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The Design of Bioethanol Production Equipment as Renewable Energy from Coconut Water Waste through Fermentation and Distillation

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Abstract: The limitations of fossil fuels and their environmental impact in the form of greenhouse gas emissions have encouraged the development of renewable energy sources. Bioethanol is a promising alternative because of its renewable nature, high octane value, and potential to reduce carbon emissions. Indonesia, as the world's largest coconut producer, generates abundant coconut water waste, which still contains fermentable sugar but is often discarded. This study aims to design and evaluate a laboratory-scale bioethanol production prototype that integrates a fermenter and distillation unit with waste coconut water as raw material. Fermentation was carried out using Saccharomyces cerevisiae with variations in yeast mass (50, 75, and 100 g/L) and fermentation time (3, 5, and 7 days). The ethanol concentration of the fermentation product ranged from 7 to 10%, while the distillation process increased the concentration to 24% under optimal conditions (100 g/L yeast, 7 days). The prototype, consisting of a stainless-steel fermenter, electric heating distiller, and Liebig condenser, demonstrated effective and integrated performance. The results of this study confirm the potential of coconut water waste as a bioethanol substrate and demonstrate the feasibility of a simple prototype for the development of a small-scale renewable energy system based on agro-industrial waste. However, further purification stages, such as fractional distillation or molecular dehydration, are still needed to meet bioethanol fuel standards.

Keywords: bioethanol, coconut water waste, fermentation, distillation, renewable energy.

1. Introduction

The increasing consumption of fuel due to economic and population growth has caused a global energy crisis, particularly an oil crisis. The world's energy needs are still heavily dependent on non-renewable fossil fuels [1]. Therefore, innovative development is needed in the form of energy conversion technology that is capable of replacing fossil fuels with renewable alternative energy sources. Energy from biomass such as bioethanol and biodiesel is a potential alternative to fossil fuels that can be a solution to reduce dependence on fossil fuels and reduce greenhouse gas emissions [2]. Bioethanol is ethanol obtained from the fermentation of organic materials, such as agricultural waste, agro-industrial residues, and another biomass. One promising raw material for bioethanol is coconut water, which is a waste product from the coconut processing industry. Coconut water that is not utilized and is disposed of carelessly, especially into waterways, can cause environmental pollution. This is because discarded coconut water can cause unpleasant odors, discoloration of the water, and can even damage aquatic ecosystems [3].

Indonesia has great potential to develop bioethanol due to its abundance of agroindustrial waste. One particularly promising waste product is coconut water, which is produced from the processing of coconuts for products such as coconut oil or grated coconut. As the world's second largest coconut producer, Indonesia produced 2.8 million tons of coconuts in 2022 [4]. South Sumatra has a significant problem with coconut water waste. Coconut production in this region reaches 61,279 tons [5].

Coconut water is often discarded into the environment, creating problems such as water pollution and unpleasant odors. In addition, green coconut water has economic value for coconut farmers or small businesses that process coconuts [6]. To overcome this problem, this study aims to design a tool for producing bioethanol from coconut water waste into liquid fuel in the form of bioethanol.

Various studies have been conducted to obtain bioethanol from coconut water waste through fermentation and distillation, which produces high bioethanol content with high efficiency using fermentation and distillation technology [7] [8]. Recent studies show that fermenting coconut water with Saccharomyces cerevisiae yeast can produce bioethanol with a concentration of up to 76–80% after distillation [9].

During fermentation, microorganisms such as Saccharomyces cerevisiae convert the sugar in coconut water into ethanol [10]. This process occurs optimally at a temperature of 30–34°C and pH 4–5,5 [11]. Further distillation was used to separate and purify the ethanol based on its boiling point (78.37°C).

However, the conversion technology currently in use is still not optimal in terms of production efficiency and operational costs. Therefore, it is necessary to design further tools to develop bioethanol production equipment that is more efficient in converting coconut water into liquid fuel.

The objective of this study is to create a simple bioethanol production tool as an innovative solution for processing coconut water waste into liquid fuel. This tool consists of several components, namely fermentation, distillation, condensation, and mixing tanks. This tool is capable of producing fuel that is economical and environmentally friendly. The fermentation tank used is 5.5 liters, while the distillation tool is equipped with a 5-liter condenser. In South Sumatra, this device has the potential to reduce coconut water waste by up to 12.25 million liters per year, while also supporting environmental pollution control efforts. This device is also in line with Indonesia's national target of achieving 23% renewable energy use by 2025. With its simple design, this bioethanol production device contributes to environmental sustainability.

2. Methods

2.1. Materials and Equipments

2.1.1. Materials

Coconut water waste is obtained from the coconut processing industry in the Palembang area. The coconut water used comes from mature coconuts with a relatively low sugar content, but still sufficient for the fermentation process. Additional ingredients include:

a. Saccharomyces cerevisiae yeast as a fermentation microorganism. A total of 675 g.
b. 1 L of molasses as an additional nutrient to increase fermentation activity.
c. Distilled water for sterilization and dilution

2.1.2. Equipments

a. Fermentor: 5 L capacity fermentation vessel, equipped with a funnel (raw material input), fermentor tube, level indicator, and residue valve.
b. Distiller: a simple distillation column with an electric heating system, condenser, and cooler.
c. Analytical Instruments: pH meter, pycnometer, alcohol meter, viscometer.

2.2. Research steps

2.2.1. Raw Material Preparation

Coconut water is filtered to remove solid impurities, then the pH is adjusted (4.5–5.0) using NaOH. Sterilization is carried out by heating to 80 °C for 15 minutes to reduce wild microbial contamination.

1. Fermentation
a. Coconut water is placed in a fermenter.
b. *S. cerevisiae* yeast is added in varying amounts (50 g, 75 g, 100 g/L).
c. Fermentation takes place at a temperature of 30–32 °C for varying lengths of time (3, 5, and 7 days).
d. The fermentation results in a crude ethanol liquid with an alcohol content of ±5–10%.

2. Distilation
a. The fermentation liquid is fed into the distiller.
b. Heating is carried out at a temperature of 78–80 °C to separate the ethanol from the water with a setting box of 95 °C.
c. The distillate is fed through a condenser (condensing the vapor into liquid) and collected in a receiving flask and cooled.

3. Product Analysis
a. The ethanol content was analyzed using an alcohol meter.
b. Physical properties (density, viscosity) were measured for comparison with bioethanol standards.
c. The results were compared with Indonesian bioethanol quality standards (SNI 7390:2012) [12]

2.3. Design Equipment

2.3.1 Fermentor Design

a. Stainless steel cylinder tube, equipped with a raw material inlet hole, fermentation outlet, and level indicator.
b. Tight cover with silicone rubber to prevent the entry of contaminants.

2.3.2 Distiller Design

a. Heating tube equipped with 1000–1500 W electrical element.
b. Simple distillation column (glass/SS column) with thermometer to control temperature.
c. Liebig-type condenser with water cooling.

2.3.3 System Integration

a. The fermenter and distiller are connected as a single working unit.
b. The fermentation product can be transferred directly to the distiller without contamination.
c. The design is based on the principles of ease of operation, low cost, and suitability for laboratory to semi-pilot scale.

2.4. Research Variables

a. Independent variables: Yeast mass, fermentation time.
b. Dependent variables : Ethanol content produced.
c. Control variables : Media pH, fermentation temperature, yeast type.

3. Result and Discussions

3.1. Designing Bioethanol Production Equipment

The designed equipment consists of two main systems with three units, namely a fermentation unit, a distillation unit, and a condensation unit, which are then integrated into a single process chain. The designed device series can be seen in Figure 1 below.

In Figure 1, numbers 1, 2, and 3 are visible. Number 1 is a unit of fermentation equipment, namely a container where the fermentation process takes place. The tool is designed and built with anaerobic process conditions and at room temperature. Number 2 is a unit of distillation equipment, namely as a separator that uses the principle of boiling point differences. In the process of making bioethanol, a distillation tank is used to separate water from ethanol produced in the fermentation process, so that ethanol with a higher content is produced. While number 3 explains a condenser unit, namely to condense the steam produced from the distillation process. The panel box is used to show the temperature that occurs in the distillation process. A functional and structural understanding of Figure 1 can be seen in Table 1 and Table 2.

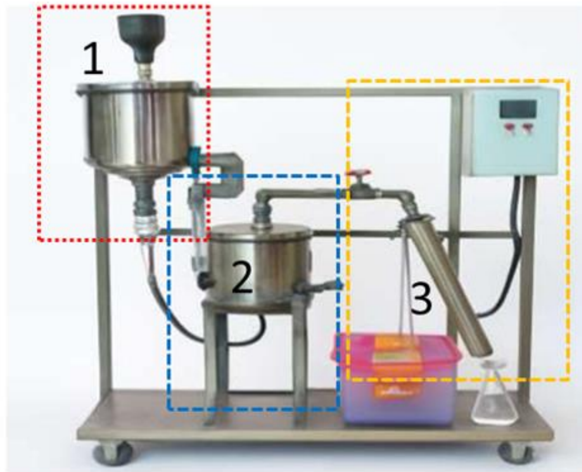


Figure 1. *Bioethanol Production Equipment.*

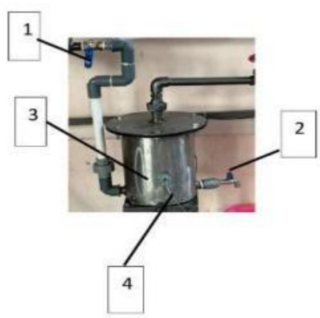
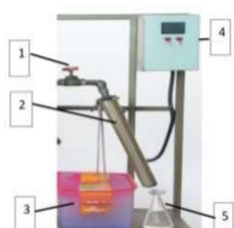
3.2. Procedures for Operating Equipment

1. Clean and sterilize the fermentor and other equipment using hot water or disinfectant to prevent contamination.
2. Pour coconut water that has been mixed evenly with Saccharomyces cerevisiae yeast into the fermentor, according to the planned yeast concentration.
3. Seal the fermenter tightly and install an airlock filled with sterile water to maintain an anaerobic environment and release CO_2 gas.
4. Store the fermenter at room temperature (±30°C) for 3–7 days. Fermentation is complete when the bubbles in the airlock stop and an alcohol smell is detected.
5. Filter the fermentation product to separate the pulp, then carefully open the valve to enter the heating tank (reactor).
6. Close the heating tank valve tightly so that steam does not leak during heating.
7. Check the pipe connections, condenser, and valve to ensure that everything is tight and not leaking.
8. Turn on the heater via the control panel, then set the temperature to 78–80°C (the boiling point of ethanol).
9. When the vapor condenses into liquid, slowly open the output valve to drain the bioethanol into the collection container. Note: Only open the valve when condensation has stabilized, and do so slowly to avoid excess pressure.
10. Monitor the temperature and flow of the distillate during the distillation process to ensure that the equipment is working properly and safely.
11. After distillation is complete, close the valve again, turn off the heater, and allow the equipment to cool.
12. Empty the tank of any remaining material, open all valves, then wash all parts of the equipment with clean water.
13. Store the bioethanol in a clean, sealed container.

Tabel 1. Functional Understanding of Bioethanol Production Equipment

Equipment	Description
Fermenter	The main function of the fermentor tank is to mix coconut water with Saccharomyces cerevisiae yeast, which is then fermented at a room temperature of 25-30°C to produce ethanol.
Airlock Fermenter	CO_2 gas escapes through the airlock, forming bubbles that indicate fermentation activity. If no bubbles form within 24 hours, the fermentation process has likely failed. Size: 12 cm long, 8 mm diameter, contains 5 mL of water.
Level Indicator	Its main function is to ensure that the fermentation process runs optimally and safely, as well as to prevent conditions such as overfilling or underfilling, which can affect the quality of the final product.
Valve	It functions to regulate the flow of fermented liquid that will be further processed in distillation, and is resistant to high temperatures and corrosive conditions.
Distiller	Separation of mixtures based on differences in the boiling points of each component, which consists of two main stages: evaporation and condensation. In the evaporation stage, the fermentation mixture is heated to the boiling point of ethanol (around 78°C), so that ethanol vapor is formed. This vapor is then fed into a condenser to be cooled and condense back into a liquid. The distillation apparatus is equipped with a heater for evaporation and a condenser to return the vapor to a liquid.
Control Panel Box	Controlling various processes in the distillation system automatically, such as temperature control and pump operation. This panel allows temperature control via a thermocontroller, ensuring that the distillation process temperature remains within the appropriate range for maximum efficiency.
Condenser	To condense the vapor formed during distillation, so that the vapor condenses into a liquid that can then be collected as the final product. This process occurs by utilizing the temperature difference between the vapor and the cooling medium around the condenser.
Coolant Pump	to pump coolant into the condenser, which aims to accelerate the cooling process of the distillation vapor.
Coolant Tank	It functions to store the cooling liquid used in the condenser system and assists in the cooling process of the distillation vapor.

Table 2. Structural Understanding of Bioethanol Production Equipment

No	Images	Equipment Specifications
1	 Fermentation Unit	1. Funnel (Raw Material Input) Material: plastic, length 10 cm, diameter 15 cm 2. Fermenter Tube Material (2): Steainless steel 304, Capacity 5 l, cylindric, height 22 cm, diameter 15,96 cm, Temp.(25 30) ^{O}C 3. Level Indikator 4. *Valve* Residu, diameter 1/2 inch
2	 Distillation Unit	1. *Stainless Ball Valve,* 1/2 inch 2. Valve, 1/2 inch 3. Distillation Tube Material: Stainless steel, cylindric, height 19 cm, diameter 17,83 cm. Temp.85^{o}C 4. Temperature controller/ Thermocouple
3	 Condenser	*1. Gate Valve, 1/2 inch* 2. Condenser Tube Stainless steel material, 48 cm long, 6.69 cm in diameter, 5 mm thick 3. *Coolant Tank* 4. *Control Panel Box* 5. Erlenmeyer, 500 mL

No	Images	Equipment Specifications
4	 *Airlock Fermenter*	Size: length 12 cm, diameter 8 mm, volume 5 mL of water.
5	 Pump	Power : 50 – 100 Watt

3.3. Result

3.3.1 Fermentation Process

The data on the fermentation of old coconut water waste with an initial sugar content of 4.48% is presented in Table 3. Variations in yeast mass (50, 75, and 100 g/L) were tested for fermentation periods of 3, 5, and 7 days.

Table 3. Ethanol Content from Fermentation of tender Coconut Water Waste

Yeast mass (g/l)	Day-3 (%)	Day-5 (%)	Day-7 (%)
50	7	7	9
75	7	7	10
100	9	8	10

On days 3 and 5, the ethanol content was relatively low (7–9%). This was due to the yeast adaptation phase (lag phase) and suboptimal sugar consumption [13]. On day 7, there was an increase in ethanol content (9–10%). This indicated an optimum fermentation point when the sugar was completely fermented. Variations in yeast mass show that adding a larger amount of yeast (100 g/L) slightly increases the ethanol content, but not significantly compared to 75 g/L. This could be due to the limitation of the sugar substrate (only 4.48%), so that even though there is more yeast, the availability of glucose remains a limiting factor. The ethanol content from fermentation (maximum 10%) is in line with the literature, which states that simple fermentation generally produces 5–12% crude ethanol. [14].

3.3.2 Distillation

The distillation results from the fermentation liquid are shown in Table 4. Distillation increased the ethanol content threefold, although it was still below the fuel standard (99.5%). There was a significant increase after distillation, from crude ethanol (7–10%) to ethanol with a concentration of up to 24%. Distillation on the third day for a yeast mass of 50 g/L produced a low concentration (4%). This was thought to be because the fermentation results were not yet optimal. The most effective distillation was obtained at a yeast mass of 100 g/L and a fermentation period of 7 days, with an ethanol content of 24%. However, this content is still far below the standard for fuel bioethanol (SNI 7390:2012 => 99.5%) [12]. This means that the distillation system is designed only to achieve initial purification. To meet standards, redistillation or dehydration (molecular sieve/azeotropic distillation) is still required [15].

Tabel 4. Ethanol Content from Distillation of Tender Coconut Water Waste

Yeast mass (g/L)	Day-3 (%)	Day-5 (%)	Day-7 (%)
50	4	17	22.08
75	12.05	18	20
100	13	20	24

3.3.3 Analysis of Designed Equipment

a. Fermenter

1. The fermentor works well, producing 7–10% crude ethanol.
2. Limitations: the initial sugar content (4.48%) is too low, resulting in low ethanol yield even when the amount of yeast is increased.
3. The closed fermentor design with an airlock is quite effective in preventing contamination, as evidenced by consistent fermentation.
4. Recommendations: Add nutrients (e.g., nitrogen, phosphate) to increase yeast activity, or perform pre-treatment (add external sugar) to improve yield. [16]

b. Distiller

1. Distillation can increase the ethanol content by 2–3 times (from 10% to 24%).
2. The condenser works well because it can condense ethanol vapor.
3. Limitations: the distillation system is still simple, so purification is not yet optimal (only reaching 24%).
4. Recommendations: add a fractionation column (with packing/stage), or apply multi-stage distillation to improve separation.

c. System Integration

1. The integration of the fermenter distiller runs smoothly without contamination.
2. However, thermal insulation is needed on the distiller to prevent heat loss.
3. The modular scheme that has been created is good for laboratories and can be scaled up to semi-pilot.

3.3.4 Implications of Results

The results of this study indicate that the fermentation process is capable of converting coconut water waste into ethanol, although the resulting ethanol concentration remains relatively low due to limited sugar content in the substrate.

Subsequently, the distillation system was able to enhance the ethanol concentration; however, additional optimization is still required to achieve fuel-grade standards. Overall, this research highlights the promising potential of utilizing old coconut water waste as a renewable energy source while simultaneously addressing issues related to agro-industrial waste management.

3.3.5 Graph Interpretation

In the 2D Distillation Graph, a significant increase in ethanol content can be seen on day 3, distillation from 50 g/L only produced 4%, while 75–100 g/L produced 12.5–13%. On day 5, the ethanol content increased to 17–20%. On day 7, the highest ethanol content was achieved: 24% (100 g/L yeast).

This trend shows that distillation effectively increases the ethanol content by 2–3 times that of fermentation, although it has not yet reached fuel standards (99.5% ethanol according to SNI 7390:2012) [18].

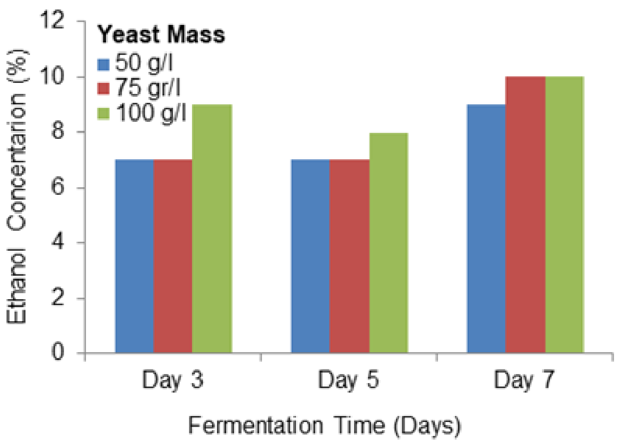


Figure 2. Ethanol Content of Distillate

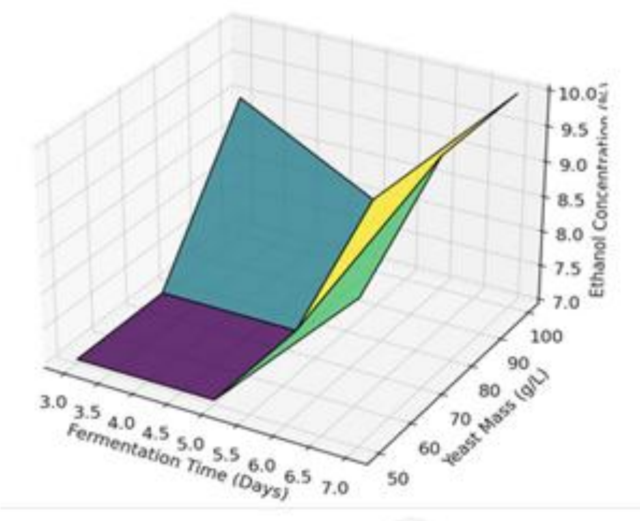


Figure 3. Ethanol Concentration Surface – Fermentation

The Figure 3 (3D fermentation graph) shows a flat surface that tends to rise slightly on the 7th day, confirming that fermentation time has a greater effect than yeast mass variation. The main limiting factor in fermentation is sugar content, so even if yeast is added, the increase in ethanol is limited [19].

The figure 4 (3D distillation graph) shows a more dynamic surface compared to fermentation. This indicates that both yeast mass and fermentation time affect the distillation results. The longer the fermentation and the higher the yeast mass, the higher the ethanol content after distillation [20]. The peak surface area was observed at a combination of 100 g/L and 7 days (24%).

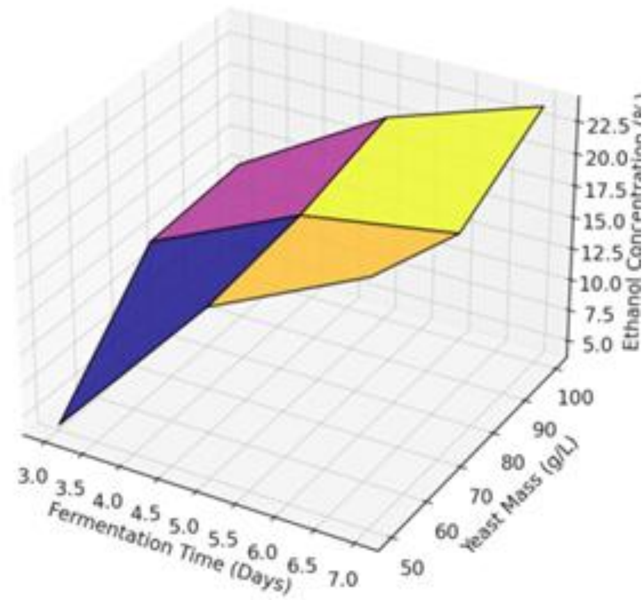


Figure 4. Ethanol Concentration Surface - Distillation

Based on the graph analysis, the fermentor demonstrates consistent performance in producing crude ethanol with a concentration of 7–10%, in accordance with simple fermentation literature. Two- and three-dimensional graphs confirm that the fermentor operates stably [21]. Furthermore, the distillation and condenser units successfully increase the ethanol concentration to 24%. The graphs indicate that the distillation process follows a positive trend with respect to time and yeast mass, while the condenser functions properly, as no anomalies or drastic decreases in ethanol yield are observed [22]. Technically, the device design successfully exhibits trends consistent with theory, where fermentation produces crude ethanol and distillation increases its concentration. The main limitation lies in the distillation column design, which remains simple, resulting in ethanol purity that is not yet optimal.

4. Conclusion

This study successfully designed and tested a prototype bioethanol production device from old coconut water waste through fermentation and distillation processes. The fermenter unit worked well, producing crude ethanol with a concentration of 7–10% depending on the yeast mass and fermentation time. The distillation unit was able to increase the ethanol content to 24% under optimal conditions, namely the use of 100 g/L of yeast with a fermentation time of 7 days. Although the ethanol content obtained is still below the bioethanol fuel standard (SNI 7390:2012), the results of this study show that the integrated fermentor-distiller system is feasible for application on a laboratory and small scale. Further optimization, such as the use of a fractionation distillation column and a dehydration stage, is needed to achieve fuel-grade ethanol content.

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References

[1] PGN LNG Indonesia. (2025). Mengapa Krisis Energi Menjadi Ancaman Serius Untuk Ekonomi Dunia?. https://pgnlng.co.id/berita/wawasan/dampak-krisis-energi/

[2] Wijaya Karna. (2011). Biofuel dari Biomassa. Pusat Studi Energi Universitas Gadjah Mada. https://pse.ugm.ac.id/biofuel-dari-biomassa/

[3] Hasnawati, Wahyuli, L,Z. (2020). Pengolahan Limbah Air Kelapa. Penrbit Kencana Kerjasama dengan LP2M UIN Imam Bonjol Padang. Cetakan Pertama. ISBN 978-623-218-711-5. https://scholar.uinib.ac.id/id/eprint/1305/1/Pengolahan_Limbah_Air_Kelapa.pdf

[4] FAO. (2023). Faostat Statistical Database. https://www.fao.org/faostat/

[5] Badan Pusat Statistik. (2023). Produksi Kelapa Menurut Provinsi, 2022. https://www.bps.go.id

[6] Hasnawati, Sutiharni, Dini Deswarni, Jasiah, Wetri Febrina. [2023]. Pemanfaatan limbah air kelapa untuk industri kecil di Pedesaan. Masyarakat Berdaya dan Inovasi. 4 (2), 2023, 160-168. https://doi.org/10.33292/mayadani.v4i2.116

[7] Wulandari R, R, A. & Utami, b. (2015). Pembuatan Bio-etanol dari Air Kelapa Tua Menggunakan Proses Fermentasi," pp. 147–152, 2015,[Online]. Available: https://www.researchgate.net/publication/307588162

[8] Marlina, L & Hainun, W.N. (2020). Pembuatan Bioetanol dari Air Kelapa Melalui Fermentasi dan Destilasi-DehidrasiI Dengan Zeolit. TEDC Vol. 14 No. 3,. Hal. 255-260.http://ejournal.poltektedc.ac.id/index.php/tedc/article/view/425

[9] Mahendra, K,A. & Liliana. (2023). Potensi Listrik Bioetanol Air Kelapa Tua Serta Analisis BiayaInvestasinya di Provinsi Riau. BRILIANT: Jurnal Riset dan Konseptual Volume 8 Nomor 3, hal. 748-762. https://doi.org/10.28926/briliant.v8i3.1362

[10] Khazalina, Tiara. (2020). Saccharomyces Cerevisiae Dalam Pembuatan Produk Halal Berbasis Bioteknologi Konvensional dan Rekayasi Genetika. Journal of Halal Product and Research (JHPR). Volume 3 Nomor 2, Hal.88-94.. doi: 10.20473/jhpr.vol.3-issue.2.88-94

[11] Chamidy, H,N, Saripudin, Ayu Ratna Permanasar. (2023). Pengaruh Waktu, Jumlah Yeast dan Konsentrasi Substrat padaFermentasi Limbah Kulit Nanas Menjadi Bioetanol Skala Home Industry. Jurnal Serambi Engineering, Volume 8, Nomor 4, Hal. 7430-7436. DOI: 10.32672/jse.v8i4.6784

[12] SNI 7390:2012. (2021). Bioetanol terdenaturasi untuk gasohol. https://ebtke.esdm.go.id/informasi-publik/sni-bioenergi

[13] Yumas,M.,& Rosniati. (2014).Pengaruh Konsentrasi Starter Dan Lama Fermentasi Pulp Kakao Terhadp Konsentrasi Etanol. BIOPROPAL INDUSTRI Vol. 5 No.1, Juni 2014.hal. 13-22. https://media.neliti.com/media/publications/53742-ID-none.pdf

[14] F. W. Bai, W. A. Anderson, and M. Moo-Young, "Ethanol fermentation technologies from sugar and starch feedstocks," Biotechnol. Adv., vol. 26, no. 1, pp. 89–105, Jan.–Feb. 2008, doi: 10.1016/j.biotechadv.2007.09.002.

[15] M. Balat and H. Balat, "Recent trends in global production and utilization of bio-ethanol fuel," Appl. Energy, vol. 86, no. 11, pp. 2273–2282, Nov. 2009, doi: 10.1016/j.apenergy.2009.03.015.

[16] H. Zabed, J. N. Sahu, A. N. Boyce, and G. Faruq, "Fuel ethanol production from lignocellulosic biomass: An overview on feedstocks and technological approaches," Renew. Sustain. Energy Rev., vol. 66, pp. 751–774, Dec. 2016, doi: 10.1016/j.rser.2016.08.038.

[17] International Energy Agency (IEA), Renewables 2023: Analysis and forecast to 2028, Paris: IEA, 2023. [Online]. Available: https://www.iea.org/reports/renewables-2023

[18] Z. I. S. G. Adiya, S. S. Adamu, M. A. Ibrahim, E. V. C. Okoh, and D. Ibrahim, "Comparative study of bioethanol produced from different agro-industrial biomass residues," Earthline J. Chem. Sci., vol. 7, pp. 143–152, Jan. 2022, doi: 10.34198/ejcs.7222.

[19] M. Yerizam, D. Meilinda, and D. Puspa, "Pemanfaatan limbah air kelapa sebagai substrat bioetanol melalui fermentasi," J. Teknol. Kim. Unimal, vol. 12, no. 2, pp. 45–53, 2023, doi: 10.29103/jtku.v12i2.8567.

[20] F. W. Bai, W. A. Anderson, and M. Moo-Young, "Ethanol fermentation technologies from sugar and starch feedstocks," Biotechnol. Adv., vol. 26, no. 1, pp. 89–105, Jan.–Feb. 2008, doi: 10.1016/j.biotechadv.2007.09.002.

[21] A. Gupta and J. P. Verma, "Sustainable bio-ethanol production from agro-residues: A review," Renew. Sustain. Energy Rev., vol. 41, pp. 550–567, Jan. 2015, doi: 10.1016/j.rser.2014.08.032.

[22] M. Balat and H. Balat, "Recent trends in global production and utilization of bio-ethanol fuel," Appl. Energy, vol. 86, no. 11, pp. 2273–2282, Nov. 2009, doi: 10.1016/j.apenergy.2009.03.015