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Revolutionizing Palm Oil Waste Management: Cost and Benefit Analysis of Plasma Nanobubble Innovative Technology

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Palm oil is a crucial agricultural commodity that holds substantial importance in the Indonesian economy, enhancing the export revenues and developing a rural economy. Production levels have consistently and substantially increased during the previous decades. However, this increase aligns with the substantial amount of palm oil mill waste (POME) that has the potential to pollute the environment, causes damage through water pollution and greenhouse gas emissions. The utilization of Plasma Nanobubble (PNB) technology could efficiently tackle this problem. Nevertheless, more research is necessary to assess the effects of this method on the treatment of palm oil residue. The aim of this study is to provide a thorough review of the costs and benefits related to the use of PNB technology for treating palm oil waste. The results of this study demonstrate a significant reduction in costs by 23%, from Indonesia Rupiah or IDR. 9,370,939,000 to IDR 7,214,155,960. The utilization of PNB technology generates several benefits, including improved environmental effects. A notable benefit discovered is the considerable decrease in color before and after the application of the PNB technology. In addition, there was a significant decrease in total suspended solids (TSS) of –969.8%, biological oxygen demand (BOD) of –1790.2%, and chemical oxygen demand (COD) of –2534.1% after the implementation of PNB technology. Therefore, PNB technology emerges as a viable solution for the palm oil industry to address the POME waste problem, contributing to creating new knowledge on waste management that can be applied by other palm oil producing countries.

Keywords: green economy, innovative technology, palm oil, waste management.

Introduction

Palm oil is one of the leading agricultural commodities in Indonesia. The export competitiveness of Indonesian palm oil, both in the form of crude and refined palm oil, is one of the highest in Indonesia, apart from Malaysia and Niger (Tandra et al., 2022). Indonesia's palm oil production and export levels are the highest in the world, reaching 46 million tonnes and 28.45 million tonnes, respectively, in 2022 (Indexmundi, 2022). Establishing oil palm plantations can serve as a beneficial initiative for local governments to generate foreign currency and job prospects, hence enhancing the well-being of the population (Suroso and Ramadhan, 2012). According to Acosta and Curt (2019), oil palm farms have the potential to enhance the quality of life and financial resources of farmers. Indonesian oil palm plantations are developing in 22 out of 33 provinces in Indonesia, with the two main island centers for oil palm plantations in Indonesia being Sumatra and Kalimantan (Purba and Sipayung, 2017). Even though the palm oil industry has a strategic role in the national economy, oil palm plantations also have a negative impact on society, especially environmental damage (Ngadi and Noveria, 2017). Economy is a priority aspect to be able to implement sustainable development (Suroso et al. 2021). The expansion of oil palm plantations into a thriving agricultural sector in Indonesia gives rise to an additional predicament, specifically the generation of waste from the palm oil industry, commonly called Palm oil mill effluent (POME). This waste is liquid and contains several toxic substances, which can have a harmful impact on microorganisms because it contains suspended dissolved solids in the form of colloids and oil residues. Therefore, it has biological oxygen demand (BOD), chemical oxygen demand (COD) values, and suspended solids content, which tends to be high. (Suprihatin et al., 2015). Hence, inappropriate disposal might result in ecological harm.

Generally, palm oil processing plants utilize an anaerobic process, followed by an aerobic process including many ponds (Silalahi and Supijatno, 2017). Nevertheless, this procedure necessitates a significant amount of time to handle the trash and substantial costs for constructing and maintaining the pond. On the other hand, the aerobic process often experiences a lack of oxygen in the pond which results in the low effectiveness of aerobic microbes in the process of decomposing organic compounds. This has an impact on the quality of the processed wastewater, which still has color and smell. Plasma Nanobubble (PNB) technology offers a potential solution for addressing the liquid waste processing requirements of palm oil mills in the Business and Industrial World. This method utilizes plasma to generate nanobubbles, which are extremely tiny in size and exhibit exceptional stability in the waste processing pool. Electrified nanobubbles are able to generate ozone in a plasma reactor, which has potential applications in water and waste treatment. The application of plasma could implicate on decolorization of organic dyes, applying for organic waste processing (Sugiarto et al., 2002; Sugiarto et al., 2003). On the other hand, a higher oxygen supply in ultrafine bubble water with higher Dissolved Oxygen (DO) minimizes the chance of seeds experiencing hypoxia (Raga et al., 2023). By modifying the design, the combination of plasma and nanobubbles on the water's surface enhances the processing efficiency. Reactor tests demonstrate the emission spectrum, ozone, dissolved oxygen, and certain distinct radicals (Luvita et al., 2022). This technique has been utilized in several instances, including the successful reduction of the most persistent residues of organophosphate class pesticides and the extension of the shelf life of cayenne pepper by 14 days (Syafadriana, 2023). Apart from that, the implementation of this technology has also succeeded in expediting the breaking of the dormancy phase and enhancing the germination of shallot bulb seeds to a higher level (Christopher, 2023). Nevertheless, no previous investigations have explored the development of PNB technology specifically for palm oil waste. Conversely, the rise in Indonesian palm oil waste may correspond with the fast growth in palm oil output. On the other hand, our study addresses the previous limitation raised by Awoh et al. (2023) regarding the need for in-depth studies on waste management. Hence, our study provides a solution by developing PNB technology for sustainable waste processing. Using PNB technology might effectively decrease waste generated by the palm oil industry, leading to cost reduction and improved benefits compared to traditional methods of processing palm oil waste. The objective of this study is to examine the costs and benefits resulting from the implementation of PNB technology for managing palm oil waste, using Limited Liability Company – XYZ LLC as one of the companies engaged in palm oil agribusiness in Indonesia. The specific name of the company cannot be disclosed due to confidentiality reasons.

Research related to cost and benefit analysis of waste processing technology has developed rapidly in the last decade. Chaerul and Rahayu (2019) compare the total costs required and benefits taken in scenario A (capacity optimization) and scenario B (providing two facilities in each sub-district), using cost and benefit analysis of Waste Processing facilities in Pekanbaru. The results show that the cost and benefit ratios for scenario A and scenario B are 2.90 and 4.48, respectively. Hence, the additional waste processing is an important policy consideration for the local government. Susanti et al. (2020) analyzed the operational costs of the Domestic Waste Water Management System (SPALD) covering an urban scale with a case study in Palembang City. The results reveal that income received from the SPALD levy has not been able to maintain the cessation of SPALD operations, as stated by the negative Net Present Value (NPV). Operational support from regional and central governments is needed to stop SPALD operations on a city scale so that the sanitation system can operate smoothly. Sasongko et al. (2020) analyzed the costs and benefits of various produced air remediation techniques for both oil and gas industry activities. The results of this research found that bioremediation techniques that can be used include: 1) landfarming processing, 2) bio-cell processing, 3) composite processing, 4) bio-venting processing, 5) bio-slurry processing, and 6) phytoremediation processing using techniques. The best bioremediations are landfarming and phytoremediation with low cost, supported by high benefit. Putra et al. (2020) utilized cost and benefit ratios, Net Present Value (NPV), and Internal Rate of Return (IRR) to compare the viability of studies in various agrotourism in Indonesia. The findings of this analysis indicate that Jamu Ramuan Madura agrotourism is highly viable, as evidenced by its NPV value of Indonesian Rupiah or IDR. 13,979,701,973, an IRR value of 30.52%, and a cost and benefit ratio value of 10.22. In their study, Sulistiani et al. (2020) examined the cost and benefit analysis of CV Laut Selatan Jaya, a company involved in the distribution of cosmetics in Bandar Lampung. These research findings indicate that the sales method at CV Laut Selatan Jaya yields a higher benefit-to-cost ratio, making it a viable operation for the company. Hsu (2021) utilized the cost-benefit analysis in the type of recycling in Taiwan agricultural wastes. This study found that processing chicken manure with other agricultural waste to make compost and utilizing rice straw as a material for making biomass fuel rods is estimated to be more economically profitable. Khan et al. (2022) evaluated the municipal solid waste management systems in India through cost-benefit analysis, determining the most appropriate treatment or disposal strategy. The findings show that composting and bio-methanation are viable options. This is due to the high organic content of waste, and recycling activities that significantly reduce costs while adding social value. Erfanita et al. (2024) analyzed the fish waste utilization in the fish cracker center in Bintan Regency by using a cost-benefit analysis. This study revealed that the utilization of fish waste into fishmeal has the potential to provide significant economic benefits, because effective waste management can reduce negative impacts on the environment while producing value-added products. The utilization of this waste is also financially feasible with a payback period of 4 years.

Different from previous studies, this research only focusses on the cost reduction in POME effluent treatment before and after the use of PNB technology. This is because the POME effluent that we observed in Indonesia is currently not processed into a value-added product as one of the income sources. This study enhances the understanding of the environmental impact of PNB technology, distinguishing it from previous studies conducted by Suroso et al. (2024) through an examination of the PNB Business Model. Therefore, this study only analyzes the environmental benefits resulting from the application of PNB technology in palm oil mill effluent treatment ponds. This is a limitation in the research that can be developed in the future.

Methods

The data collected in this research is primary data acquired through interviews with factory managers and heads of administration at XYZ LLC on palm oil waste processing activities prior to the implementation of PNB technology. The research team conducted surveys in nine ponds, with particular emphasis on the last pond as the primary focus of observation in this study. In addition, interviews were held with innovators to gather information on the prospective costs and benefits associated with PNB technology. The cost-benefit ratio is assessed to compare the costs and benefits of using PNB technology before and after its deployment. In the first method of analysis, a comparison of costs before and after the implementation of PNB is made. The formula can be seen as follows:

$$CR = \frac{Cpnb_a}{Cpnb_b} \quad (1)$$

where CR is the cost ratio obtained from the comparison between $Cpnb_a$ and $Cpnb_b$, $Cpnb_a$ is the cost after using PNB technology and $Cpnb_b$ is the cost before using PNB technology. If the ratio is less than 1, then there is a decrease in costs after implementing PNB technology or vice versa, there is an increase in costs if the ratio value is more than 1.

The cost components analyzed consist of operational costs and investment costs for land creation. The expenditures include: 1) costs related to labor, 2) costs related to diesel fuel, 3) costs related to dredging, 4) costs related to transport trucks, 5) costs related to electricity, 6) costs related to pool upkeep, 7) costs related to aerator pump replacement, and 8) costs related to lab testing. The investment costs examined are outlined in the following details: 1) Land acquisition costs for the pool, 2) Construction costs for the pools, 3) Costs for the installation of PNB pipes and pumps in the pools, 4) Costs for the installation of waste disposal machines in the pools, 5) Costs for aerators, 6) Costs for palm oil mill waste centrifuges, 7) Costs for machine pumps, 8) Costs for electrical installations in the pools, and 9) Costs for purchasing PNB. In this study, we only examined the POME waste activity, meaning that no profit was generated. Therefore, we only calculate the costs incurred in value or percentage of reduced costs between before and after the implementation of PNB technology.

This study also examines a potential benefit resulting from the use of PNB technology. The benefits observed consist of two types, namely direct and indirect benefits. The direct benefits in this study consist of a reduction in chemicals used, a reduction in pool maintenance costs and supporting equipment, a reduction in lab testing costs, a reduction in waste transportation activities, and a reduction in retention time for pool transfers. Meanwhile, indirect benefits consist of reducing the need for land for pools, reducing the need for building pools, and visualizing the waste produced. The benefits testing was carried out only toward pool 8 and 9 by looking at how it affected the environment both visually and by testing laboratory samples.

Results and Discussion

Product description plasma nanobubble (PNB) technology for processing palm oil waste

PNB technology is an innovative technology that is capable of being an effective and safe waste processor for the environment (*Fig. 1*). This technology is inspired by natural phenomena in the form of lightning or plasma which has a powerful electric current so that the lightning strike makes the surrounding air in the form of O_2 which is a stable compound split into O_3 or Ozone which is an unstable compound and requires other substances to bind thus that it can become stable again. This phenomenon can be applied to waste because it is able to remove pollutants and bind them with O_3 or Ozone. However, Ozone has a tendency to move upwards even before binding to pollutants. Therefore, this technology also requires a tool to distribute Ozone in the form of Nanobubbles, so that it does not immediately evaporate into the air. This tool is in the form of a nozzle that is connected to a special ozone pump and submerged in a pool so that the ozone has time to bind pollutants so that the processed waste is safer in terms of color, smell, and texture. The way PNB technology works consists of two systems, namely a plasma generator and a nanobubble generator. Oxygen from the air is taken by the oxygen collector, then some is put into the plasma generator which will then be reacted with the plasma and the rest is converted into ozone which will then flow through the nano nozzle into the water pool in the form of micro and nano-sized particles. These micro and nano-sized ozone and oxygen particles are then flowed through the nano nozzle into the water pool at a rate of 45 g/hour, breaking down odors and organic substances and killing pathogenic bacteria. Meanwhile, the nanobubble generator functions to increase dissolved oxygen in the water column by 10 lpm. On the other hand, electricity is needed in this technology to be able to process POME waste as the operation of PNB technology.

Fig.1. *PNB technology for POME waste processing*

a) Prototype of PNB b) Commercial product of PNB

Cost analysis before and after implementation of PNB technology

Table 1 displays the costs before implementation of PNB technology. The waste processing technique used is the use of waste ponds consisting of cooling ponds, mixing ponds, anaerobic ponds, aerobic ponds, polishing ponds, and storage ponds.

Table 1. *The cost before and after implementation of PNB technology*

1. The cost before implementation of PNB technology				
Operational cost (in year)				
Number	Detail	Quantity	Price (IDR)	Total (IDR)
1	Cost of labor	12 months	3,800,000	45,600,000
2	Cost of fuel	5400 liter	12,000	64,800,000
3	Cost of dredging	300 hours	600,000	180,000,000
4	Cost of transport trucks	75 unit	1,000,000	75,000,000
5	Cost of pool maintenance	12 months	500,000	6,000,000
6	Cost of aerator pump replacement	2 pieces	9,000,000	18,000,000
7	Cost of lab testing	12 times	385,000	4,620,000
Total				394,020,000
Investment cost				
Number	Detail	Quantity	Price (IDR)	Total (IDR)
1	Cost of pool acquisition	5 hectares (Ha)	60,000,000	300,000,000
2	Cost of pool construction	9 pools	950,000,000	8,550,000,000
3	Cost of pool pipe installation	16 pieces	2,410,000	38,560,000
4	Cost of aerator	3 units	27,000,000	81,000,000
5	Cost of pump machines	30 units	245,300	7,359,000
Total				8,976,919,000
Total cost of operational and investment				9,370,939,000

2. Cost after implementation of PNB technology				
Operational cost (per year)				
Number	Detail	Quantity	Price (IDR)	Total (IDR)
1	Cost of labor	12 months	3,800,000	45,600,000
2	Cost of fuel	5400 liter	12,000	64,800,000
3	Cost of dredging	144 hours	600,000	86,400,000
4	Cost of transport trucks	75 unit	1,000,000	75,000,000
5	Cost of electricity	12 months	478,080	5,736,960
6	Cost of pool maintenance	12 months	500,000	6,000,000
7	Cost of aerator changing	2 pieces	9,000,000	18,000,000
8	Cost of lab testing	12 times	385,000	4,620,000
Total				306,156,960
Investment cost				
Number	Detail	Quantity	Price (IDR)	Total (IDR)
1	Cost of pool acquisition	5 hectares (Ha)	60,000,000	300,000,000
2	Cost of pool making	6 pools	950,000,000	5,700,000,000
3	Cost of pool pipe installation	4 pieces	2,410,000	9,640,000
4	Cost of aerator	3 units	27,000,000	81,000,000
5	Cost of POME	1 unit	250,000,000	250,000,000
6	Cost of pump machines	30 units	245,300	7,359,000
7	Cost of PNB acquisition	4 units	140,000,000	560,000,000
Total				6,907,999,000
Total cost of operational and investment				7,214,155,960
Comparation of cost (after and before)				0.770

The results of cost analysis before implementing PNB technology show that operational costs and investment costs each reach IDR. 394,020,000 and IDR. 8,976,919,000. The biggest operational cost before implementing PNB technology was dredging costs which reached IDR. 180,000,000 with a total usage of 300 hours. The biggest investment cost before implementing PNB technology was the cost of building a pool which reached IDR. 8,550,000,000 with 9 pools used. The total costs before implementing PNB technology have reached IDR. 9,370,939,000. In addition to information about costs before implementing PNB technology, the table also displays costs after implementing PNB technology. This processing technique can reduce the use of the number of pools from 9 pools to only 6 pools. The results of cost analysis after implementing PNB technology show that operational costs and investment costs each reach IDR. 306,156,960 and IDR. 6,907,999,000. Similar to costs before implementing PNB technology, the largest operational costs after implementing PNB technology have reached IDR. 86,400,000 with a total usage of 144 hours. The biggest investment cost after implementing PNB technology is the cost of building a pool which reaches IDR. 5,700,000,000 with 6 pools used. The total cost after implementing PNB technology has reached IDR. 7,214,155,960. The two types of costs were then compared to see what the cost ratio was like before and after implementing PNB technology. The cost comparison ratio value before and after the implementation of PNB technology obtained 0.770. This figure shows a reduction in costs after implementing PNB technology with a value below 1. The remaining value of the ratio is 0.230, indicating a reduction in costs of 23%, from an initial value of IDR 9,370,939,000 to IDR 7,214,155,960. Adoption of waste processing technology can create cost reductions through reducing energy consumption requirements (Wikaningrum and Hakiki, 2020). The development of clean production can create opportunities to increase efficiency in terms of reducing pollution and resulting production costs (Widodo, 2017).

Benefit analysis before and after implementation of plasma nanobubble (PNB) technology

There are many benefits obtained from PNB technology both before and after implementation. Apart from reducing waste processing costs, there are other benefits that can result from implementing PNB technology. Based on several previous literatures, the benefits that generally arise from the use of waste processing technology are reducing the environmental pollution caused (Kholif et al., 2020; Ratnawati et al., 2010; Suherman et al., 2020). The same results were found in the case of waste processing with PNB technology. *Fig. 2* shows a comparison of water conditions before and after implementing PNB technology. Visually, there is a clear color difference after applying PNB technology from dark to light. This can help PKS to overcome problems in processing brownish POME waste with a water content of 95–96 percent, oil (0.6–0.7%), and 4–5% total solids with high BOD and COD values so which has implications for ecosystem damage if it is disposed of directly into the environment.

Table 2 shows the testing results before and after implementing PNB technology. Due to formal certification, laboratory tests were conducted in a formal health office close to the mills. There are three tests, including total suspended solid (TSS), biological oxygen demand (BOD), and chemical oxygen demand (COD). Based on the health office in West Sumatera Province, the maximum quality limits achieved for each TSS, BOD and COD are 250, 100 and 350 mg/L units. Before applying PNB technology, the test results showed that each of the TSS, BOD and COD values far exceeded the specified quality limits, namely 828, 809 and 1944 in mg/L units. However, tests using PNB technology show different results for all parameters tested. Each value of TSS, BOD and COD shows values below the quality limit, namely 77.4, 42.8 and 73.8 in mg/L units. A decrease in BOD and COD values can be produced from this technology, so the results of this PNB technology are similar to previous literature, which can reduce BOD and COD values using different methods (Ilmannafian et al., 2020; Suprihatin et al., 2015).

Fig. 2. *Comparison of Water Conditions Before and After the Implementation of PNB Technology*

a) Pool 8 (Left is Before Implementation, and Right is After Implementation)

b) Pool 9 (Left is Before Implementation, and Right is After Implementation)

Source: Suroso et al. (2024)

Table 2. *Testing results before and after the implementation of PNB technology, in case of pool 9*

Number	Parameter	Testing before implementation of PNB technology (mg/L)	Testing after implementation of PNB technology (mg/L)	Changing percentage (%)	Quality standard (mg/L)
1	TSS	828	77.4	–969.8	250
2	BOD_5	809	42.8	–1790.2	100
3	COD	1944	73.8	–2534.1	350

Source: The Health Office of West Sumatera Province (2023)

Conclusion

The results of this study show a significant reduction in costs of 23%, from a value of IDR 9,370,939,000 to IDR 7,214,155,960 in one year of implementation on the case of XYZ LLC, one of the palm oil companies in Indonesia. Furthermore, there is an increase in environmental benefits from the comparison before and after the application of the technology from a visual perspective (a significant color change occurs) and from a testing perspective (there is a significant decrease in the respective TSS, BOD and COD values). The recommendations from this study are 1) improving competence in POME waste processing, so that the implementation of PNB technology can operate well, 2) utilizing waste products to be used as biogas before processing it through PNB, which can produce added value for the palm oil industry, and 3) the palm oil industry is advised to allocate funds for waste processing, one of which is investment in PNB technology. In further research, this result could be supported by exploring the feasibility of PNB technology within three years of implementation, determining whether this technology is proper to be used. {Gurauskiene, 2006, Eco-design methodology for electrical and electronic equipment industry}

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