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BENOSIN: Bread Waste Bioethanol Conversion Unit as an Innovation in Bioethanol Production Using Apple Peels to Achieve a Sustainable Green Economy

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Abstract

Currently, fuel oil is a primary natural resource in the transport sector. However, the availability of fossil fuels is shrinking while the demand for fuel is rising. Expired bread is not worthy of consumption and is often discarded without being used as something more economical and environmentally friendly. Therefore, the study aims to convert bread waste into bioethanol (C_2H_5OH) as a gasoline mixture that can reduce emissions of pollutants such as carbon monoxide (CO) and potentially improve air quality. These bioethanol products will create energy security, reducing dependence on a single energy source. Bread waste serves as a substrate with an apple peel catalyst. This method of making bioethanol is through fermentation assisted by Saccharomyces cerevisiae with the addition of urea fertilizer as a nutrient. The multistage distillation column is equipped with hydrophobic material to help the separation process. The results of this study show that bioethanol from expired bread waste is worthy of being used as a gasoline mixture for motor vehicle fuel. The ethanol produced is directly proportional to the amount of bread waste, but there is still a maximum limit. The time variations used are 24 hours, 48 hours, and 72 hours. Based on this study, the optimal condition of Saccharomyces cerevisiae works at a temperature range of 30-35°C with a pH of 4-6.

Keywords: *bioethanol; distillation; fermentation; apple peel; bread waste*

1. Introduction

Nowadays, human activities never escape using equipment and goods, which are later thrown away as waste. The significant birth rate influences the need to consume waste, which risks polluting the environment. So, a solution to this challenge is essential. Waste is materials or materials used by human activities that are no longer used and tend to be thrown away (Susmiati, 2018). Waste is divided into two types, namely B3 waste (Hazardous and Toxic Materials) and non-B3 waste. B3 waste negatively impacts the environment and the health of living creatures, such as chemicals, medical equipment, and materials that contain radioactivity, so they must be processed before being disposed of (Susmiati, 2018). Non-B3 waste is in the form of household/domestic waste, organic waste, and others, which are not dangerous and can still be recycled to make them useful. Household or domestic waste can be processed using sorting and 3R: Reduce, Reuse, and Recycle. One of the problems with household waste and industrial waste that needs to be processed is expired bread waste. This bread comes from leftover production from sales that is not yet moldy or has not rotted. Efforts to manage this waste through a fermentation process involving Saccharomyces cerevisiae.

Bioethanol is an environmentally friendly alternative fuel that can reduce dependence on fossil fuels and reduce greenhouse gas emissions. Bioethanol (C_2H_5OH) is a type of renewable fuel produced through the fermentation of biomass containing carbohydrates, such as food crops (corn, sugar cane, and potatoes) and organic waste (bread waste and food waste) (Distillation; Herawati et al., 2021). Bioethanol is an alternative fuel that can be mixed with gasoline to reduce carbon dioxide emissions and other pollutants (Janković et al., 2024). Its existence not only helps reduce dependence on fossil fuels but also reduces greenhouse gas emissions. In addition, bioethanol production can support the local economy by creating new jobs in the agricultural and energy sectors. The production process is through fermentation, which involves the conversion of sugar into alcohol by microorganisms such as yeast. Fermentation is a

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chemical process that changes complex compounds into simpler compounds using the help of certain enzymes in anaerobic and aerobic conditions (Kemala et al., 2021). The fermentation results in organic compounds, water, alcohol, and other gases.

Apple peel can catalyze bioethanol from bread waste because it contains natural enzymes that can speed up fermentation. The enzyme that plays a vital role in apple skin is amylase, which breaks down starch and complex carbohydrates into simple sugars, more easily fermented by microorganisms such as yeast (Singh et al., 2022). This process increases the efficiency of bioethanol production by accelerating the conversion of carbohydrates into alcohol (Singh et al., 2022). In addition, apple peels also contain pectinase, which helps break down fiber and other components in raw materials, thereby increasing the amount of sugar available for fermentation (Singh et al., 2022). Apple skin is also available in large quantities as a by-product of the chips and other processed apple processing industries. Apart from containing pectinase, which can catalyze biodiesel production, apple peel is also available in large quantities as industrial residue.

Urea fertilizer is important in bioethanol fermentation using Saccharomyces cerevisiae because it is an essential nitrogen source for yeast growth and metabolic activity (Bahri et al., 2019). Nitrogen is a key component in synthesizing proteins, enzymes, and nucleic acids for the proliferation and efficiency of yeast fermentation. By providing nitrogen in the form of urea, the fermentation process can run more optimally because the yeast has enough nutrients to reproduce and maintain its metabolic activity.

2. Materials and Method

2.1. Bread Waste Preparation and Nutrient Mixing

Bread waste obtained from bakery factories will first be cut or chopped into smaller sizes to increase the surface area so that the hydrolysis and fermentation processes are more efficient (Pietrzak & Kawa-Rygielska, 2015). Apple peel and urea fertilizer are added as a source of nutrients to support the growth of microorganisms during fermentation. Apple skin contains fiber and sugar, which can help convert glucose, while urea fertilizer provides the nitrogen needed for enzymatic activity in fermentation.

2.2 Sterilization

After mixing, the raw materials (bread waste, apple peel, and urea fertilizer) are sterilized to remove pathogenic microorganisms or contaminants that could interfere with fermentation (Cho et al., 2019). This sterilization helps increase fermentation efficiency by ensuring optimal conditions for using microbes such as yeast.

2.3 Hydrolysis and Fermentation

At this stage, extraction of the amylase enzyme obtained from apple peel will help convert glucose in hydrolysis. Then, the simple sugar obtained from the hydrolysis process will be fermented using yeast (Saccharomyces cerevisiae). The amylase enzyme (either from yeast or added externally) will break down the starch from the bread into simple sugars (glucose), which will be fermented into ethanol. Meanwhile, urea helps speed up yeast metabolism by providing nitrogen nutrients.

Fermentation co-occurs with hydrolysis, where the starch present in bread waste is converted into sugar. The hydrolysis process in bread waste aims to convert complex starch into simple sugars so that yeast can utilize them during fermentation. This hydrolysis is done with the help of the amylase enzyme, which comes from apple skin. Amylase is an enzyme that breaks down long chains of starch molecules into simple sugar molecules such as glucose. This process begins when amylase from apple peel is activated and begins to act on the starch substrate in bread, breaking the glycosidic bonds

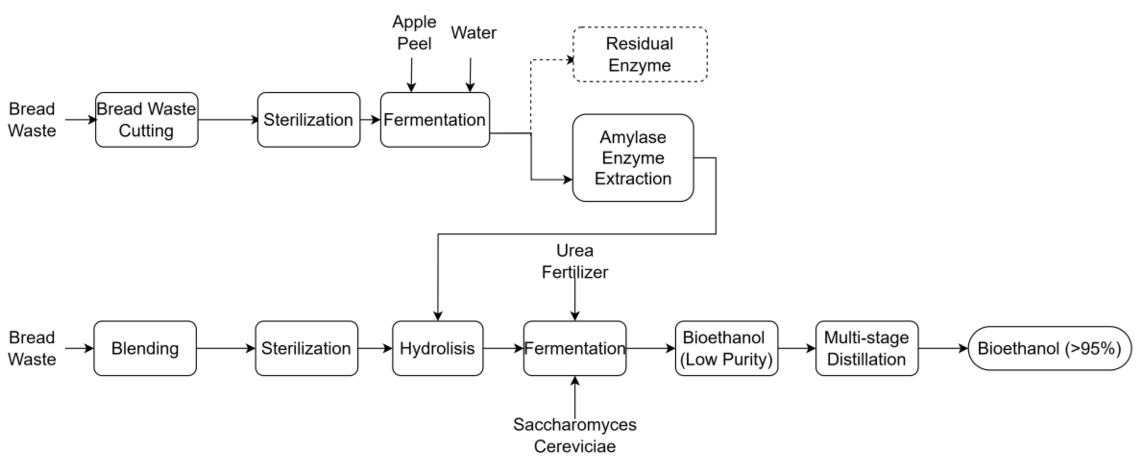

Figure 1. Flowchart of Bioethanol Production Process

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between starch molecules.

2.4. Low-Purity Bioethanol Production

After fermentation is complete, the result is bioethanol with low purity. This bioethanol still contains water and several other compounds that must be separated. The best results from the independent variables listed, such as the length of fermentation time, will then be purified using a distillation column with a polyvinylidene fluoride (PVDF) membrane.

2.5. Multistage Distillation with PVDF Membrane

Bioethanol produced from the fermentation process will go through a multistage distillation process. In this stage, a PVDF membrane separates ethanol from a mixture of water and other components. PVDF membranes have superhydrophobic characteristics, which allow ethanol to pass through the membrane while preventing water from passing through. This distillation process increases the purity of bioethanol.

2.6. Final Result

After going through this distillation process, ethanol with high purity is produced (99.5%). This ethanol can be used as biofuel or in other industrial applications.

3. Results and Discussion

3.1 Purified Bioethanol Fermentation Results Using PVDF Membrane Distillation Column

The bioethanol fermentation process from bread waste with the help of Saccharomyces cerevisiae at a yeast concentration of 4.29% was carried out for 72 hours (Maryana et al., 2020). The ethanol content produced from the fermentation and distillation process depends on the quantity of raw bread waste materials used. The more bread waste material used, the higher the ethanol content produced (Singh et al., 2022). In this fermentation, Saccharomyces cerevisiae plays a role in converting simple sugars produced from bread waste into bioethanol through an alcoholic fermentation process. It works effectively in the pH range of 4-6 (Pietrzak & Kawa-Rygielska, 2015). During this process, urea fertilizer is added as a nutrient source to support microorganisms' growth and metabolic activity, especially providing the nitrogen needed to synthesize proteins and important enzymes. Adding urea increases fermentation efficiency by providing nutrients that can accelerate yeast cell growth so fermentation can run more optimally (Bahri et al., 2019). At the end of the fermentation process, the purity of the bioethanol produced reaches 60%.

The PVDF-Bentonite membrane used in the Vacuum Membrane Distillation (VMD) process for separating bioethanol and water has a design, structure, and arrangement designed to maximize separation through the membrane distillation process. **Figure 2** and 3 are illustrations of the PVDF membrane used in the Vacuum Membrane Distillation (VMD) process. This membrane consists of polyvinylidene fluoride (PVDF), which is known for its hydrophobic properties (Bose et al., 2024). PVDF provides excellent thermal and chemical stability and is resistant to organic solvents such as bioethanol. The addition of bentonite, a type of clay mineral, is used as a filler to increase the mechanical properties and improve the hydrophobic properties of the membrane (Muhamad et al., 2024). Bentonite also helps increase the membrane's selectivity towards bioethanol vapor compared to water (Muhamad et al., 2024). The membrane is designed to support the selective transport of bioethanol vapor to retain water in the liquid phase from penetrating the membrane. This is important in the membrane distillation process, where the vapor pressure difference between water and bioethanol is exploited. PVDF-Bentonite Membrane Structure includes, the active layer or membrane surface is composed of PVDF modified with bentonite. Bentonite is uniformly distributed throughout this layer to create microporous channels that allow bioethanol vapor to permeate the membrane. Support Layer, the more porous bottom layer supports the overall structure of the membrane. This layer maintains the membrane's integrity during the VMD process and ensures the pores do not collapse. Pore Size, the pores in the PVDF-Bentonite membrane are less than 0.5 µm, ensuring that only bioethanol vapor can pass through the membrane

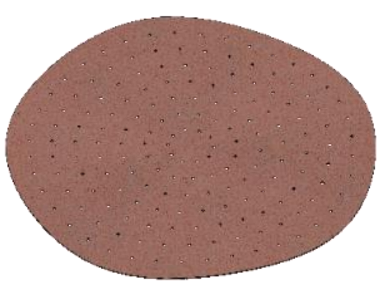

Figure 2. Top View of PVDF-Bentonite Membrane

Figure 3. Top View of PVDF-Bentonite Membrane

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while water remains in liquid form. Hydrophobicity, the PVDF-bentonite membrane structure enhances hydrophobicity, meaning the membrane repels liquid water penetration but allows more volatile bioethanol vapor to pass through.

3.2. Innovation of PVDF Membrane Distillation Column Configuration

Based on research (Cunha et al., 2020) and industry practices, Stainless Steel Austenitic (Type 316L) is the material of choice for distillation column construction. **Figure 4** is a configuration of a distillation tower with a PVDF membrane. This material can withstand corrosive conditions, high temperatures, and pressures that may occur during distillation. Additionally, the material must be compatible with the PVDF membrane, which is supported by its excellent corrosion resistance, especially to various organic acids commonly found in bioethanol, as well as its good mechanical properties and ease of forming. For small-scale applications, membranes are often arranged in multiple layers parallel to each other. A spacer separates each membrane layer to ensure an even flow of the bioethanol-water feed across the entire membrane surface. Flat sheet modules have a smooth and uniform surface, allowing for a more controlled and even flow of the bioethanol-water feed across the entire membrane area. This results in a consistent pressure distribution, essential to ensure selective evaporation of bioethanol. The uniform feed flow also helps prevent the buildup of unwanted substances on the membrane surface, such as fouling, which can reduce separation efficiency.

The surface area of the PVDF-bentonite membrane ranges from 0.5 to 2 square meters per module. Each bundle of hollow fiber modules can contain thousands of fibers with a comparable total

Figure 4. Configuration of A PVDF Membrane Distillation Tower Resulting from The Restructuring of A Conventional Distillation Tower

surface area. The PVDF-Bentonite membrane has a thickness between 100 and 300 micrometers, with pores smaller than 0.5 µm to ensure that only bioethanol vapor can pass through. The feed capacity that can be processed can vary from 50 to 200 liters per hour per module, depending on the membrane size and operating conditions (pressure and temperature).

In multistage distillation, trays are used to separate components of a mixture based on differences in volatility (vapor pressure) (Sun et al., 2024). The number of trays in a multistage distillation system affects the purity of the final product, including bioethanol. In the combination of VMD and multistage distillation, the PVDF-Bentonite membrane roughly separates bioethanol from water, resulting in bioethanol with moderate purity. After passing through VMD, the

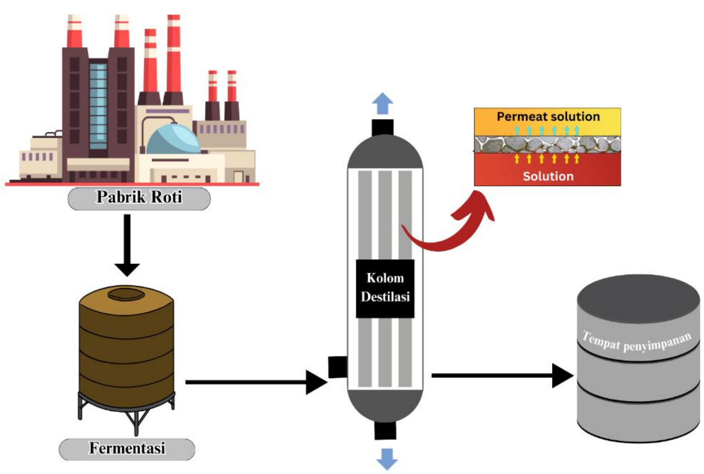

Figure 5. Schematic of Bioethanol Production from Bread Waste

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result can be continued to a multistage distillation system for further purification. The more trays used in multistage distillation, the higher the purity of bioethanol that can be obtained. Therefore, if VMD only produces bioethanol with a purity of around 70-85%, the trays in multistage distillation must be increased to achieve a purity of more than 95% (according to bioethanol industry standards). The number of trays in multistage distillation can be reduced using VMD as the initial separation stage. This is because the VMD process has significantly reduced the water content in the bioethanol mixture, so the subsequent distillation process requires fewer trays to achieve high purity.

For example, it takes 30 trays without VMD to achieve 95% bioethanol; with VMD, it might be enough to use only 10-15 trays. Combining VMD and multistage distillation reduces overall energy consumption because VMD works at a vacuum and lower temperatures, whereas multistage distillation usually requires high heat. Thus, using VMD can reduce heat requirements in the final distillation stage.

Further research and optimization and techniques such as membrane distillation are needed to improve the desalination process's effectiveness, cost, and sustainability (Bose et al., 2024). Using membrane distillation makes it possible to produce a purer permeate than conventional distillation methods, which, in this case, is effective in purifying bioethanol. According to (Sun et al., 2024), membrane distillation research can increase bioethanol's purity, which is purer than purification using conventional methods, which produces 90-95% purity of bioethanol. The purity of the permeate from membrane distillation is greatly influenced by the feed temperature rather than the feed flow rate (Yan et al., 2024). This emphasizes that controlling and optimizing the feed temperature is essential to achieve the desired results of the membrane distillation process, such as increasing flux (the rate of vapor transport through the membrane) and rejection (the ability of the membrane to reject some passages).

3.3 Application of PVDF Membrane Distillation for Bread Waste

Figure 5 shows a schematic of the bioethanol process from bread waste. The initial process starts with identifying and separating bread waste. Each type of bread waste is marked and separated based on type (white bread, filled bread, etc.). This needs to be done because the carbohydrate content of different types of bread affects fermentation efficiency. After collection, the bread waste will be temporarily stored in a refrigerated room. This aims to slow down spoilage and maintain the quality of bread waste. Next, the bread waste is transported to the processing site using closed vehicles with maintained hygiene.

PVDF-Bentonite Membrane Distillation can be applied on a larger scale as a purification process in making bioethanol. In this research, PVDF membrane distillation is used for the purification of fermented bioethanol products, so it is hoped that the final purity of bioethanol can reach above 99% so that it passes for consumption as a substitute for transportation fuel with a minimum purity threshold of 99.5%. Bioethanol for the transportation sector must have a purity above 99.5% for use in E85 and E100 (Bahri et al., 2019). Bioethanol that does not use a membrane has lower purity than bioethanol that uses a membrane in distillation.

Distilled bioethanol is used in specially designed-vehicles fueled by a mixture of bioethanol and gasoline. In addition, bioethanol can help reduce greenhouse gas emissions because bioethanol generally produces less CO2 carbon dioxide emissions. Bioethanol also reduces dependence on fossil fuels and helps waste management, especially in bread production factories.

4. Conclusion

Bioethanol from bread waste using the hydrophobic membrane distillation method produces a higher purity of 99% than conventional distillation, which produces 90-95% bioethanol content. The application of hydronic membrane distillation with PVDF membranes effectively and efficiently increases product purity to above 95% so that the final bioethanol product is suitable for distribution as a fossil fuel substitute for the transportation sector, where this has a positive impact in terms of reducing CO gas emissions, considering the residue burning bioethanol which contains fewer emissions than fuel with 100% gasoline.

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