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Research Article

The Adoption of Plasma Fine Bubble Innovation in a Seaweed Processing Factory to Implement Blue Economy Concept (A Case Study of PT. Hakiki Donarta)

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ABSTRACT

Introduction: Seaweed is one of Indonesia's leading commodities in the mariculture sector, and its production produces wastewater. PT Hakiki Donarta is a leading seaweed processing company that currently handles its IPAL still using Polyaluminium chloride chemicals and aeration ponds with the help of water wheels.

Objectives: This condition receives special attention in the waste handling process so that the business can be environmentally friendly and sustainable as the blue economy concept is applied. Thus, Plasma Fine Bubble (PFB) will be tested to compare chemical handling and PFB handling to manage wastewater and support the blue economy concept.

Methods: Two of the principles of the blue economy are innovation and adaptation. IPB has innovative Plasma Fine Bubble (PFB) technology and has the expertise to develop commercialization strategies for PFB to support the implementation of the Blue Economy. To be in line with the roadmap, there are five main steps (key phases) and milestones in program development (innovation solutions), as follows: Prepare the Plasma Fine Bubble (PFB) System to be implemented; PFB System manufacturing and assembly process; Implementation and performance testing of the PFB generator at the Factory; Adopt and Scale the PFB System using Benefit-Cost Analysis; Create a business plan using PFB technology.

Results: The 5 key phases are completed step-by-step. Key phases 1 and 2 were completed from July to September 2023. The results of completing key phases 1 and 2 are explained. Key Phase 1: Preparing the Fine Bubble (PFB) plasma system to be implemented. Functional requirements of the PFB system implementation. Condition of the wastewater of the factory. The current situation surrounding the factory. Key Phase 2: PFB System Manufacturing and Assembly Process

Conclusions: The study confirms that Plasma Fine Bubble (PFB) technology is highly effective and sustainable for managing seaweed processing waste. By reducing waste management costs by 2%, reducing chemical costs by 40%, and addressing environmental concerns, PFB represents a significant step forward in advancing the blue economy.

Keywords: blue economy, plasma fine bubble, seaweed processing, sustainable business, wastewater management.

INTRODUCTION

Seaweed is one of the leading commodities in the mariculture sector. Over the past decade, the economic value of seaweed production has shown a steady increase, with an average growth rate of 14.75%. However, production volume has declined over the last five years (KKP, 2023). In 2021, Indonesia produced approximately 9.12 million tons of seaweed, valued at IDR 28.48 trillion (provisional data) (KKP, 2023). This growth is driven by rising global demand for processed seaweed products, particularly gelatin and carrageenan, which were valued at USD 275.19 million and USD 1.13 billion, respectively, in 2018 (ITC, 2019).

Despite its economic potential, seaweed processing generates significant environmental challenges. Approximately 65–70% of seaweed input becomes waste (Kim et al., 2007), containing high levels of organic matter, nitrogenous compounds, and hydrocolloids. The extraction process, which involves alkaline treatment, results in strong odors and elevated nitrite (N) levels (Kim et al., 2007). The high organic content in seaweed waste necessitates complex treatment processes, often requiring multiple repetitions, leading to increased operational costs (Sari & Yuniarto, 2016).

Currently, wastewater treatment plants (IPAL) in seaweed processing still rely on chemical treatments such as Polyaluminium chloride and aeration ponds supported by water wheels, which are less environmentally friendly and generate entropy or residue from economic activities (Hakiki Donarta, 2023). Some of this entropy can be absorbed by nature, but much of it cannot or requires long periods to decompose, creating environmental challenges. PT Hakiki Donarta in Surabaya exemplifies a leading seaweed processing company striving for sustainable waste handling aligned with the blue economy concept (Hakiki Donarta, 2023). Addressing these issues requires a more sustainable approach that optimizes resource efficiency while minimizing environmental impact.

One promising solution is Plasma Fine Bubble (PFB) technology, which enhances oxidation efficiency, reduces water and chemical usage, and lowers industrial waste production (Xiao et al., 2022). This innovation aligns with the Blue Economy principles, which emphasize sustainable economic activities that balance resource utilization with long-term environmental preservation (Pauli, 2010). By adopting PFB technology, PT Hakiki Donarta aims to improve wastewater management efficiency while supporting environmentally responsible business practices.

One promising solution for sustainable seaweed processing is Plasma Fine Bubble (PFB) technology, which enhances oxidation efficiency, reduces water and chemical usage, and minimizes industrial waste production (Xiao et al., 2022). This innovation aligns with the Blue Economy principles, which advocate for economic activities that optimize resource utilization while ensuring long-term environmental sustainability (Pauli, 2010). The Blue Economy concept challenges businesses to adopt more responsible models that balance economic growth with ecological preservation, emphasizing efficient production systems, higher economic value, job creation, and equitable benefits distribution. In the seaweed industry, implementing PFB technology presents a significant opportunity to improve wastewater management by reducing chemical dependency and operational costs while increasing overall process efficiency. By integrating this technology, PT Hakiki Donarta seeks to enhance its sustainability efforts, demonstrating a business model that supports both economic viability and environmental responsibility. This paper aims to explore how PT Hakiki Donarta can adapt this technology for sustainable wastewater management.

Output and Outcome

The output of this program are as follows:

1) Increasing added value and competitiveness: increasing added value and power product competitiveness for export and meeting domestic needs.
2) Production system modernization: efficiency and modernization of upstream production systems and downstream.
3) Sustainable Business: the principle of balance between resource utilization nature and long-term environmental protection.

This program has several outcomes:

1) Reduction of overhead costs through:
    a. Less use of chemicals
    b. Increasing the efficiency and effectiveness of waste management and processing.
2) The benefits of reducing overhead costs cannot yet be calculated with certainty, but reducing the use of chemicals and increasing the efficiency of waste management will have a significant impact on the company.
3) Environmental aspects:
    a. Reduce waste management pool usage time
    b. Minimize waste residue
    c. Improving the quality of liquid waste to support the implementation of a blue economy.

4) The benefits of this environmental aspect will only be visible when compared before and after implementing PFB technology, so it is hoped that it will have an effect on reducing the negative impacts caused, such as water pollution and the use of additional land for waste management ponds.
5) Company reputation and brand image of the seaweed processing industry:
    a. Demonstrates the company's commitment to the Blue Economy
    b. Improve environmental certification/audits (IPAL and Proper).
6) The benefits of this reputation aspect will help improve the company's image in the seaweed processing industry and demonstrate commitment to sustainable business practices. PT. Hakiki Donarta as a partner who is also the chairman of the ASTRULI (Indonesian Seaweed Industry Association), hopefully can be the perfect example as a user of this technology for all seaweed processing industries in Indonesia.

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OBJECTIVES

The concept of the *Blue Economy* was developed to answer the challenge that the world economic system tends to be exploitative and damaging to the environment. Apart from waste, nature is also damaged because exploitation exceeds its capacity or carrying capacity. The concept of *Blue Economy* is also intended to challenge entrepreneurs that *a blue economy business model* provides opportunities to develop investments and businesses that are more economically and environmentally profitable by using available natural resources more efficiently and without damaging the environment, more efficient production systems, producing greater products and economic value, increasing labor absorption, and provide opportunities to provide benefits to each contributor more fairly.

Therefore, the implementation of *the blue economy* through *Plasma Fine Bubble* (PFB) technology innovation in the seaweed industry can be an alternative that has a significant impact on the waste treatment of the seaweed industry. The technology can help reduce the amount of waste generated by the industry by minimizing the use of water and chemicals and improving efficiency in the production process

METHODS

Road Map

Two of the principles of the blue economy are innovation and adaptation. IPB has innovative Plasma Fine Bubble (PFB) technology and has the expertise to develop commercialization strategies for PFB to support the implementation of the Blue Economy.

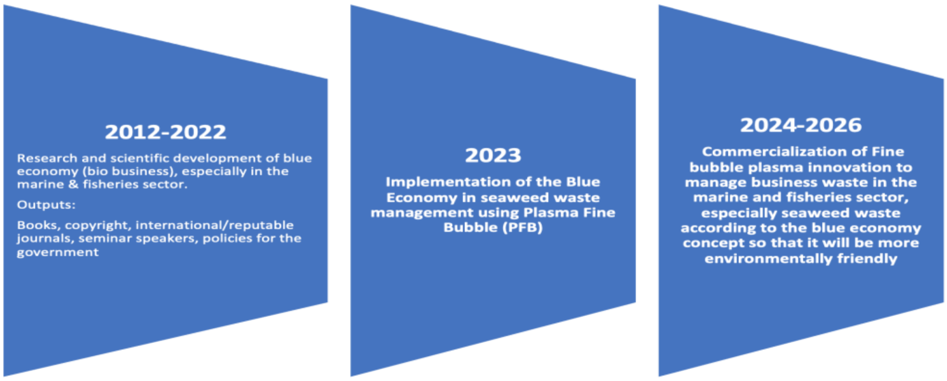


Figure. 1 Roadmap to develop commercialization strategies for PFB to support the implementation of the Blue Economy

To be in line with the roadmap, there are five main steps (key phases) and milestones in program development (innovation solutions), as follows:

1) Prepare the Plasma Fine Bubble (PFB) System to be implemented
2) PFB System manufacturing and assembly process
3) Implementation and performance testing of the PFB generator at the Factory
4) Adopt and Scale the PFB System using Benefit-Cost Analysis

5) Create a business plan using PFB technology

Figure 2 Key phases in developing the program

Key Phases

Key phases will support the roadmap to develop the commercialization strategies for PFB to support the implementation of the Blue Economy. There are 5 phases with explanations as follow:

Key Phase 1 - Preparing the Fine Bubble (PFB) Plasma System to Be Implemented Fine bubble plasma technology combines plasma and fine bubble technology. Plasma generates ozone, while fine bubble technology produces very fine air bubbles in water with a nanometer diameter (under 1 micrometer). These ozone-enriched bubbles can survive for extended periods in water, making them highly effective for accelerating wastewater oxidation processes (Xiao et al., 2022).

PFB system requirements analysis involves identifying and analyzing the needs for effective implementation. This ensures that the PFB system meets the desired seaweed waste management goals. Initially, the PFB system was installed in an aeration pond to handle seaweed waste without disrupting production processes. The trial involved a system of 4 units with a capacity of 10-15 m^3/hour to manage 1000 m^3 of liquid waste (Nanobubble Innovations, 2024).

Key Phase 2 - PFB System Manufacturing and Assembly Process

The implementation of the blue economy through PFB technology in the seaweed industry is expected to significantly improve waste management by minimizing water and chemical usage while increasing process efficiency (Pauli, 2010). PFB works by injecting nanobubbles—approximately 100 million bubbles per ml—into liquid waste. Their small size enhances mixing, circulation, and oxygen transfer, enabling efficient pollutant breakdown through advanced oxidation processes as seen in Figure 3 (Nanobble, 2024).

Hydroxyl radicals produced by plasma and fine bubble generators effectively oxidize COD, BOD, and ammonia, surpassing traditional chemical treatments (Xiao et al., 2022). On a laboratory scale, fine bubble plasma technology has been tested for removing pesticide residues and wastewater treatment for aquaponics and shrimp ponds (Nanobubble Innovations, 2024). The assembly process ensures all components function optimally to produce cleaner waste.

Key Phase 3 - Implementation and Performance Testing of PFB Generators at Factory Locations The PFB system was installed in aeration ponds at seaweed processing locations without disrupting existing operations. Testing for capacity, efficiency, stability, and effectiveness provided crucial data on the system's performance in managing seaweed waste (Hakiki Donarta, 2023).

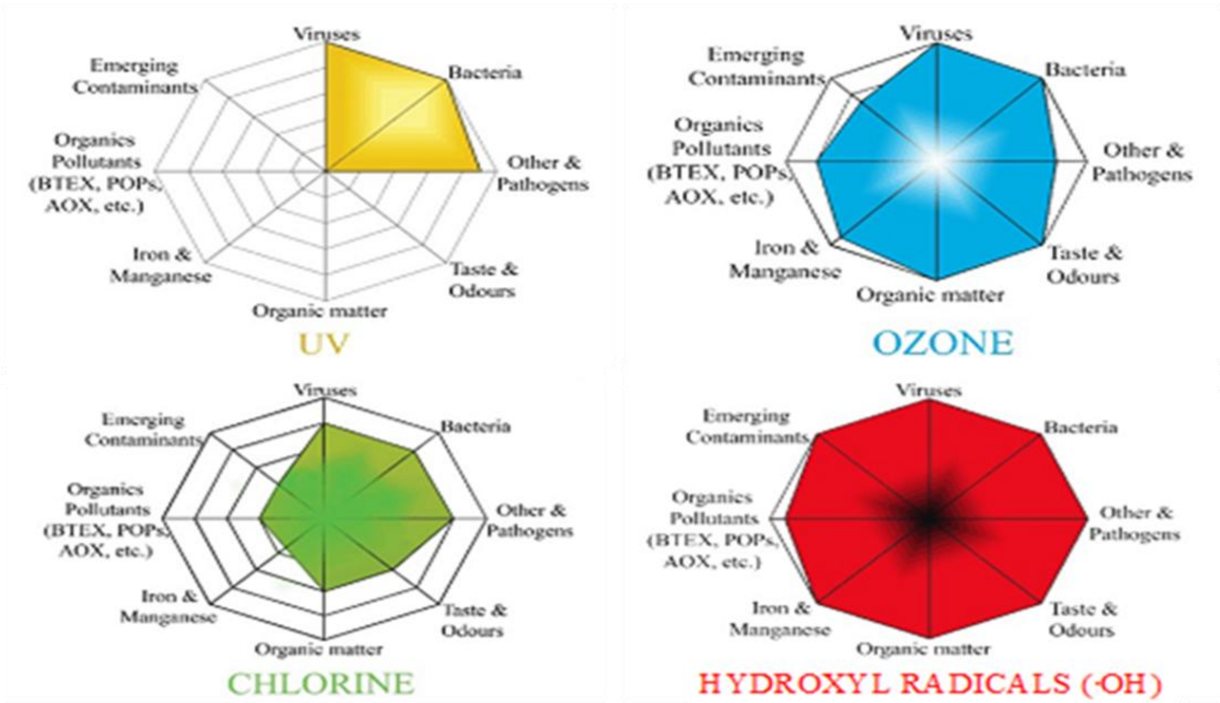
Key Phase 4 - Adopt and Scale the PFB System Using Benefit-Cost Analysis

Benefit-Cost (B/C) analysis evaluates the feasibility of implementing PFB technology in seaweed processing. Costs include technology procurement, infrastructure, training, and operations. Expected benefits include efficiency improvements, better product quality, enhanced farmer welfare, and sustainable resource management (Sari & Yuniarto, 2016).

Key Phase 5 - Create a Business Plan for PFB Technology

The business plan outlines the product's type, specifications, benefits, and market needs. It also includes details about processes like raw material requirements and technology setup. The plan facilitates feasibility studies and decision-making, focusing on generating social and economic benefits while supporting the blue economy (Pauli, 2010).

The proposing team, with expertise in bio-business and marine economics, collaborates with PT Hakiki Donarta to innovate PFB technology implementation. The program also engages students in practical research at partner locations (Hakiki Donarta, 2023).



Preparation Phase

5 key phases will support the roadmap to develop the commercialization program for PFB to support the implementation of the Blue Economy. On the other hand, this paper will only be focused on the preparation stage, which is key phase number 1 and number 2. The mechanism to analyze each key phase will be as follows:

1) Key Phase 1 - Preparing the Fine Bubble (PFB) plasma system to be implemented
   Some of the activities that will be carried out in this activity are:

   a. Plasma Fine Bubble (PFB) system requirements analysis is a process for identifying and analyzing the needs that must be met by the PFB system to be designed and implemented. The aim is to ensure that the PFB system can meet the desired targets and needs of seaweed waste management. This analysis includes:
      - Identify problems to be overcome through seaweed waste management by using PFB technology
      - Determining the goals to be achieved through processing seaweed waste
      - Identify functional and non-functional requirements of the PFB system.
        The ability to kill microorganisms and oxidize organic substances are functional requirements for a PFB system, while safety, reliability, and energy efficiency are non-functional requirements.
      - Create PFB system requirements specifications based on previous analysis to guide the design and development of an appropriate PFB system.

   b. Chemical, biological, and geological analysis of waste content at the factory
      Chemical analysis was carried out by taking samples of seaweed waste from the lamella of the settling pond at the factory location. Next, seaweed waste samples are analyzed to determine chemical content such as oil content, fat content, organic matter content, and acidity degree (pH). Apart from that, it is also to determine the concentration of heavy metals and other organic compounds contained in seaweed waste.

   c. Condition and Environmental Mapping
      Understand the current technical and economic conditions of the industry or market where the innovation will be applied. This can help identify potential opportunities and challenges for innovation. A field survey needs to be carried out, in this case, to obtain information regarding field conditions at the factory location to determine the Wastewater Treatment Plant pool that will be

used, the physical condition of the environment (soil, water, and air conditions), characteristics of seaweed waste, available infrastructure and potential sources, and local power (water resources, energy, and raw materials).

2) Key Phase 2 - PFB System Manufacturing and Assembly Process
The PFB System assembly process includes several stages, namely:

a. Preparation of materials and equipment; namely PFB system components such as plasma generators, pumps, tanks, pipes and filters, which are all in good condition
b. Plasma generator assembly, where the plasma generator is the main component in the PFB system, which functions to produce plasma. The assembly of plasma generators includes electrode installation, connecting cables, and electrical control.
c. Piping system assembly: The piping system consists of pipes and valves connecting the plasma generator with the waste tank.
d. Waste tank assembly; installation of pump, input pipe, output pipe, and water level sensor.
e. Install a filter on the waste tank outlet pipe to filter liquid waste before processing it by the PFB system.
f. Connections between components in the PFB system to connect the entire PFB system

After assembling, the PFB system is tested to ensure all components function properly in the plasma generator, pump, water level sensor, and electrical controls. Next, adjustments are made to the PFB system parameters, which include pump speed, air pressure, and electric current for optimal results.

RESULTS

The 5 key phases are completed step-by-step. Key phases 1 and 2 were completed from July to September 2023. The results of completing key phases 1 and 2 are explained below.

Key Phase 1: Preparing the Fine Bubble (PFB) plasma system to be implemented

Based on a desk study, in-depth interview, and field observation:

1) Functional requirements of the PFB system implementation
Plasma Fine Bubble (PFB) is an innovation that utilizes plasma and fine bubble technology to produce oxidation techniques in wastewater treatment processes. PFB is categorized under Advanced Oxidation Processes (AOP), which involves oxidizing pollutants in wastewater using hydroxyl radicals (·OH). Hydroxyl radicals, with an oxidation potential of 2.8 eV, are stronger oxidizing agents compared to ozone gas (2.07 eV) or chlorine (1.36 eV) (Xiao et al., 2022). Moreover, PFB increases oxygen levels in water, enhancing wastewater treatment efficiency (Nanobble, n.d.).
The wastewater from seaweed processing factories cannot be directly discharged into water bodies due to its high COD, BOD, ammonia, and TSS levels, which can severely pollute water bodies and ecosystems (Sari & Yuniarto, 2016). Therefore, wastewater treatment is essential to meet environmental quality standards. Conventional wastewater treatment methods in the seaweed industry often combine chemical and biological processes. Chemical methods such as Dissolved Air Flotation (DAF) use flocculant chemicals to separate suspended solid pollutants, while biological processes utilize aeration bacteria that require oxygen to decompose pollutants (Hakiki Donarta, 2023). However, the high organic content in seaweed wastewater often renders these methods inefficient, leading to challenges like excessive chemical usage and inadequately treated, colored water. Environmental factors such as weather, oxygen supply, and factory operations further hinder the performance of biological treatments (Nanobubble Innovations, 2024).
The innovative solution is to integrate PFB technology into the DAF process. In this approach, PFB is introduced in the DAF input pool to enhance its efficiency. The oxidation process by PFB converts dissolved pollutants into suspended forms, simplifying their separation during the DAF process. This reduces chemical usage, particularly flocculants, and increases pond aeration with nanometer-sized oxygen bubbles. These dissolved oxygen bubbles significantly boost the effectiveness of microorganisms in decomposing organic compounds (Xiao et al., 2022).
The advantages of incorporating PFB in wastewater treatment include:
1. Reduction of COD, BOD, and TSS levels: This ensures that the processed water meets environmental waste quality standards.
2. Efficient oxidation of organic pollutants: Minimizes the use of chemicals during the DAF process.

3. Enhanced aerobic bacteria effectiveness: The dissolved oxygen content in nanobubbles improves the decomposition of organic compounds in aerobic ponds.

2) Condition of the wastewater of the factory

The current processing of seaweed industry wastewater at PT Hakiki Donarta is based on the process flow, namely the Lamela EBO 020-point, Sulfa Acid, and Anionic Flocculant AP 205; at the DAF point, EBO 020 and WPC 2967 ST Cationic Flocculant; and for the Belt Press position, cationic flocculant WPC 2967 ST.

Based on a literature study conducted, according to Sari and Yuniarto (2016), it is known that liquid waste resulting from processing seaweed, especially those processed as gelatin, has a mineral content, namely 5.30% nitrogen (N), 0.24% phosphorus (P), 6.04% potassium (K), 5.81% calcium (Ca), 1.06% magnesium (Mg), 1.26% sodium (Na), 1.17% sulfur (S), 8124 ppm iron (Fe), 8954 ppm aluminum (Al), 2273 ppm manganese (Mn), 18 ppm copper (Cu), 252 ppm zinc (Zn), and 1482 ppm boron (B). According to Samekto (2006), the high content of nitrogen (N), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), and manganese (Mn) in agar waste can increase plant growth, helping plant assimilation processes, compose chlorophyll, and control acidic soil pH. Meanwhile, according to Lingga (1998), the content of phosphorus (P), copper (Cu), and zinc (Zn) which is lower than the nutrient content of compost can cause the color of the leaves to become too old, the tips of the plant's leaves wilt unevenly and sometimes experience chlorosis, and the leaves become hollow, dry and die.

In addition, based on a case study conducted by Sekaringgalih and Rachmah (2023), seaweed liquid waste also contains Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), and pH with concentrations of 1480.87 mg/L, 316 respectively. mg/L, and 11 mg/L. These three indicators apparently have content that exceeds the quality standards stipulated in the 2013 East Java Governor's Regulation (East Java Gubernatorial Regulation No. 52, 2014) concerning Wastewater Quality Standards for Industry and/or Other Business Activities. Illustrations of waste tests in seaweed processing can be seen in Figure 4.

Figure 4. Comparison of wastewater before and after PFB implementation

3) The current situation of surrounding the factory

In depth interviews were conducted with farmers who experienced directly the waste produced by PT Hakiki Donarta in Pasuruan, Surabaya. The interview was structured in the form of 16 statements with two variables: adequate and inadequate.

Table 1. Interview results regarding waste produced by PT Hakiki Donarta

No	Public perception	Percentage	
		Adequate	Inadequate
1	To what extent are you confident that the current seaweed factory wastewater is of adequate quality for use on your farm?	92.00%	8.00%
2	How would you assess the current cost effectiveness of using such wastewater?	91.11%	8.89%
3	To what extent do you agree that current wastewater quality has a positive impact on your agricultural yields?	95.65%	4.35%
4	Do you believe that current wastewater use contributes to environmental problems?	93.62%	6.38%
5	How often do you experience problems with wastewater quality nowadays?	50.00%	50.00%
6	How do you assess the risks associated with current wastewater use to your crops?	51.11%	48.89%
7	To what extent are you satisfied with the current quality of wastewater?	91.30%	8.70%
8	How would you assess the sustainability of current wastewater use in the long term?	100.00%	0.00%
9	To what extent do you believe that your current use of wastewater has increased your crop yields?	47.73%	52.27%
10	How would you assess the current impact of wastewater on the health of your plants?	54.17%	45.83%
11	To what extent do you feel that wastewater currently has the potential to be improved in its use on farms?	89.58%	10.42%
12	How do you assess the current level of wastewater needed to irrigate your corn crops?	97.78%	2.22%
13	To what extent do you believe that current wastewater treatment methods maximize resource efficiency?	97.78%	2.22%
14	How would you assess the sustainability of current wastewater use in the long term?	97.78%	2.22%
15	What do you think about the efforts made by seaweed factory waste to recycle its waste?	100.00%	0.00%
16	How do you assess the transparency of the company's seaweed waste management?	100.00%	0.00%
Overall Community Perception Assessment		**84.40%**	**15.60%**

DISCUSSION

Based on in-depth interviews with farming communities located around PT Hakiki Donarta, their views on variables related to the use of seaweed wastewater and their implications for the agricultural sector were revealed. Statement **point 1** states that the public's perception of the current quality of seaweed factory wastewater is adequate. As many as 92.00% of the farming community stated that the quality of seaweed factory wastewater is currently adequate, and only 8% answered that it was inadequate. The community believes that the wastewater is of good quality and can be used to irrigate plants. Statement **point 2** states that the public's perception of the cost-effectiveness of using seaweed factory wastewater is adequate. As many as 91.11% of the farming community stated that the cost-effectiveness of using seaweed factory wastewater was adequate, and only 8.89% answered that it was inadequate. The community considers that the costs incurred to obtain wastewater are quite affordable and can save on the cost of clean water.

Statement **point 3** states that the public's perception of the positive impact of the current quality of seaweed factory wastewater on agricultural products is adequate. As many as 95.65% of the farming community stated that the positive impact of the current quality of seaweed factory wastewater on agricultural products was adequate, and only 4.35% answered that it was inadequate. The community believes that wastewater positively impacts agricultural results, such as increasing soil fertility and crop yields. Statement **point 4** states that the public's perception of the contribution of seaweed factory wastewater to environmental problems is inadequate. As many as 93.62% of the farming community stated that the contribution of using seaweed factory wastewater to environmental problems was adequate, and only 6.38% answered that it was inadequate. The community believes using wastewater does not contribute to environmental problems because the company has a good waste processing system. Statement **point 5** states that the public's perception of the current frequency of seaweed factory wastewater quality problems is balanced. As many as 50.00% of the farming community stated that the current frequency of seaweed factory wastewater quality problems is frequent, and 50.00% stated that it is not. The community believes that seaweed factory wastewater quality is relatively stable, and problems do not often occur. Statement **point 6** states that the public's perception of the risks associated with using seaweed factory wastewater on plants is balanced. As many as 51.11% of the farming community stated that the risk associated with using seaweed factory wastewater on crops was low, and 48.89% said it was high. The community believes the risks associated with using wastewater are relatively low because the company has a good waste processing system.

Statement **point 7** states that the public's perception of satisfaction with the current quality of seaweed factory wastewater is adequate. As many as 91.30% of the farming community stated that their satisfaction with the current quality of seaweed factory wastewater was adequate, and only 8.70% answered that it was inadequate. The community believes they are satisfied with the current quality of seaweed factory wastewater because it can irrigate crops and increase crop yields. Statement **point 8** states that the public's perception of the sustainability of the current use of seaweed factory wastewater in the long term is adequate. As many as 100.00% of the farming community stated that the sustainability of the current use of seaweed factory wastewater in the long term is adequate. The community believes that farmers need wastewater flowing around the fields to irrigate crops sustainably. Point **9** states that the use of wastewater for harvesting is not sufficient. The surrounding community rated 52.27% as inadequate; the rest answered as adequate, with a total of 47.73%. The local community believes that wastewater around the plants has little impact and does not interfere with the growth of plants such as corn or rice. **Point 10** explains the impact of wastewater on plant health. The survey proved that 54.17% were adequate, and only 45.83% answered inadequate. According to locals, even though it comes from waste, they can still use the water for plant growth.

Point 11 explains whether current wastewater will have potential use on the farm. As many as 89.58% were adequate, and 10.42% were inadequate. The community believes their area is very far from rivers and often faces dry weather, so wastewater is an alternative. **Point 12** regarding community needs for wastewater flows for corn crops. As many as 97.78% answered adequate, and only 2.22% inadequate. The wastewater flow produced by the company has a positive impact on the surrounding community. This can be seen from the corn plants growing well and harvesting according to the time. **Point 13** explains the extent to which the public believes current wastewater treatment methods are efficient. As many as 97.78% were adequate, and only 2.22% answered inadequate. The community considers that so far, their use of wastewater has not caused problems for plants. **Point 14** is about the long-term sustainability of wastewater. The public rated 97.78% as adequate and only 2.22% answered as inadequate. The community believes that the wastewater that flows around the fields is really needed by farmers to find water.

Point 15 describes PT Hakiki Donarta's efforts to recycle the seaweed waste it produces. The farming community answered that 100% of companies were very concerned about the waste produced. Point 16 assesses PT Hakiki Donarta's transparency in managing seaweed waste. The survey proves that 100% of companies are adequate in terms of transparency in seaweed waste management.

Based on the description above, the public has a good perception of the processing of processed seaweed waste at PT Hakiki Donarta, with an overall perception value of 84.40%. This shows that the choice of PT Hakiki Donarta as a research partner is very appropriate because it has a strong commitment shown by waste management, so that the surrounding community does not feel disturbed by waste processing activities. However, PT Hakiki Donarta feels it is necessary to improve its performance in waste processing based on points 5, 6, 9 and 10 which have a TTB value ≤ 50.00%.

Key Phase 2: PFB System Manufacturing and Assembly Process

This activity is the framework for designing a prototype and producing a PFB. The implementation of a green economy through PFB technology in the seaweed industry is expected to have a significant impact on waste processing. This technology can help reduce the amount of waste produced by industry by minimizing the use of water and chemicals and increasing the efficiency of production processes. Apart from that, this technology can also help improve the processing of liquid and solid waste by reducing the number of pollutants and increasing the biodegradation rate. The correct PFB system assembly process aims to ensure that liquid waste can be processed effectively and efficiently so that it can produce cleaner waste. The PFB System assembly process includes several stages, namely:

1. Material and equipment preparation: prepare the PFB system components such as the plasma generator, nano bubble generator pump and piping so that they are all in good condition.
2. Plasma generator assembly: The plasma generator is the main component in the PFB system, which produces plasma. The assembly includes electrode installation, connecting cables, and electrical controls.
3. Piping system assembly: The piping system consists of pipes and valves that connect the plasma generator to the nano bubble generator.
4. Nanobubble generator assembly includes pump, input pipe, and output pipe installation.
5. Connection between components in the PFB system to connect the entire PFB system. After assembly, the PNB system was tested to ensure all components functioned adequately in the plasma generator, pump, nano nozzle, and electrical controls.

Next, adjustments are made to the PFB system parameters, which include pump speed, air pressure, and electric current for optimal results. Activity 2 gives the following results:

1. PFB generator that can produce PFB with good quality and enough for the process of handling seaweed wastewater,
2. A pump system that can channel liquid waste into the PFB generator and flow the processed water into the DAF input waste tank,
3. A control system that can regulate and monitor the performance of PFB generators, pumps, and tanks to guarantee optimal performance and
4. The documentation and usage manuals are complete and easy to understand, allowing users to use the system effectively and safely.
5. A prototype of the PFB technology was created and applied to workshop activities in Sumedang.
6. A limited production scale for PFB technology has been implemented, so the product is finished and ready for use.
7. PFB products have been distributed to factory locations so that the products can be applied and tested for their performance in seaweed wastewater treatment activities

Implementing Plasma Fine Bubble (PFB) technology in seaweed waste management has demonstrated significant benefits, particularly at PT Hakiki Donarta. Studies reveal that PFB can reduce waste management costs by 2% and chemical costs by 40%, highlighting its economic advantages. Beyond cost reduction, PFB effectively addresses the environmental challenges associated with seaweed processing, such as high chemical oxygen demand (COD) and biological oxygen demand (BOD) levels. By minimizing the use of water and chemical additives while enhancing production efficiency, PFB technology aligns with the principles of the blue economy. This innovative approach ensures sustainable practices, contributing to environmental preservation and economic efficiency. These findings underscore the potential of PFB as a transformative solution for industries seeking to adopt eco-friendly waste management strategies.

CONCLUSSION

The study confirms that Plasma Fine Bubble (PFB) technology is highly effective and sustainable for managing seaweed processing waste. By reducing waste management costs by 2%, reducing chemical costs by 40%, and addressing environmental concerns, PFB represents a significant step forward in advancing the blue economy. To ensure this technology's successful and widespread adoption, collaboration between government agencies, seaweed processing companies, and local communities is essential. Such partnerships can provide the necessary financial and technical support, enabling PFB technology to be implemented effectively and sustainably. Integrating PFB into seaweed waste management systems enhances environmental sustainability and promotes cost-efficient practices, making it a viable solution for long-term industry development.

Additionally, the implementation of the PFB system at PT. Hakiki Donarta provides further insights into its practicality and benefits:

1. PFB is used to increase the effectiveness of DAF, where after going through the PFB process, the dissolved pollutant content will be oxidized to become suspended. This makes the DAF process easier to separate pollutants from the water. This will increase the efficiency of using chemicals, such as flocculants. More than that, activating PFB will impact pond aeration, whereby applying PFB, you can increase dissolved oxygen in water to a very small size, namely in nanometer-sized bubbles. Enough dissolved oxygen will greatly increase the effectiveness of microorganisms in decomposing organic compounds.
2. The current processing of seaweed industry wastewater at PT Hakiki Donarta is based on the process flow, namely the Lamela EBO 020-point, Sulfa Acid and Anionic Flocculant AP 205; at the DAF point using EBO 020 and WPC 2967 ST Cationic Flocculant; and for the Belt Press position using cationic flocculant WPC 2967 ST.
3. The public has a good perception of the processing of processed seaweed waste at PT Hakiki Donarta, with an overall perception value of 84.40%. This shows that the choice of PT Hakiki Donarta as a research partner is very appropriate because it has a strong commitment shown by waste management so that the surrounding community does not feel disturbed by waste processing activities. However, PT Hakiki Donarta feels it is necessary to improve its performance in waste processing based on points 5, 6, 9, and 10, which have a TTB value $\leq$ 50.00%.
4. The PFB System assembly process includes several stages, namely:
   a. Material and equipment preparation: Prepare the PFB system components, such as the plasma generator, nano bubble generator pump, and piping, so they are all in good condition.
   b. Plasma generator assembly: The plasma generator is the main component in the PFB system, producing plasma. Plasma generator assembly includes electrode installation, connecting cables and electrical controls.
   c. Piping system assembly: The piping system consists of pipes and valves that connect the plasma generator to the nano bubble generator.
   d. Nanobubble generator assembly includes installation of pump, input pipe, output pipe.
   e. Connection between components in the PFB system to connect the entire PFB system. After assembly was completed, the PNB system was tested to ensure all components functioned properly in the plasma generator, pump, nano nozzle and electrical controls.

Prospects for Further Research and Implementation

To optimize the large-scale adoption of *Plasma Fine Bubble* (PFB) technology, further research is required to evaluate its long-term efficacy, operational stability, and economic feasibility. Comprehensive assessments should be conducted to analyze the durability of PFB systems, maintenance requirements, and cost-effectiveness over extended operational periods. Additionally, integrating PFB with other advanced wastewater treatment technologies may enhance its efficiency and broaden its applicability beyond the seaweed processing industry.

Interdisciplinary collaborations between academia, industry, and government institutions are crucial in fostering technological innovation and facilitating knowledge transfer. Establishing pilot projects in diverse industrial settings can provide empirical evidence on the scalability and effectiveness of PFB technology, reinforcing its potential as a sustainable wastewater treatment solution. Furthermore, policy support, regulatory frameworks, and financial incentives should be considered to encourage widespread adoption.

By strengthening multi-stakeholder partnerships and advancing scientific research, PFB technology can be further developed to maximize its environmental and economic benefits, positioning it as a critical component in the transition toward sustainable industrial practices.

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