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Utilization of Palm Solid Residue For Bioethanol Production In Sumatra Indonesia – A Review

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Abstract

The combustion of fossil fuels causes an increase in the release a group of gases found in the earth atmosphere that trap heat and contribute to the greenhouse effect, which in turn contributes to the occurrence of global warming. The advancement of sustainable energy sources plays an important role in human life due to renewable and environmentally friendly. This problem can be resolved by using alternative fuels as renewable sources of energy that are more environmentally friendly, such as bioethanol. Empty fruit bunches (EFB) constitute a portion of the solid waste that cause problems in storage, transportation, and processing costs. This is because EFB is waste in a solid that is produced from a processing facility where the fruits of the oil palm tree are processed to extract palm oil in large quantities. The process of producing bioethanol by utilizing coconut fruit bunches that are devoid of their contents as a raw material involves two essential stages: hydrolysis and drying. Hydrolysis with an acid catalyst results in a lower yield, but the catalyst itself is inexpensive. Conversely, when using enzyme catalysts, hydrolysis produces a greater quantity of reducing sugars. Enzyme catalysts can be employed in the simultaneous saccharification and fermentation (SSF) process using S. cerevisiae yeast, while chemical catalysts can be used in separate hydrolysis and fermentation (SHF) methods. The SSF method provides a comparatively elevated ethanol yield, demands less enzyme usage, has a shorter duration for ethanol production, and is environmentally friendlier when compared to the SHF procedure.

Keywords: Bioethanol, Palm Solid Residue, Sumatra

1. Introduction

Fossil fuels pose intricate challenges as non-renewable energy sources [1]. At present, approximately 80% of the fossil fuels fulfill the majority of the world's energy consumption needs, including oil, coal, and natural gas [2]. Utilizing fossil fuels leads to a rise in a group of gases found in the earth atmosphere that trap heat and contribute to the greenhouse effect and play a part in the long-term increase in the Earth's average temperature, leading to climate changes and environmental impacts [3]. Gas produced from burning fossils is expected to cause world temperatures to increase by around 5.8°C in 2100 compared to 1990 [4]. Carbon dioxide as the main greenhouse gas producer has increased over the last decade and total Carbon dioxide emissions consumed were reported at 32,578.645 million tonnes in 2011. Therefore, the advancement of eco-friendly energy sources plays an important role in human life due to renewable and environmentally friendly [5]. The solution to this issue can be found in the utilization of alternative fuels like bioethanol, which serves as a renewable energy source that is more eco-friendly [6].

Bioethanol is derived from anaerobic fermentation involving yeast and sugar compounds, and it is categorized into three groups based on the raw material used [7]. The initial group contains starch (such as oil palm, cassava, and coconut), the second group contains glucose (such as molasses and sap), and the third group is derived from cellulose fibers (such as straw and wood) [8]. The advantage of bioethanol compared to fossil fuels is that the combustion process is perfect so that the levels of carbon monoxide are lower with higher oxygen during the combustion process so that it is cleaner and environmentally friendly [9].

Oil palm is a cultivated crop characterized by a tall, straight trunk treerete belonging to the Palmae family. It originated from the western coast of Africa and subsequently expanded its cultivation to Indonesia. Its national production will reach 44.76 million tons in 2020 [10]. Palm oil is extensively employed as a primary ingredient in the production of cooking oil Empty fruit bunches (EFB) constitute a portion of the solid waste that cause problems in storage, transportation, and processing costs. This is because EFB is a solid waste produced from a Oil Palm Mill in large quantities. An Oil Palm Mill with a capacity of 30 tons and an input of 120,000 tons of Fresh Fruit Bunch produces 27,600 tons of EFB every year [12]. Generally, EFB is used as mulch on plantation lands. However, its use as much requires large transportation and distribution costs. In addition, the time required for the decomposition process of EFB which is placed on garden land as mulch is relatively long. This is due to its large size, high C/N (54.4), and high content of cellulose (52.81%), hemicellulose (14.83%), and lignin (13.71%) [13] Lignocellulosic-based biomass consist of three polymers namely cellulose, hemicellulose, and lignin [14]. This polymer is a complex substrate because its content includes polysaccharides, extractive substances, and other organic compounds [15]. Polysaccharides are the most important and abundant component, especially cellulose, which is wrapped in lignin with strong bonds. In terms of the conversion of EFB to ethanol, polysaccharides can be saccharified or hydrolyzed into monosaccharides (glucose, xylose) before further processing into ethanol. The Utilization of oil palm bunches is currently not maximized. So far, bunches have been left behind and left to rot in the plantation area. Palm fronds and bunches with lignocellulosic content have the potential to be converted into G2 bioethanol.

Palm oil waste can be processed in 3 ways including pretreatment, hydrolysis, and fermentation processes. The pretreatment process aims to unlock the lignocellulosic composition of the material used, namely in the form of palm fruit bunches using sodium hydroxide to decompose or to dismantle the lignin that binds cellulose and hemicellulose so that later it will facilitate access to sulfuric acid which will break down polysaccharide polymers into glucose [16]. The second pprocess is hydrolysis, which aims to break down cellulose and hemicellulose into a simple form using acids, namely in the form of glucose [17]. The final process is fermentation, which converts glucose into ethanol using Saccharomyces cerevisiae [18].

This paper examines the accessibility of raw materials derived from solid waste in palm oil production for the purpose of bioethanol production. Additionally, it explores various methods of pre-treatment, fermentation, and purification. The research conducted in this study aims to promote the transformation of agricultural waste into higher-value products in Indonesia.

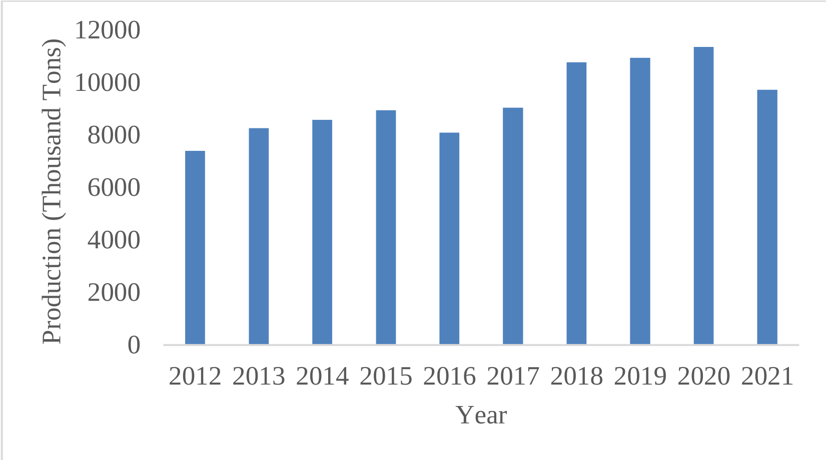

Figure 1. Palm Oil Consumption in Sumatra [10]

2. Selection of Raw Materials: Availability, Quantity of Production, and Continuity

Sumatra is one of the provinces in Indonesia which has the largest oil palm plantation company, reaching 336 companies [10]. The number of oil palm plantation companies is certainly proportional to the quantity of palm oil waste generated. The waste from oil palm plantations amounts to approximately 47 tonnes per year, comprising various components of palm oil waste as outlined in Table 1 [19]. Table 1 shows the composition of the empty palm fruit bunches in palm waste which has a percentage of 23% of the total production or around 10.81 million tonnes and table w shows the nutritional composition of the empty palm fruit bunches. As much as 10% of the empty palm fruit bunches have been used as boiler fuel and compost, while 90% of the empty palm fruit bunches have not been used optimally [10], [20]. Oil palm empty fruit bunches are lignocellulosic biomass that contains 35–50% cellulose, this cellulose is used as a substrate to produce glucose which will be used as feed in the fermentation process to produce bioethanol [21]. The cellulose content is proportional to the amount of glucose produced in the hydrolysis process, therefore empty palm fruit bunches are a potential substrate or raw material for bioethanol [22].

Table 1. Nutritional Label of Palm [21]

Nutrition	Concentration (%)
Empty Fruit Bunch	23
Shell	6,5
Palm Mud	4
Fiber	13
Liquid waste	50

Table 2. Nutritional Composition of The Empty Palm Fruit Bunches [23]

Nutrition	Concentration (%)
Dry Proteins	6,2
Coarse Fiber	47,93
Lipid	4,7
Ash	7,89
Dry Matter	92,1

3. Production Process

This paper presents an initial exploration of an oil-palm-based biorefinery that focuses on biodiesel as the primary product. The biorefinery model involves the utilization of ethanol produced on-site from specific lignocellulosic residues generated during crude palm oil extraction. The analysis employed process simulation and followed the integration principle outlined in previous works. The analysis was based on process simulation applying the integration principle described elsewhere [24]. In the subsequent section, a concise description of the processes involved in conducting this analysis is provided.

3.1 Pre-treatment Process

The first stage namely the initial treatment stage (pre-treatment) which aims to remove lignin, reduce cellulose crystallinity, increasing porosity and turning Oil Palm Empty Fruit Bunches (OPEFB) into pulp. As mentioned earlier in this review, the elimination of lignin during the pre-treatment phase plays a crucial role in the advancement of commercial technology for bioethanol production from lignocellulosic materials. This includes OPEFB, which contains lignocellulosic components. Lignocellulosic components generally consist of cellulose, hemicellulose and Lignin [25]. The transformation of lignocellulosic biomass into bioethanol holds potential as a promising technology; however, it does encounter various challenges and limitations. These include issues related to biomass transportation and handling, as well as the need for efficient pretreatment techniques to achieve complete delignification of lignocellulosic materials. Effective pretreatment techniques have the capacity to enhance the levels of fermentable sugars following enzymatic saccharification, leading to enhanced overall process efficiency [26]. The pre-treatment process of the raw material modifies the biomass structure into a powdered form, facilitating greater contact between the catalyst and the biomass, thereby accelerating the reaction [27] Furthermore, the physical pre-treatment aids in decreasing the polymerization level, bulk density, and porosity. The physical pre-treatment can involve various methods such as fragmentation, grinding, shearing, or milling of the biomass [28]. Using electromagnetic waves for mechanical pretreatment is believed to enhance the pre-treatment process, thereby increasing the cellulose content during the process. Microwaves is one of the electromagnetic waves with a wavelength interval between 0.1 cm up to 100 cm and frequency intervals between 0.3 GHz and 300 GHz [29]. Characteristics Microwave heating is heating that is generated from within due to vibrations the molecules of the material to be heated [30].

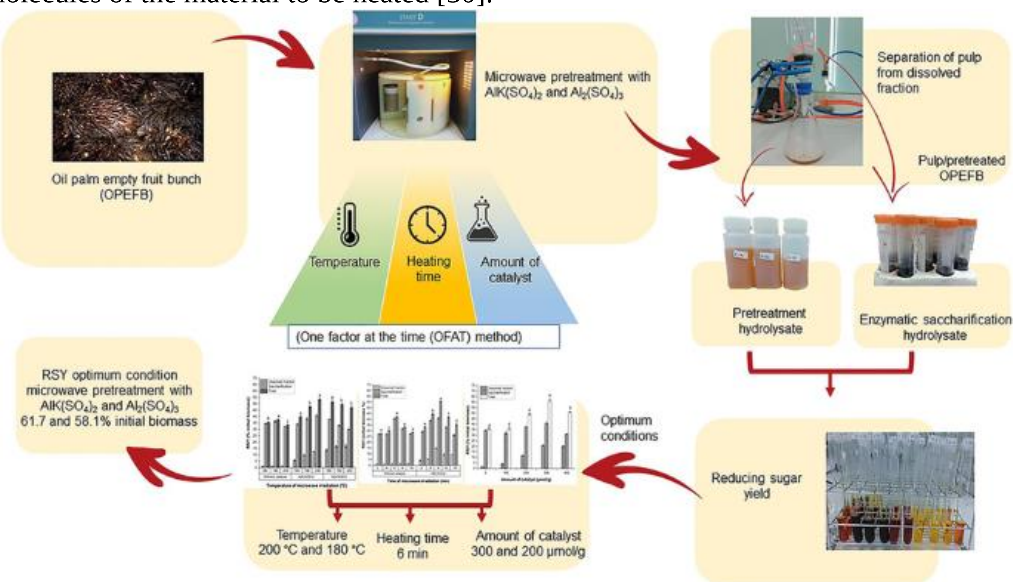

Figure 2. Pre-treatment process of Oil Palm Empty Fruit Bunches

3.2 Hydrolisis Process

Hydrolysis refers to the breakdown of polymer compounds into individual monomer compounds [31]. The enzymatic hydrolysis process expedites the hydrolysis process by utilizing enzymes, which are biocatalysts that enhance the speed of biological reactions. Enzymes function as catalysts, lowering the activation energy required. Various factors, including temperature, pH, and other conditions, can influence the performance of enzymes [32]. Enzymes exhibit reduced activity and are not heat-resistant, leading to diminished performance at higher temperatures. As a result, enzyme hydrolysis is typically conducted at lower temperatures, offering an energy consumption advantage over acid hydrolysis [33].

Tabel 3. Glucose Production from Oil Palm Empty Bunches by Hydrolysis using Enzyme Catalyst

Substrate	Method	Yield	Reference
Oil Palm Empty Bunches	Hidrolisis enzim Selulase	187 mg/L	[34]
Oil Palm Empty Bunches	Hidrolisis enzim Lignoselulosa	1,38 g/L	[35]
Oil Palm Empty Bunches	Hidrolisis enzim Selulase	1,2272 %	[36]
Oil Palm Empty Bunches	Hidrolisis enzim Maleat	11,9 %	[23]

3.3 Fermentation process

Fermentation is a microbial process wherein carbohydrates are converted into ethanol and carbon dioxide by fungi or anaerobic microorganisms in the absence of oxygen [37]. After the hydrolysis stage, the cellulose that has been converted into glucose will be fermented using S.Cerevisiae to convert glucose into ethanol [38]. Enzymatic hydrolysis can be conducted through two different approaches: Separated Hydrolysis and Fermentation (SHF), where hydrolysis and fermentation are performed separately, or Simultaneous Saccharification and Fermentation (SSF), where both processes occur simultaneously [39].

Table 4. Production of Bioethanol by Various Methods and Types of Microbes

Microbe	Method	Substrate	Productivity	Reference
S. Cerevisiae	SHF	Palm oil	0,4 %	[40]
S. Cerevisiae	SHF	Palm Oil Mill Waste	2,65%	[41]
S. Cerevisiae	SSF	Palm Leaves	7,5%	[42]
S. Cerevisiae	SSF	Oil Palm Empty Bunches	4,69%	[43]
Aspergillus Niger	SSF	Oil Palm Empty Bunches	1,448 g/L	[44]

3.3.1 Separated Hydrolysis and Fermentation (SHF)

The cellulose hydrolysis process and the fermentation process take place separately, so that each process requires a different reactor. This process incurs considerable costs because the hydrolysis process is a separate stage that requires time, energy, investment in the reactor, as well as the fermentation process [21].

3.3.2 Simultaneous Saccharificiation and Fermentation (SSF)

The SSF method is a saccharification and fermentation process that is carried out simultaneously in one bioreactor [45] Other advantages of using the SSF method are that fewer enzymes are used and the time for ethanol formation is faster, microorganisms grow easily on solid substrates with a low water content (50-60%) besides that the SSF method is also environmentally friendly [46].

4. Conclusions

Bioethanol presents itself as an independent alternative energy source that can be developed with diverse technologies in different countries. This review examines the feasibility of producing bioethanol using empty fruit bunches as the primary raw material. The potential for utilizing these raw materials is significant, considering the substantial amount of unused empty fruit bunch waste available. The bioethanol production process involves two crucial stages: hydrolysis and fermentation. Hydrolysis utilizing an acid catalyst yields lower output, but the catalyst cost is economical. Conversely, hydrolysis employing an enzyme catalyst yields a favorable amount of reducing sugars. However, the expenses associated with enzyme raw materials are relatively high, and managing enzyme storage can be challenging. Enzyme catalysts can be used for simultaneous saccharification and fermentation (SSF) to produce bioethanol, alongside S. cerevisiae yeast. Alternatively, chemical catalysts can be utilized in separate hydrolysis and purification (SHF) methods. The SSF approach results in higher ethanol yields, reduces the dependency on enzymes, accelerates ethanol production time, and exhibits greater environmental friendliness compared to the SHF process. This research aims to advance technology and promote the utilization of local substrate materials for bioethanol production in Indonesia.

Acknowledgements

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