Application of a membrane photobioreactor combined with microalgae for shrimp culture wastewater treatment

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Abstract. Shrimp farming has emerged as a multi-billion-dollar industry in our country, creating numerous economic benefits. However, this sector has several negative environmental impacts. Recent studies on the utilization of microalgae for wastewater treatment are of current interest due to their environmental remediation ability, as well as their potential to generate economic value from the biomass produced after treatment. This study aimed to evaluate the wastewater treatment efficiency of *Chlorella Vulgaris* using a PMBR membrane photobiological model in shrimp aquaculture. The evaluation process included an acclimatization phase and a treatment effectiveness evaluation phase, which lasted a total of 101 days. Algae biomass, the removal efficiency of COD, $N\text{-}NO_2^-$, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, and $P\text{-}PO_4^{3-}$, and membrane fouling behavior were analyzed. The initial results demonstrated that the algae were well-adapted to shrimp aquaculture wastewater. The removal efficiency of $N\text{-}NO_2^-$, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, and $P\text{-}PO_4^{3-}$ and COD was 88.55%, 76.15%, 84.58%, 78.07%, and 81.33%, respectively. The algae biomass steadily increased from 91.3 mg/L to 327.69 mg/L, reaching an average level of about 208 mg/L. Additionally, the transmembrane pressure (TMP) evaluation indicated that the necessary time for membrane fouling removal was approximately 25-26 days.

1 Introduction

In recent years, Vietnam has emerged as a significant global seafood exporter, with remarkable developments in shrimp farming technology and processes [1]. According to the Vietnam Association of Seafood Exporters and Producers, shrimp exports reached

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nearly \$3.8 billion by the end of October 2022, representing a 19% increase compared to the same period in 2021. This has elevated the quality and reputation of Vietnamese shrimp in the international market and brought about high economic value to the country's total export turnover. Nevertheless, shrimp farming is confronted with environmental challenges, primarily related to wastewater treatment and increasing pathogens [2]. Numerous studies on shrimp farming wastewater have demonstrated that the characteristics of shrimp culture wastewater were organic pollution and nutrient content from nitrogen and phosphorus. The parameters recorded were COD ranging from 65 to 180 mg/l, BOD_5 of about 20 - 60 mg/l, total nitrogen of about 5 - 20 mg/l, $P-PO_4^{3-}$ about 0.1 – 10 mg/l, $N-NH_4^+$ about 1 – 10 mg/l, $N-NO_2^-$ about 0.1 – 5 and $N-NO_3^-$ about 0.4 – 3 mg/l [3-12].

In the cultivation process, untreated or unsatisfactory wastewater is often discharged into the natural environment by farmers [13]. Shrimp feed typically contains 30-40% crude protein, of which only 20-25% is used by the shrimp, with the remaining settling in the pond bottom as organic waste [14]. Studies indicate that up to 50 g of $N-NH_4+$ is produced for every kilogram of shrimp feed ingested [15]. Shrimp droppings and dead organisms also release ammonia, nitrite, and hydrogen sulfide into the pond water, thereby rendering it unsuitable for discharge into the environment [15]. The accumulation of excess nutrients in the aquarium creates an environment for pathogenic microorganisms, leading to the use of many antibiotics in the long run [16, 17]. In Vietnam, antibiotics in surface water (both surface and bottom) were detected in high concentrations of up to milligrams per liter [18, 19]. Therefore, treating excess nutrients in farming wastewater before discharge to the natural environment is an urgent issue to meet export standards, reduce the use of antibiotics, and alleviate the burden of environmental pollution.

The discharge of polluted water from aquaculture negatively affects the quality of surface water, resulting in diseases and health hazards to people residing in the surrounding areas. Statistics show that annually, more than one billion people suffer from water quality issues, leading to over 10 million child deaths globally [20]. Several wastewater treatment methods have been proposed and improved, including coagulation, advanced oxidation, membrane filtration, plant catalytic decomposition, and biological methods [21, 22]. These techniques have been proven effective in removing various contaminants, including conventional and some special ingredients but not antibiotics. However, their implementation cost is prohibitively high, making them unsuitable for application and investment in rural settings [15]. Therefore, ongoing research and development of new technologies that can efficiently treat pollutants at a reasonable cost while being practical in rural environments and utilizing extra-economic resources is a pressing concern.

In the present era of green technology development, the utilization of microalgae in wastewater treatment has garnered increasing attention due to its excellent advantages. These advantages include low investment and operating costs, high pollutant treatment efficiency, and recovery of algal biomass [23]. Microalgae, in particular, exhibit great potential for wastewater treatment with a fast growth rate, high biomass yield, and adaptability to shrimp culture wastewater [24]. Ahmad's research findings indicate that *Chlorella Vulgaris* can effectively treat wastewater and generate biomass to meet livestock feed demands [25]. Moreover, its salt tolerance provides an advantage for application in treating saline wastewater, such as aquaculture wastewater [26]. Lau et al. demonstrated the ability to remove 86% of $N-NO_3^-$ and 78% of $P-PO_4^{3-}$, while Gonzales et al. reported that *C. Vulgaris* could absorb 55% of the total phosphorus concentration (111 ppm) from agro-industrial wastewater in 216 hours [27]. Furthermore, *Chlorella Vulgaris* has a good symbiotic relationship with microorganisms in wastewater, resulting in higher treatment efficiency. Xijan Yi et al. showed that the combination of *Chlorella Vulgaris* - *Bacillus licheniformis* resulted in total nitrogen, ammonium, phosphorus orthophosphate removal

efficiency, and chemical oxygen demand of 88.82%, 84.98%, 84.87%, and 82.25%, respectively. Overall, numerous studies have demonstrated the wastewater treatment capability of *Chlorella Vulgaris* in shrimp aquaculture.

Utilizing microalgae to treat wastewater in a membrane photobioreactor is a promising approach for effective removal of contaminants and generation of valuable microalgae biomass. A conventional membrane photobioreactor (PMBR) comprises a photobioreactor (PBR) and a membrane filtration system, and is engineered and operated to optimize light penetration and facilitate dense algal growth. This can be attributed to the ease of accessibility of inorganic carbon sources by the algae under low hydrodynamic pressure, while reducing the cost of water treatment via sedimentation-filtration. Nitrogen and phosphorus removal in PMBR is primarily driven by various metabolic processes [28, 29], which are influenced by multiple factors such as wastewater characteristics, HRT retention time, BRT biomass retention time, and biomass concentration. Furthermore, environmental factors such as temperature, available CO_2, and light intensity are also crucial in these processes [30, 31]. According to Honda et al., a submerged membrane filtration process was successfully integrated into a membrane photobioreactor system using synthetic wastewater as a nutrient source [32]. In addition to nutrient removal, the bioreactor retains microalgae cells and the passing medium in a porous form, thereby preventing washout and improving biomass concentration [28].

Growing microalgae using wastewater in a membrane photobioreactor is a novel, highly viable strategy for removing contaminants from wastewater while generating useful microalgae biomass. A typical membrane photobioreactor (PMBR) system combines a photobioreactor (PBR) and membrane filtration. PMBR is designed and operated to enhance light access and facilitate algae growth at higher densities. This can be explained because the inorganic carbon source is easy to access by algae under low hydrodynamic pressure. At the same time, it reduces the cost of water treatment through the sedimentation-filtration system. During the treatment of PMBR, the removal of nitrogen- and phosphorus is mainly achieved through various metabolic processes. These processes are affected by many factors, including wastewater characteristics and operational factors such as hydraulic retention time (HRT), biomass retention time (BRT), and biomass concentration. Besides, environmental factors such as temperature, available CO_2, and light intensity also play an important role. According to the research of Honda et al., they have successfully combined the submerged membrane filtration process in a membrane photobioreactor system using synthetic wastewater as a nutrient source [32]. In addition to removing nutrients in the PMBR, the bioreactor can completely retain the microalgae cells and the passing medium in a porous form. Since then, this system could prevent washout and improve the biomass concentration in the bioreactor.

Therefore, in order to leverage the benefits and assess the applicability of *Chlorella Vulgaris* in treating shrimp aquaculture wastewater, this study was conducted using a membrane photobioreactor (PMBR). The findings provide valuable insights into the adaptability of microalgae in treating shrimp culture wastewater, which could ultimately help to alleviate the environmental burden caused by the industry, reduce the reliance on antibiotics in shrimp farming, and improve the overall quality of aquaculture in Vietnam. The resulting dataset can serve as a foundation for the development of effective wastewater treatment systems and inform the decision-making of environmental managers in rural areas seeking to implement sustainable environmental protection solutions.

2 Materials and research methods

2.1 Research Materials

The source of shrimp culture wastewater is synthetic wastewater. The components are built to simulate the composition of shrimp culture water with COD of about 150 - 170 mg/l, total nitrogen (calculated by the amount of $N-NH_4^+$) of about 30 mg/L, and $P-PO_4^{3-}$ about 10 mg/L. The ingredients include: CH_3COONa 4.54 g/l, $C_6H_{12}O_6$ 3.2 g/l, NH_4Cl 0.267 g/l, KH_2PO_4 0.24 g/l, $FeSO_4.7H2O$ 0.075 g/l, $MgSO_4.7H_2O$ 0.036 g/l, $CaCl_2.2H_2O$ 0.075 g /l. There are also some trace elements added at a dosage of 1ml/l of synthetic wastewater, and trace solution composition includes H_3BO_3 11.4 g/l, $MnCl_2.4H_2O$ 5.06 g/l, $ZnSO_4.7H_2O$ 22 g/l, $CuSO_4.5H_2O$ 1.57 g/l, $CoCl_2.6H_2O$ 1.61 g/l, $(NH_4)6Mo_7O_{24}.4H_2O$ 1.1 g/l, Na_2EDTA 50 g/l, and $CaCl_2.2H_2O$ 0.05 g/l. The chemicals used were purchased from Himedia (India) and Xilong (China). The nutrient compositions of the synthesized wastewater are described in Table 1.

Table 1. Properties of synthetic wastewater composition simulated shrimp farming wastewater

| Num	The parameters	Unit	Concentration
1	pH		7 ± 0.49
2	TDS	ppm	3553 ± 531
4	COD	mg/L	178.22 ± 22.64
5	TN	mg/L	10.44 ± 0.70
6	$N - NH_4^+$	mg/L	2.72 ± 0.2
7	$N - NO_2^-$	mg/L	0.30 ± 0.06
8	$N - NO_3^-$	mg/L	0.47 ± 0.04
9	$P - PO_4^{3-}$	mg/L	1.96 ± 0.12

Microalgae *Chlorella Vulgaris* was obtained and cultured from the Laboratory of Environmental Engineering - Institute of Applied Technology and Sustainable Development - Nguyen Tat Thanh University. Algae were biomass grown in the laboratory to a 10^6 cells/ml concentration before the wastewater treatment application.

2.2 Membrane photobioreactor system

The membrane photobioreactor model is depicted in Figure 1. The model system has a 70L main tank reactor and has operating parameters, as shown in Table 2.

Table 2. Operating parameters of the PMBR system

Operating parameters	Unit	Value
Adaptation time	Days	30
Membrane aspiration/rest time	mins/mins	8:2
Daily membrane flux (Q)	L/day	20
Tank volume (V)	L	70
Organic loading rate (OLR)	$kgCOD/m^3.day$	0.051
Hydraulic retention time (HRT)	hour	84
Algae biomass retention time (BRT)	days	14
Amount of biomass discharged daily	L/day	5
Light: dark mode	Hour: Hour	12: 12
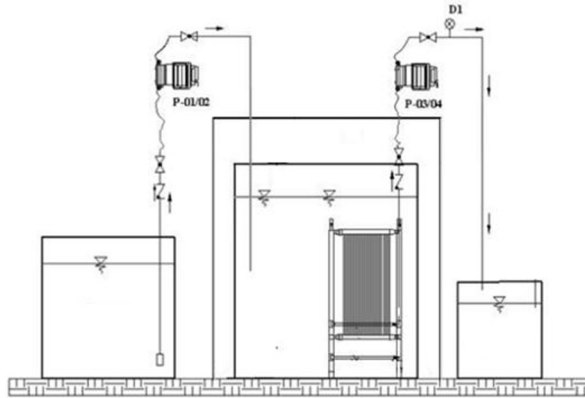
Figure. 1. Membrane photobioreactor PMBR model

The membrane module used in this study is a microfiltration (MF) membrane from Motimo. Membrane module parameters are shown in Table 3.

Table 3. Membrane parameters.

Membrane parameters	Unit	Value
Membrane type	-	Hollow yarn
Material	-	PVDF
Design Throughput (Flux)	L/(m^2.h)	10-18
Inner - Outer Diameter	mm	0.6 – 1.1
Pore size	μm	0.2
Membrane area	m^2	0.11
Operating temperature	$^\circ$C	5-45
Membrane fiber length	cm	40
Number of yarns	yarns	75

2.3 The method of adaptation of algae evaluation in the model to shrimp culture wastewater.

To evaluate the stability of algae in the membrane photobioreactor model and record the treatment efficiency of the model with shrimp culture wastewater, a process was conducted. The steps to adapt algae in the membrane photobioreactor tank were as follows: (1) Pumping of wastewater to the system until it flows through the microalgae treatment system, filling the tank to about one-third or two-thirds of its capacity. Clean water was then supplied to dilute the concentration until the tank was almost full; (2) Addition of algae in an amount equivalent to about 20-30% of the tank volume; (3) Activation of the stirrer to supply air and agitate the algae in the membrane photobioreactor tank; (4) Evaluation of environmental parameters, including pH, DO, TDS, temperature, and biomass growth through optical density (OD) measurement with a wavelength of 680 nm.

2.4 Evaluation of the efficiency of shrimp farming wastewater treatment by PMBR system.

Samples are taken at the inlet, bioreactor, and outlet tank locations. Pollution parameters were analyzed according to standard methods. Measured parameters include pH, DO, alkalinity (SMEWW 2320 B), COD (SMEWW 5220 C:2012), total nitrogen (SMEWW 4500 – N B&C), $N-NH_4^+$ (SMEWW 4500 NH_3 B&C), $N-NO_3^-$ (SMEWW 4500-NO_3 E:2012), $N-NO_2^-$ (SMEWW 4500-NO_2 B:2012), $P-PO_4^{3-}$ (SMEWW 4500-P B&E:2012), MLSS SMEWW (2540 D:2012), MLVSS (SMEWW 2540 D:2012). Indicators were assessed at a frequency of every three days.

The assessment of biomass was determined based on the study of Nguyen et al. [33]. Microalgae biomass is measured through the content of chlorophyll extracted from microalgae cells. Such concentrations are then converted to dry weight via a calibration curve with the equation $y = 4216.4 \times - 302.43$. The content of chlorophyll (chlorophyll-a) was extracted with an acetone solution [34].

The collected data will be statistically, and preliminary graphed in Excel 2019. The difference evaluation and difference analysis are performed using SPSS 20.

3 Results and discussion

3.1 The adaptability of algae in synthetic wastewater conditions simulating shrimp culture water

Dissolved oxygen (DO) is a crucial factor that reflects the growth of microalgae biomass [35]. During phototrophic growth, microalgae consume dissolved carbon dioxide (CO_2) and produce oxygen (O_2), leading to the accumulation of high oxygen concentrations in a closed photobioreactor (PBR). However, excessive dissolved oxygen concentrations can negatively impact biomass yield by inhibiting cell microalgae growth. The symbiotic combination of microalgae and bacteria in the PMBR model maintains a stable balance of dissolved oxygen concentration, as the microorganisms perform the respiration process that consumes DO and produces carbon dioxide. Consequently, dissolved oxygen concentration is considered vital for bacterial respiration and chemical oxygen demand (COD) removal. Under different conditions, dissolved oxygen concentrations tend to increase, indicating good photosynthetic activity followed by oxidation and nitrification of heterotrophic carbon. Figure 2A shows the variability of DO concentration in the PMBR system due to the activity of microalgae and bacteria. The concentration of DO is maintained within a reasonable range, from 5.5 to over 7.5, which is suitable for the growth medium of microorganisms and the environmental treatment process.

The measurement of Optical Density (OD) provides an estimation of the algal-bacterial biomass in membrane photobioreactors. The results depicted in Figure 2B demonstrate that during the initial thirty days, the algae underwent an adaptation phase, leading to substantial growth in biomass from OD 0.2 to 0.8 Abs. The conclusion of the acclimation process evidenced that Chlorella algae can tolerate the salinity of shrimp culture wastewater and grow the most significant biomass. Subsequently, the algal biomass began adapting well to the optimal growing environment, and by day 42, the algae exhibited robust growth, reaching a high density of over 1.0 Abs. These findings indicate that the algae have stabilized and adapted to the salinity environment, and the OD level remained stable from 1.0 to 1.21 Abs, corresponding to a dry algae biomass of about 301.3 - 369.1 mg/l. Almutairi et al. also reported that *Chlorella Vugaris* adapts well to mild saline

water and can thrive, implying that the slight salinity of shrimp culture wastewater, around 3 - 5 ppt, positively impacts algae growth [36].
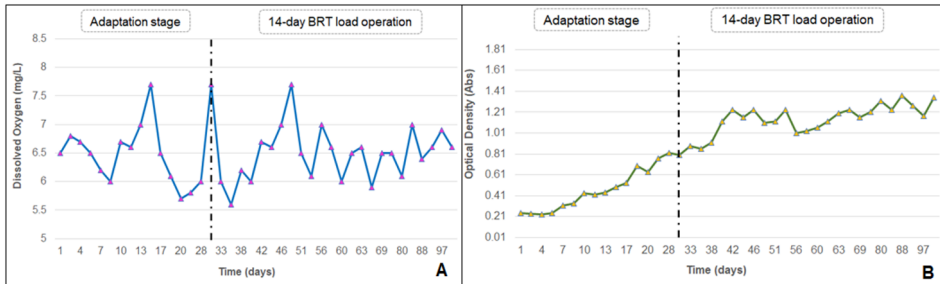
Figure 2. The volatility of dissolved oxygen parameters and biomass estimation in the PMBR system.

3.2 The removal and metabolism of nutrients of the PMBR system.

During the growth process, photosynthetic algae absorb CO_2 to produce O_2 along with aeration and increase the amount of dissolved oxygen in the water, creating favorable conditions for aerobic bacteria to grow and promote reactions that lead to oxidation-reduction of organic matter at a faster rate. This process leads to a simultaneous reduction in the amount of COD present in the wastewater. As shown in Figure 3A, during the treatment period from day 30 to day 100, the COD concentration of all samples decreased significantly, with output samples showing a decrease from 227.56 mg/l to 47.41 mg/l. This can be attributed to the vigorous growth of algae (entering the log phase) and the photosynthesis process producing a large amount of O_2, which promotes the decomposition of organic matter. The highest COD processing efficiency is about 81.33% of the input value. Comparison with the national technical regulation on brackish water shrimp farming facilities, QCVN 02-19:2014/BNNPTNT, shows that the COD concentration of the output samples meets the allowable standard of ≤150 (mg/L).
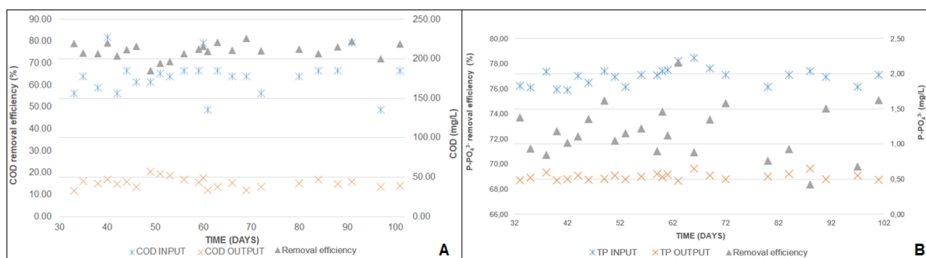

Figure 3. Effective removal of organic matter (A) and phosphorus (B) in synthetic shrimp culture wastewater of PMBR model.

Phosphorus compounds in aquatic environments exist in various forms, such as organophosphorus, monophosphate (H_2PO_4, HPO^{2-}, PO_4^{3-}) soluble in water, polyphosphate, phosphate salts, and phosphorus within biomass cells. Consequently, during wastewater treatment processes, algae primarily absorb phosphorus in the form of phosphate (PO_4^{3-}). Commonly, phosphate forms in wastewater are insoluble precipitates, which are absorbed and accumulated intracellularly by polyphosphate bacteria such as *Acinetobacter*, *Pseudomonas, Aerobacter*, and *Moraxella*. These bacterial species can accumulate phosphate in quantities exceeding their cellular needs by 1 to 3% of their dry mass [37]. Algae utilize CO_2 as a carbon source and inorganic nitrogen and phosphorus sources to

build cells under the influence of sunlight energy while releasing O_2. This principle forms the basis for using phosphorus in algae for wastewater treatment applications.

The results from Figure 3B demonstrate that algae thrive in shrimp culture wastewater and effectively absorb a significant amount of nutrients, resulting in rapid phosphorus content reduction from 2.18 mg/L to 0.48 mg/L. Overall, the total phosphorus removal efficiency of the PMBR system reached 78.07%. This wastewater's phosphorus utilization and removal efficiency are roughly consistent with similar studies. A study by Tran Chan Bac employed pond wastewater to cultivate *Chlorella* algae and reported the highest phosphorus absorption efficiency of 88.66%. Algae growth in catfish pond wastewater was optimal during the first 3 to 5 days, with the best nutrient absorption [38]. Liandong Zhu et al.'s study also demonstrated that *Chlorella* algae effectively treated livestock wastewater, achieving a 75% phosphorus removal rate [39]. Similarly, Wang et al. showed that the dephosphorylation efficiency decreased by approximately 70-79% [40].

Algae utilize nitrogen and soluble phosphorus in wastewater to increase density and biomass. They absorb $N-NH_4^+$ and $N-NO_3$ from nitrogen to synthesize biomass and generate energy [41]. The $N-NH_4^+$ removal results revealed that the highest treatment efficiency sample decreased from 3.23 mg/L to 0.50 mg/L, with an average efficiency of 84.58%. Figure 4A demonstrates that the ammonium nitrogen removal in membrane photobioreactors is relatively high, which is consistent with the findings of Feng Gaoa et al. [42]. This indicates that the PMBR system can effectively remove most nutrients and nearly all combined ammonia from aquaculture wastewater, with short retention times that are significantly lower than those used in other treatment models.
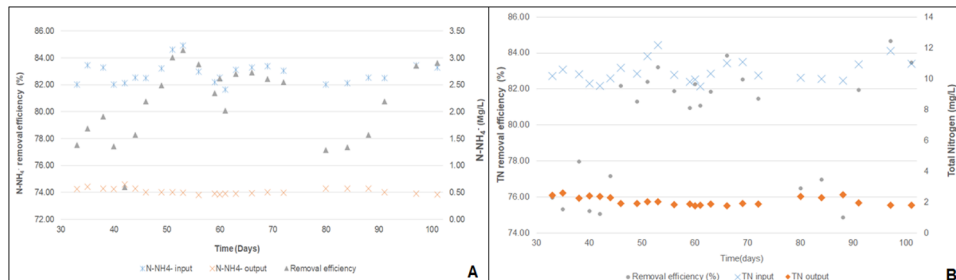

Figure 4. Effective removal of ammonia nitrogen (A) and total nitrogen (B) in synthetic shrimp culture wastewater of PMBR model.

Microalgae can generally assimilate nitrogen from various sources, including ammonium, nitrate, nitrite, and urea [40, 43], although ammonium is the preferred nitrogen source. Ammonia is the most energy-efficient nitrogen source, as algae require less energy to absorb it compared to other species. Overall, the total nitrogen removal efficiency depicted in Figure 4B ranges from 74.8% to 84.6%, with the total nitrogen content of the inlet flux between 9.49 and 12.17 mg/L. Research by Ruiz-Marin et al. [44] reported that microalgae *C. vulgaris* preferred ammonium over other forms of nitrogen in wastewater. Under autotrophic and heterotrophic conditions, ammonium is transported across the membrane by a group of proteins belonging to the ammonium transporter family. Additionally, a group of evolutionarily-related proteins is commonly found in bacteria, yeast, algae, and higher plants [45]. At a temperature of about 25°C, the order of preference for the consumption of nitrogen sources, such as ammonium $N-NH_4^+$ and then $N-NO_2^-$, is converted into new algal biomass.

C. vulgaris exhibits good performance in terms of biomass yield and growth rate. It has been evaluated in PMBR for continuous biomass production and nutrient removal from aquaculture wastewater. The incorporation of the submerged membrane module, in

particular, allows the bioreactor to operate with a constant supply and prevents the washing away of microalgae cells. Consequently, the model can achieve high-density concentrated microalgae culture in PMBR [46, 47]. In this study, as shown in Figure 5, the biomass concentration of *Chlorella vulgaris* in the membrane bioreactor continued to increase during the culture period. The total biomass grew steadily from low to high, with the lowest value at 0.13 g/L and the highest at 0.596 g/L.
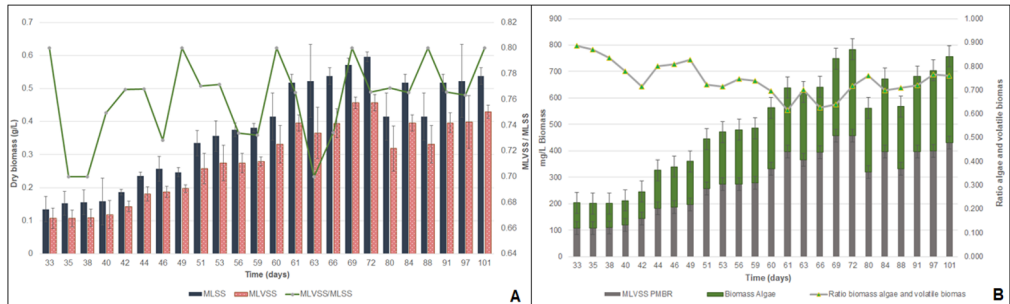

Figure 5. The ratio between MLVSS - MLSS and the ratio between algal biomass - MLVSS during model operation.

In the shrimp culture wastewater examined in this study, the algae Chlorella vulgaris adapted well and exhibited a reasonable level of biomass conversion. Algae biomass was calculated based on the amount of chlorophyll, following the methodology of Nguyen et al. [33]. Throughout the 14-day BRT period, the algae and bacterial biomass developed appropriate densities in the bioreactor tank. Biomass concentrations increased from 107 mg/L to a peak of 456 mg/L on the 72nd day of the study. From the 44th day onwards (approximately 11 days after acclimatization), microalgae biomass began to stabilize, maintaining an average of over 300 mg/L. The lowest and highest microalgae biomass values were observed on days 38 and 72, at 91.3 and 327.7 mg/L, respectively. The ratio between microalgae and bacterial biomass remained generally stable at around 0.74, with the highest ratio of approximately 0.88 reached in the early days following acclimatization (33-38). This can be attributed to the predominance of microalgae biomass in the model initially. Through photosynthesis and an adequate supply of dissolved oxygen gas, a favorable environment for aerobic microorganism growth was established. The increase in bacterial biomass created a balance between microalgae and bacterial biomass, fostering a balanced symbiosis that resulted in a co-culture of bacteria and microalgae playing a crucial role in the removal of pollutants from shrimp wastewater [48].

3.3 The process of membrane fouling.

The variation in transmembrane pressure (TMP) during the operation of the PMBR system is characterized by a gradual change in adaptive operating time from day 1 to day 19. The membrane transfer pressure increases progressively due to the formation and accumulation of fouling layers, averaging 1 kPa per day as a result of flow-adjusted permeation (flowmeter). The membrane fouling rate escalates over time, primarily due to the algae layer and suspensions adhering to the membrane surface. As the operation continues, the membrane surface experiences increasing pump pressure, and the amount of algae attaching to the membrane surface grows. This ongoing process results in overlapping layers that cause the membrane pores to become increasingly blocked.
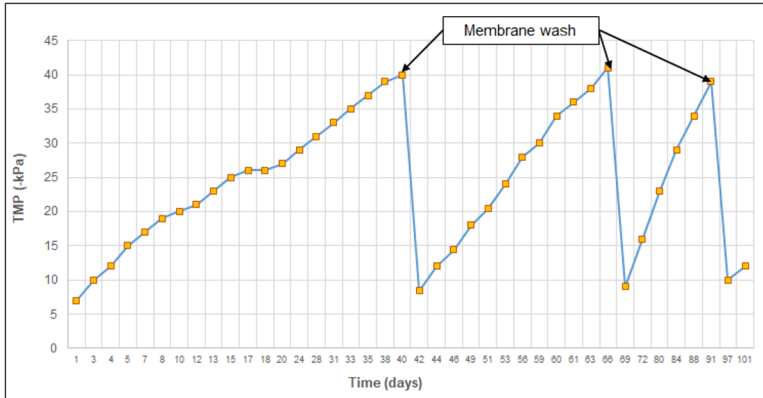
Figure 6. The process of changing transmemberane pressure (TMP) during the entire acclimatization and treatment operation.

During the treatment period on day 40, the membrane fouling rate reached nearly 40 kPa. According to the manufacturer's recommendation, the TMP index should be maintained between 40 and 60 kPa. Figure 6 shows that on days 39-40, the membrane required cleaning. The membrane was flushed with water to remove the layer of plaque on the surface for the first time. However, the membrane failed to return to its initial state, with the post-washing TMP measuring approximately 8 kPa. Membrane fouling continued to increase during operation, with the fouling rate accelerating and necessitating subsequent membrane cleanings on day 66 (26 days later) and day 91 (25 days later). Consequently, it can be inferred that the membrane fouling rate may increase and become more rapid in later stages. The TMP trend will gradually rise with operating time, and each membrane cleaning will reduce a portion of the membrane's lifespan. This result aligns with the findings of Yin et al., who reported that after 28 days of operation, the TMP of Control-MBR reached 25 kPa with a membrane fouling rate of 0.89 kPa/day [49], and subsequent cleaning intervals were shorter than the initial cycle.

4. Conclusion

This study has demonstrated that *Chlorella vulgaris* is well-suited for use in a membrane photobioreactor system under natural light and with nutrient sources derived from synthetic wastewater that simulates shrimp farming wastewater. The algae effectively adapted to the salinity of shrimp farming wastewater, exhibiting rapid and substantial biomass growth. All pollution indicators were efficiently metabolized, with daily algal biomass increasing from 91.3 mg/L to 327.69 mg/L. After over 100 days of operation, membrane fouling exhibited an initial fouling rate of approximately 40 days for the first batch of new membranes, with an accelerated fouling rate thereafter. While additional research is necessary, the potential environmental benefits and prospects for recovering algal biomass are promising.

Acknowledgments

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