Pradeep Kumar Singh, Dipuraj, Pankaj Singh; Bio-Ethanol Production from Banana peel by Simultaneous Saccharification and Fermentation Process using cocultures *Aspergillus niger* and *Saccharomyces cerevisiae*, 2014; International Journal of Current Microbiology and Applied Science 3(5): 84-96
14. Leonidas Matsakas, Dimitris Kekos, Maria Loizidou, Paul Christakopoulos; Utilization of household food waste for the production of ethanol at high dry material content, 2014; Biotechnology for Biofuels, 7:4
15. Churairat Moukamnerd, Hidehisa Kawahara, Yoshio Katakura; Feasibility Study of Ethanol Production from Food Wastes by Consolidated Continuous Solid-State Fermentation, 2013; Journal of Sustainable Bioenergy Systems, 3:143-148
16. Pallavi Sharma, A.A. Mishra; Biofuel Production from Banana Peel by using Micro Wave, 2015; International Journal of Scientific Research & Engineering Technology, Volume 3, Issue 4
17. Piyapong Thongdumyu, Nugul Intrasingkha and Sompong O-Thong; Optimization of ethanol production from food waste hydrolysate by co-culture of *Zymomonas mobilis* and *Candida shehatae* under non-sterile condition, 2014; African Journal of Biotechnology, Vol. 13(7):866-873
18. Aiduan Li et al; Bioconversion of municipal solid waste to glucose for bio-ethanol production, 2007; Bioprocess Biosyst Eng, 30:189–196
19. Nibedita Sarkar et al; Bioethanol production from agricultural wastes: An overview, 2012; Renewable Energy 37:19-27
20. Shinnosuke Onuki et al; Ethanol production, purification, and analysis techniques: A review; Paper no- 085136
21. O'scar J. Sa ´nchez et al; Trends in biotechnological production of fuel ethanol from different feedstocks, 2008; Bioresource Technology 99:5270–5295
22. Jie Lu, XueZhi Li, Jian Zhao, and Yinbo Qu; Enzymatic Saccharification and Ethanol Fermentation of Reed Pretreated with Liquid HotWater; Journal of Biomedicine and Biotechnology Volume 2012, Article ID 276278, 9 pages
23. Shefali Chokshi, Shreya Kundu, Kunal Majmudar; Various Pretreatment Technologies for Bioethanol Production: A Review; International Journal of Science, Engineering and Management (IJSEM) Vol 1, Issue 8, December 2016; ISSN (Online) 2456 -1304; Page: 52-59