STUDY ON THE EFFECTIVENESS OF MEMBRANE BIOREACTOR IN REDUCING BOD AND COD OF SEAWEED WASTE WATER

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Abstract

The development of natural resource-based industries must consider sustainable waste water management and green economic efficiency. This condition requires a fundamental scientific understanding of the characteristics of the seaweed waste water treatment process as part of efforts to realize an efficient, environmentally friendly industry through the Bioreactor Membrane (MBR) approach, supporting the downstream of the sustainable seaweed industry. This study aims to examine the characteristics of the seaweed industrial waste water treatment process using a laboratory-scale MBR system as the basis for an initial understanding of the mechanism of biological biodegradation and membrane separation. The research method was carried out experimentally using a laboratory-scale MBR unit with a waste water source coming from the seaweed industry. The results of the study showed that MBR could reduce COD by 93.1% (from 3100 mg/l to 214 mg/l) and BOD by 90.8% (from 1050 mg/l to 97 mg/l), thus meeting the established seaweed wastewater quality standards (100 mg/l). The initial pH of 11 changed to 8.7. This study also showed that the longer the aeration time, the greater the reduction in BOD produced and experienced significant changes. This processing efficiency shows that MBR can be an alternative for effective and environmentally friendly seaweed wastewater treatment, supporting the concept of a green economy.

Keywords: *biodegradation; process characteristics; seaweed waste; bioreactor membrane (MBR); Environmentally friendly*

Introduction

Indonesia is one of the world's leading producers of seaweed with a significant contribution to the supply chain of the colloid industry and its derivative products. The increasing global demand for seaweed products is driving the growth of the seaweed processing industry (Akrim, et al., 2024).

Waste water from industrial processes, including seaweed, contains various chemicals and contaminants that have the potential to harm the environment if disposed of without proper treatment. By implementing a physicochemical treatment process, it is hoped that the negative impact of waste water on the surrounding environment can be reduced (Hifdillah, 2023).

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Received: 1 February 2026
Revised: 4 February 2026
Accepted: 16 March 2026
DOI: 10.23969/jcbeem.v10i2.43701

Factually, Indonesia's strategic position as the world's seaweed producer supports the colloidal industry and its derivative products. Increasing global demand is driving the growth of the processing industry which has an impact on increasing the volume of waste water. Waste water from the alkaline treatment stage has a complex and fluctuating content of dissolved and suspended organic matter so that it has the potential to pollute the environment if not managed optimally and sustainably.

The waste water of the seaweed processing industry contains high concentrations of dissolved and suspended organic matter, thus requiring a treatment system that is adaptive to fluctuations in pollutant loads (Lin, et al., 2021). Conventional treatment systems often show limitations in maintaining process stability and effluent quality at variations in organic loads (Iorhemen, Hamza, & Tay, 2021). The approach to minimizing environmental impact through waste management and the use of treatment technology is also in line with research related to pollution reduction based on thermal processes , Heran, & Kim, 2022). (Aslam et al., 2022).

Bioreactor Membrane Technology (MBR) combines biological biodegradation and membrane separation processes so that it is able to produce higher quality effluent than conventional systems (Arif AUA, 2020), (Aji Santoso, 2023). Recent studies show MBR is effectively applied to including the food industry and agroindustry (Martni, Yuliwati, & Kharismadewi, 2020), (Kuncoro & Soedjono, 2022). As the study of sustainable industries based on local resources is the basis for the selection of waste treatment technology approaches (Aladin et al., 2025) (Aladin, Modding, Syarif, Wiyani, & Hijrah, 2022) (Aladin et al., 2025). Proses memproduksi bioadsorben halal secara pirolisis,

Information on changes in effluent quality parameters as well as the initial performance of the biodegradation and separation process is needed as the basis for the development of sustainable waste water treatment technology (Tee, Yong, & Ng, 2021).

Various studies have reported the application of MBR technology in the treatment of industrial waste water with diverse organic load characteristics. The combination of biological biodegradation and membrane separation in the MBR system is able to improve the stability of the process and produce better effluent quality than conventional methods (Lin, et al., 2020), (Wang, et al., 2021).

he performance of MBR on different types of industrial waste shows that the MBR system has a high efficiency of depreciating organic matter, but its performance is strongly influenced by the specific characteristics of the waste and operating conditions (Lin, et al., 2020), (Liu & Fang, 2020). These findings suggest that a process study-based approach is needed before MBR technology is directed to the optimization stage or large-scale deployment.

In food and agroindustrial waste, the complexity of waste composition is a major challenge in the biological processing process, so an in-depth understanding of process characteristics is needed to ensure the stability and effectiveness of treatment (Zhao, Zhang, Li , & Wang, 2021), (Asif & Zhang , 2020). Although MBR has great potential in industrial waste treatment, studies at the laboratory scale are needed as a basis for proof-of-concept before implementation on a pilot or industrial scale (Lin, et al., 2021), (Van Hulle, De Pauw, & Van den Broeck, 2021).

Other studies on high-concentration industrial waste have shown that laboratory-scale MBRs are effectively used to assess the characteristics of the treatment process, but the response of the system is highly dependent on the type and characteristics of the treated waste (Tee, Yong, & Ng , 2021), (Jiang , Myngheer , De Pauw , & Van Hulle, 2022). Other cutting-edge studies emphasize that variations in the characteristics of industrial waste greatly influence the mechanism of biodegradation, fouling formation, as well as the stability of MBR operations (Judd, 2020) (Khan, Wang, & Xagoraraki, 2021).

Some researchers report that the process review approach at an early stage is essential to understand the interactions between biomass, membranes, and organic contaminants before optimizing operating parameters (Zhang, Fan, & Roddick, 2021), (Syarif, Aladin, & Munirah, 2025). Recent research shows that the development of Reactor Bio Membranes (MBRs) for industrial waste treatment with special characteristics still requires a strong process knowledge base at a laboratory scale (Said, et al., 2025).

Therefore, the urgency of this research is the existence of an effective and sustainable wastewater treatment system. One promising approach is the use of membrane bioreactor (MBR) technology. Membrane Bio Reactor (MBR) technology is an innovative wastewater treatment technology that combines biological processes with a membrane filtration system to produce high-quality effluent. The novelty of this research is the integrated Membrane Bio Reactor (MBR) innovation in seaweed wastewater treatment.

Research Methodology

This research method is designed to achieve the research objective, which is to examine the characteristics of the seaweed waste water treatment process using a laboratory-scale Bioreactor Membrane (MBR) system. The method approach is focused on understanding the process of biodegradation and membrane separation. (Aladin, Modding, Syarif, Wiyani, & Hijrah, Pirolisis simultan, 2022) (Nguyen , Chen , & Fane, 2021), (Meng , et al., 2022),

The research material in the form of a sample of seaweed waste water came from the seaweed processing industry of PT Bantimurung Indah, Maros Regency, South Sulawesi. This company was chosen because it is a pioneer of seaweed factories in Eastern Indonesia, which was founded in 1986 or 40 years ago. The seaweed waste water used comes from the flow of the seaweed processing industrial process, especially the waste from the alkaline treatment stage. Initial characterization was carried out to obtain an overview of the initial condition of waste as a basis for the study of the MBR process (Zhao, Zhang , Li , & Wang, 2021), (Sadhukhan , Lloyd , Scott, Eileen, & Muradov , 2021), (Akrim D. , 2014)

The seaweed waste water used comes from the flow of the seaweed processing industrial process, especially the waste from the alkaline treatment stage. Initial characterization was carried out to obtain an overview of the initial condition of waste as a basis for the study of the MBR process and the main tool is a series of seaweed waste water treatment reactors using membranes.

The research was carried out in the period March – August 2026. Wastewater sampling was carried out randomly in the waste storage tank at the PT Bantimurung Indah, Maros Regency, South Sulawesi. The research was conducted in the Research laboratory of the Department of Chemical Engineering, FTI UMI Makassar. Water quality testing is performed in accredited laboratories to guarantee data reliability, following common practice in industrial wastewater quality research (Nguyen , Chen , & Fane, 2021), (Van den Brink, Satpradit, van Bentem, & Zwijne, 2020).

The research procedures and parameters analyzed include pH, Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), and Total Suspended Solids (TSS). These parameters are the main indicators in the evaluation of the load of organic pollutants and suspended solids in industrial waste water and are commonly used in the performance study of biological processes and membranes (Van den Brink, Satpradit, van Bentem, & Zwijne, 2020), (Nguyen , Chen , & Fane, 2021).

Data collection from testing is carried out in 3 stages, namely: pretreatment stage testing, starting from coarse solids filtering and fat/oil separation. After the first phase of pretreatment is operating properly, the influent is tested prior to the process, including BOD, COD, TSS, and pH parameters. This allows for comparison of the characteristics of the influent and effluent of the waste water. In phase II, the tub is equalized with water flow testing and pH stabilization. If the operating unit and process unit in the Bio Reactor Membrane can operate properly, then proceed to phase III, namely testing of physical, chemical and biological characteristics on effluent samples for BOD, COD, TSS and pH parameters (Aladin, Semmaila , Syarif, & Azzahra, 2025), (Zhang , Fan, & Roddick, 2021) (Banti , Kefalas, & Samaras, 2021).

The process performance evaluation approach was carried out by comparing the characteristics of influenza and effluent and observing the tendency of parameter changes during the operating time. This evaluation method is commonly used in the study of MBR process characteristics to understand the effectiveness of biodegradation and membrane separation in the early stages of technology development (Chen , Wen, & Wang, 2021), (Judd , 2020).

The flow diagram of the Bioreactor Membrane (MBR) process which is a novelty from this research as an innovation in seaweed waste water treatment technology is as follows:

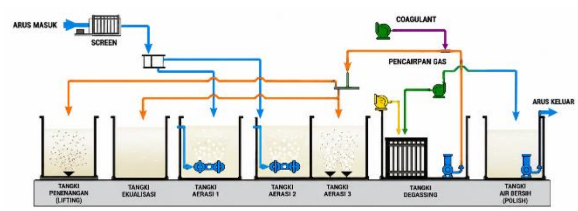

Figure 1. Reactor series tool and MBR process flowsheet

The MBR system used is a laboratory-scale unit that integrates the biological biodegradation process with separation using a submerged membrane. The Laboratory-scale MBR configuration was chosen because it provides good control over operating conditions and allows detailed observation of process characteristics prior to expansion to a larger scale (Meng, et al., 2022) (Metcalf & Eddy, 2021).

The operation of the system was carried out in stable (Judd, 2020) conditions without parameter optimization, in accordance with the character of basic research that focuses on proving the concept and understanding of the mechanism of the biodegradation process and membrane separation (Chen, Wen, & Wang, 2021). The test results data were analyzed descriptively and comparatively by comparing the influenza and effluent conditions of the process results.

Results and Discussion

Existing Condition of PT Bantimurung Indah WWTP

The source of seaweed waste water at PT. Bantimurung Indah comes from the Alkali Treatment process, which uses two process methods in the form of *High Alkali Treatment* and *Low Alkali Treatment*. Both processes use chemicals that match the characteristics of seaweed raw materials from the type of red algae.

Estimated volume of waste water produced by seaweed factories operating in Maros Regency. Using raw water for the rinsing process as much as 90 m3 and for the cooking process as much as 10 m3. As summarized in Table 1.

Table 1. Wastewater Source PT Bantimurung Indah, Maros

No.	Sources of Use	Quantity (m^3)
1.	Seaweed washing alkaline process	90
2.	Alkaline process seaweed cooking	10

The wastewater treatment process will differ based on design and function. Domestic waste treatment plants in settlements are certainly different from waste treatment plants in industrial facilities such as treatment plants. Similarly, PT Bantimurung Indah based on observations in the field, the process of treating seaweed waste water is still conventional.

In calculating of seaweed wastewater in the factory area, it is carried out by referring to water usage standards for various activities as seen in Table 1. Based on the table for seaweed waste activities, it can be estimated that the total amount of seaweed wastewater is 90% of water use or 90 m3/day.

In general, the process of processing seaweed with the alkaline treatment method is illustrated from the following seaweed processing flow chart.

Figure 2. Alkali Processing Flowchart

Based on the flow chart in Figure 2. Waste water from flushing from the alkaline treatment stage can be processed from the physical and chemical processing process to the biological processing process. Various wastewater treatment techniques to set aside pollutants have been tried and developed so far. The wastewater treatment techniques that have been developed are generally divided into three treatment methods, namely physical treatment, chemical treatment, and biological treatment (Arief, 2016).

Furthermore, chemical wastewater treatment at PT Bantimurung Indah, is carried out in various stages to remove particles that are not easily settled (colloids), heavy metals, phosphorus compounds, and toxic organic substances. This is done by applying certain chemicals that are necessary.

Meanwhile, physical wastewater treatment is usually carried out before the further treatment process of wastewater. Large and easily settling suspended materials or floating materials are set aside first. Screening is an efficient and inexpensive way to dispose of large suspended materials (Ariani & Cahyono, 2015).

Furthermore, the combination of the two process approaches is applied starting from the initial stage of filtration (filtering) then pH neutralization is carried out with the addition of Sulfuric Acid (H_2SO_4). Then the aeration process by draining the air to reduce the values of biological oxygen demand (BOD), chemical oxygen demand (COD), solute size (TSS) and suspended solids (TSS) (Fanini FS, 2023).

Effective waste treatment can also prevent pollution of the surrounding environment which can harm human health and local ecosystems. This includes as an effort to conserve and apply the concept of clean technology (green technology) environmentally friendly. As the membrane bioreactor technology is one of the solutions in the future time.

Aeration Time Analysis with Constant Flow Rate

The Flow Rate Analysis) parameters of BOD out to Aeration Time with Constant Flow Rate (Q = 0.16 m3/h) where the observation results indicate BOD influent 1,050 mg/L with an aeration time of 4 hours and BOD load = 0.168 produces BOD effluent of 97 mg/L. The results of observation of BOD out parameters on aeration time with constant water rate are described in Table 7. The following:

Aeration Time Analysis with Constant Flow Rate

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Table 2. BOD out Parameters Against Aeration Time with Constant Flow Rate *)

No	Time	BOD	Flow Rate	BOD load
1	4 hours	1,050	0.16	0.168
2	4 hours	1,050	0.16	0.168
3	4 hours	1,050	0.16	0.168
4	4 hours	1,050	0.16	0.168

*) Flow = 20 LMH
$Q = (20\ L/m^2/h \times 8\ m^2)/1000$
$Q = 0.16\ m^3/h$

Furthermore, with an aeration time of 5 hours and a BOD load of 0.168, it produces a BOD effluent of 88 mg/L. Meanwhile, with a longer aeration time of 8 hours and a BOD load of 0.168, it produces BOD effluent of 59 mg/L and an aeration time of 10 hours and a BOD load of 0.168 produces BOD effluent of 47 mg/L.

Thus, waste water treated using aerobic biological treatment is already below the standard of quality of seaweed waste water that has been set, which is 100mg/l. From table 1 2. It indicates that the longer the aeration time, the resulting reduction in BOD will also be greater and undergo significant changes.

It can also be seen that the four treatments have differences in the ability of each variable to reduce the BOD value. This is due to the development of different microorganisms within each aeration process. This process is shown for the addition of oxygen to the water. The more oxygen comes into contact with water, the more waste water absorbs oxygen, making it very efficient for the reduction or decrease in BOD value (Gintings, 1995).

As can be seen the relationship between the decrease in BOD to aeration time and the constant flow rate seen in Figure 3.

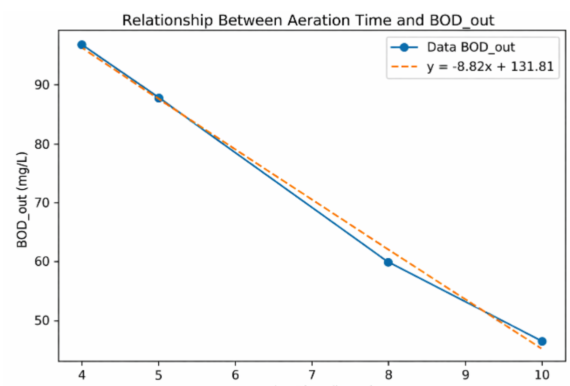

Figure 3. Graph The relationship between BOD decrease and aeration time

The relationship of Aeration Time to BOD_out the linear equation model obtained, i.e.: BOD_out = -8.82 (Aeration Time) + 131.81

Shows a negative the degradation between aeration time and BOD_out concentration in effluents. Quantitatively, a regression coefficient of −8.82 showed that an increase in aeration time by one hour contributed to a decrease in average BOD_out concentration of 8.82 mg/L.

This indicates that the duration of aeration is an operational parameter that has a significant effect on the performance of biodegradable organic load allowance.

In the process, the addition of aeration time increases the availability of dissolved oxygen (DO) in the reactor, thereby supporting the activity of aerobic microorganisms in oxidizing dissolved organic compounds.

With longer contact times, microorganisms have a greater opportunity to utilize organic substrates as a source of energy and cell growth. This condition causes a gradual decrease in the concentration of BOD in the effluent as the aeration time increases.

In addition, the tendency to decrease BOD_out that slopes further with longer aeration times indicates that the system is beginning to approach a state of biological equilibrium. At this stage, most of the biodegradable organic compounds have oxidized.

So that the addition of further aeration time provides a relatively smaller increase in efficiency. This phenomenon is common in aerobic biological treatment systems, where the effectiveness of aeration is influenced by the availability of substrates, the growth rate of microorganisms, and the characteristics of the treated waste.

The same condition in the Flow Rate Analysis of the COD out parameter to the Aeration Time with a Constant Flow Rate (Q = 0.16 m3/h) where the observation results showed that COD influent 3,100 mg/L with an aeration time of 4 hours and COD load = 0.496 produced COD effluent of 214 mg/L. From these results, it can be seen that the aeration time contributes to the results of COD reduction. These results are supported by research from (Sari, 2013) entitled "Comparison of waste and activated sludge on the effect of aeration system on CPO waste treatment". That the longer the aeration time, the greater the COD reduction results.

The results of the observation of the COD out parameter on aeration time with a constant water rate are described in Table 3.

Table 3. COD out Parameters Against Aeration Time with Constant Flow Rate *)

No	**Aeration**	**COD**	**Flow Rate**	**COD load**	**COD out**
1	4 hours	3.100	0,16	0,496	214
2	5 hours	3.100	0,16	0,496	160
3	8 hours	3.100	0,16	0,496	132
4	10 hours	3.100	0,16	0,496	95

*) Flow = 20 LMH
$Q = (20\ L/m^2/h \times 8\ m^2)/1000$
$Q = 0.16\ m^3/h$

Furthermore, with an aeration time of 5 hours and a COD load of 0.496, it produces COD effluent of 160 mg/L. Meanwhile, with a longer aeration time of 8 hours and a COD load of 0.496, it produces COD effluent of 132 mg/L and an aeration time of 10 hours and a BOD load of 0.496 produces COD effluent of 95 mg/L.

Meanwhile, the relationship between COD Decrease in aeration time and fixed (constant) flow rate provides data that correspond to several previous studies. As seen in Figure 4.

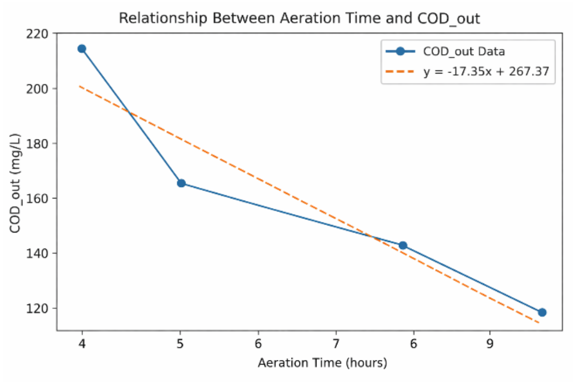

Figure 4. Graph Relationship between COD decrease and aeration time

The relationship between Aeration Time and COD_out is in the form of a linear regression equation for COD_out, namely: COD_out = -17.35 (Aeration Time) + 267.37 It shows that increased aeration time also has a significant effect on decreasing COD_out concentration.

A regression coefficient of −17.35 indicates that each additional aeration time of one hour was able to decrease the concentration of COD_out on average by 17.35 mg/L. This decrease value was greater than that of BOD_out, suggesting that aeration had a strong impact on the decrease in total organic load.

Conceptually, COD represents the total amount of organic compounds, both biodegradable and non-biodegradable. A significant decrease in COD out indicates that the aeration process not only facilitates biological degradation, but also promotes the oxidation process of more complex organic compounds. In addition, increased aeration time can lead to the formation of more stable biomass flocs, so that some organic compounds can be adsorbed and trapped in the biomass, which is ultimately separated from the effluent.

The difference in the rate of decline between COD out and BOD out suggests that some organic compounds measured as COD undergo transformation or removal through mechanisms other than direct biodegradation, such as partial oxidation and binding by active biomass. This confirms that aeration time is a key variable in determining the efficiency of reducing the overall burden of organic pollutants.

Based on the results of the graph, it shows a linear relationship between the increase in aeration time and the decrease in COD out or effluent values is significant.

Furthermore, the discussion was related to the determination of the Effectiveness and Capacity of seaweed waste water treatment with the Bio Reactor Membrane. As described in the discussion of the analysis of the results of the waste water process testing below with the formula as below.

$$\% \text{ Effectiveness} = \frac{(Qa - Qt)}{Qa} \times 100\%$$

Remarks:

Qa = value of BOD_5 / COD first

Qt = value of BOD_5 / COD last

(Sandhika IMGS, 2022)

Table 4. Effectiveness of MBR Treatment on Wastewater

Parameter	Initial Concentration (mg/L)	Final Concentration (mg/L)	Removal Efficiency (%)	Quality Standard Compliance*
BOD	1,050	97	90.8	Compliant
COD	3,100	214	93.1	Compliant

*Based on Ministry of Environment Regulation No. 5 of 2014 (Industrial Waste).

The seaweed wastewater initially showed very high BOD and COD concentrations, indicating a high organic load. This condition is mainly caused by the rinsing process after alkaline treatment, which still contains significant organic matter from the seaweed thallus.

After treatment using Bio Reactor Membrane (MBR) technology in the clarifier process, both parameters decreased substantially. BOD was reduced by 90.8%, while COD decreased by 93.1%, demonstrating the high effectiveness of the MBR system in removing organic pollutants.

The final BOD and COD concentrations were below the permitted environmental quality standards, confirming that the treated wastewater is suitable for discharge according to existing regulations. Overall, the results indicate that the MBR system is effective and reliable for treating seaweed waste water with high organic content.

Conclusions

The effectiveness of reducing waste levels is confirmed by significant data. As for the initial COD parameter of 3100 mg/l with the final COD result of 214 mg/l so that the effectiveness of the reduction is 93.1%;

The initial BOD parameter was 1050 mg/l with a final BOD result of 97 mg/l so that the effectiveness of the reduction was 90.8%; The initial pH parameter of 11 changed to 8.7 so that the waste from MBR treatment met the environmental quality standards of the Ministry of Environment Regulation No. 5 of 2014 concerning the Wastewater Quality Book.

As a recommendation to the next researcher, they should consider testing microbiological parameters and several other organic parameters with *the membrane bio reactor* (MBR) process so that the results obtained will be more optimal and comprehensive.

Acknowledgment

We would like to express our infinite gratitude to all parties involved in this research activity. Especially to LPPM Universitas Muslim Indonesia and DRTPM Kemidiktisaintek who have been sponsors in the implementation of the research. Appreciation was conveyed to the Postgraduate Director of the Indonesian Muslim University and his staff, the Director of PT Bantimurung Indah, in Maros. The Head of the Master of Chemical Engineering Study Program with the Secretary of the Master of Chemical Engineering Study Program and all lecturers in the Master of Chemical Engineering Study Program.

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