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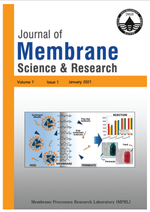

Research Paper

Membrane Filtration Pretreatment and Phytoremediation of Fish Farm Wastewater

Daniel Nesan, Navin Kumar Rajantrakumar, Derek Juinn Chieh Chan*

School of Chemical Engineering, Universiti Sains Malaysia, 14300 Nibong Tebal, Penang, Malaysia

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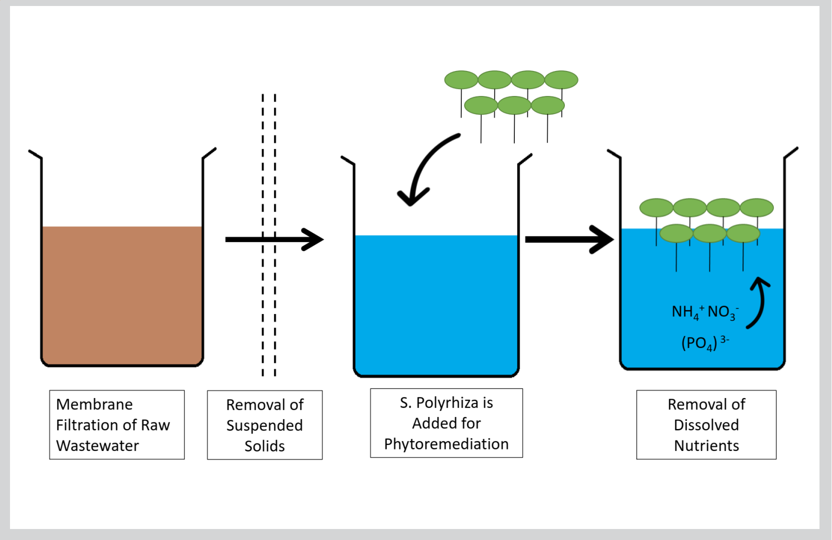
Highlights

- Membrane filtration can reduce fish farm wastewater turbidity by up to 90%
- The dissolved nutrients were not significantly affected by membrane filtration
- Membrane pretreatment reduces the amount of time required for phytoremediation
- Pretreated wastewater exhibited lower nitrate content throughout the experiment

Graphical abstract



Abstract

Phytoremediation is an effective and environmentally friendly method for the treatment and recycling of the wastewater generated by the aquaculture industry. This study investigated the phytoremediation performance of Spirodela polyrhiza on fish farm wastewater following filtration by three different microfiltration membranes. The overall goals of this study were to determine the effects of physical membrane filtration pre-treatment on the subsequent phytoremediation process. The nutrient uptake by S. polyrhiza and water quality after phytoremediation were monitored under a controlled environment for a duration of 14 days. The results showed that the smallest membrane pore size (0.2 µm) was the most effective in removal of suspended solids. However, it was also the fastest to foul. Therefore, a 20 µm pore membrane was chosen that had 3.1 times the filtration capacity by volume of the 0.2 µm membrane before fouling. The subsequent phytoremediation study showed that filtered wastewater has a significantly lower initial reading of water quality with 33%, 53%, 36% and 30% reduction of chemical oxygen demand (COD), turbidity, mixed liquor suspended solids (MLSS), as well as mixed liquor volatile suspended solids (MLVSS), respectively. The final reading for the nitrate, phosphate and ammonia level were 9.4 mg/L, 0.27 mg/L and 1.4 mg/L, respectively. This study indicates that combining phytoremediation with membrane filtration improves the overall performance of the remediation process when treating fish farm wastewater.

1. Introduction

The aquaculture industry generates huge amounts of nutrient rich wastewaters on a daily basis [1]. The main contaminants present in this wastewater effluent are suspended solids, ammoniacal nitrogen, nitrates and phosphorus, and removal of these wastes are primary goals of aquaculture wastewater management, to reduce the impact on receiving waters and to potentially recycle the treated water. An earlier assessment showed how the production of 1 ton of live channel catfish results in the release of up to 1190 kg of dry matter, 60 kg of nitrogen and 12 kg of phosphorus to the water as metabolic wastes [2]. If discharged without treatment, this large amount of nitrogen and phosphorus can act as a stimulant, enhancing the growth of aquatic algae leading to eutrophication in the receiving waters. It has also been documented that only 20 to 50% of the total nitrogen supplemented to the farmed marine organisms was retained as biomass while the rest was eventually discharged together with the effluents into receiving ecosystems [3]. This resulted in various adverse impacts such as occurrence of red tides and algal blooms [4], dispersal of pollutants by aquatic cultures, burying and death of benthic organisms and also undesirable odours as well as an increased presence of pathogens in the discharge sites [5].

Conventional fish farm wastewater treatment commonly uses a combination of physical, chemical, and biological processes with operations

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* Corresponding author: chderekchan@usm.my (D.J.C. Chan)

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designed to remove solids, organic matter and nutrients from wastewater [6]. In fish farm wastewater treatment, preliminary steps are required for the removal of large particulates, usually done by running the wastewater through filters or coarse screens. The objective of this preliminary treatment is the removal of settleable organic and inorganic solids by size exclusion [7], while floating materials are removed by either skimming or sedimentation. This is then followed by secondary treatment, which involves the removal of any dissolved or colloidal organic matter that can be biodegraded through natural and biological processes such as submerged biofilters, trickling filters and activated sludge processes. Secondary treatment facilitates oxidation, nitrification and denitrification of organic matter [8]. Tertiary treatment of wastewater is required only when specific wastewater constituents still exceed the allowable limits after the completion of secondary treatment processes. Tertiary treatment processes include chemical treatment, such as dosing with metal salts to remove phosphorus [9]. However, these conventional methods pose several drawbacks, as they are costly in terms of the initial capital investment, high electrical energy requirements and the need for constant maintenance by skilled workers. The sludge waste generated must also be disposed of [10].

An alternative approach to the treatment of these nutrient wastes is the application of phytoremediation: using the growth of living plants to recover and assimilate dissolved nutrients, especially nitrogen and phosphorus species [11]. Phytoremediation provides a low-impact, cost-effective, environmentally friendly and easy to implement waste management technique for the treatment of nutrient pollution [12]. Although aquaculture effluent can vary widely in TN and TP concentration depending on the species and environmental conditions, phytoremediation has proven to achieve average TN and TP removal rates of 80-95% A review of Iowan aquaculture showed phytoremediation removed between 10-100 mg/L TN and 0.5 mg/L TP [13]. Regardless, phytoremediation by aquatic macrophytes has a high enough removal efficiency to reduce the concentration of these nutrients to levels below the maximum acceptable contaminant levels of 10mg/L for TN and 0.2mg/L for TP [14,15]. Additionally, macrophytes should not only be considered for their high nutrient removal efficiency in agricultural and aquaculture wastewaters but also their short treatment time [16,17]. However, in aquaculture waste treatment, high levels of suspended solids and floating organic materials may possibly hinder the overall efficiency of the phytoremediation process. Biodegradation of organic suspended solid by remediation species could return the insoluble nutrient as soluble nutrients in the water column thus enriching the wastewater. This necessitates a pre-treatment process such as physical filtration to first reduce the concentration of suspended solids prior to phytoremediation. Therefore, in this study physical treatment via membrane filtration was incorporated with phytoremediation in order to evaluate the effect of pre-treatment on the subsequent performance of phytoremediation. Greater duckweed, *Spirodela polyrhiza* was used in this study since this species has been shown to significantly reduce nitrogen and phosphorus compounds, as well as the chemical oxygen demand (COD) and turbidity of tested wastewater [18]Using filtration membranes of different pore sizes, the effects of varying suspended solid removal on the phytoremediation capabilities of *S. polyrhiza is* investigated. We also evaluate the rate of filter fouling for each of the different membrane pore sizes used.

2 Materials and method

2.1. Growth of *Spirodela polyrhiza*

The aseptic macrophytes were periodically subcultured into Hoagland medium with the addition of 30 g/L sucrose [18]. The pH of the culture media was adjusted to 5.8 using NaOH solution and autoclaved at 121˚C for 15 min. For propagation, healthy, dark green plantlets of *S. polyrhiza* were selected and added to glass culture bottles containing 80 mL liquid medium. Plant subculture samples were then maintained at 26±1 ºC under the fluorescent tubes (1500 lux) with a 16-hr light: 8-hr dark photoperiod for 14 days.

2.2. Physical treatment using microfiltration

About 4 L of wastewater was collected from a catfish fish farm in Nibong Tebal, Penang and was tested for its nutrient concentration, turbidity, pH and physical characteristics including chemical oxygen demand (COD) and mixed liquor volatile suspended solids (MLVSS). The collected wastewater was stored in plastic containers in a refrigerator at 4ºC and brought up to room temperature and shaken before used. The wastewater was filtered with commercial membrane of three different pore sizes; 20 µm (Whatman Grade 41), 3.0 µm (polycarbonate membrane, Sterlitech) and 0.2 µm (cellulose acetate membrane, Sartorius). One unit of each grade of the membrane was used to filter 100 mL of the wastewater. The turbidity, pH, COD level, MLVSS and nutrients of the wastewater after filtration were measured.

2.3. Phytoremediation of aquaculture effluent

Following physical treatment, this subsequent study intended to evaluate the uptake of nutrients of *S. polyrhiza* in filtered and unfiltered wastewater and the effect towards its growth as well as water quality after phytoremediation. A total amount of 2 L of physical treated wastewater and 2 L of untreated wastewater were prepared. *S. polyrhiza* macrophyte was cultivated in a small-scale containment unit with internal circulation using treated and untreated wastewater, as shown in Figure 1. 6 g of healthy *S. polyrhiza* were transferred onto the surface of the wastewater. The wastewater was continuously circulated using a small-scale water pump at 0.1 L/min to ensure mixing and aeration of the wastewater.

The experiment was run for 14 days at a controlled temperature of 26±1ºC and light intensity of 1500 lux with a 16 h light: 8h dark photoperiod. A control group was set up using raw wastewater that did not undergo any membrane filtration and with the same amount of *S. polyrhiza* biomass as well. Both groups were tested in triplicate.

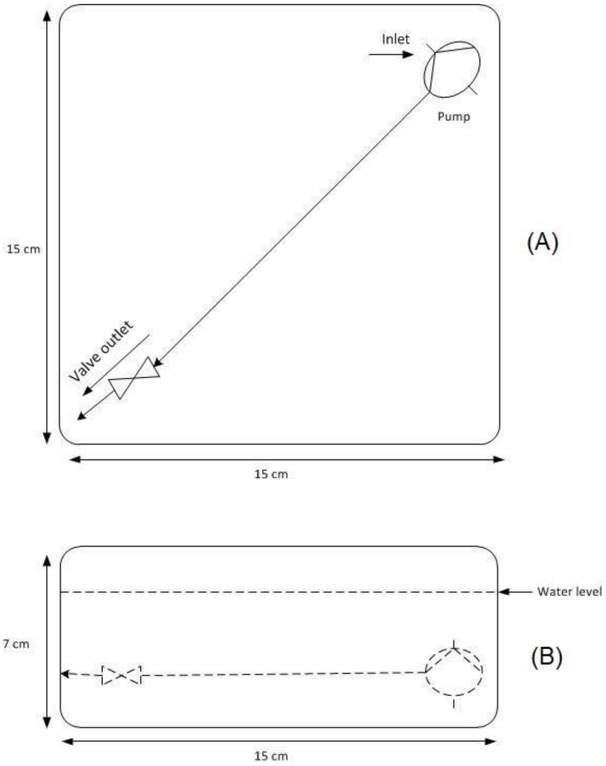

Fig. 1. The schematic diagram of the wastewater containment unit and circulation pump. (A) the top view and (B) the side view.

Throughout the 14-day experimental period, 35 mL samples of the wastewater were collected from each containment unit every 2 days. The water level in the containment unit was maintained at the starting level marked before collection by adding tap water daily. This was to avoid changes in the water level and nutrient concentration due to evaporative losses. The wastewater sample was tested for its nutrient content (nitrate, phosphate and ammonia), COD, turbidity, pH and MLVSS to evaluate the water quality changes during the treatment. At the end of 14-day evaluation the harvested *S. polyrhiza* was collected, carefully dried by blotting and weighed.

2.4. Analysis of nutrient concentration and physical properties

2.4.1. Measurement of nutrient concentration

To determine the concentration of dissolved nitrate, ammonia and phosphate in the water samples the following methods were used. Nitrate concentration was measured using the cadmium reduction method, HACH standard 8039. The reagent used was the NitraVer®5 Powder Pillows with a HACH DR2800 spectrophotometer at 500 nm with a specified range of detection between 0.3–30.0 mg/L NO_3^--N. Concentration of ammonia was measured with the salicylate method, Lovibond standard 66. Reagents needed were the VARIO Am tube test, VARIO Ammonia Salicylate and Cyanurate powder packs and the VARIO Am Diluent reaction tube. The vials were measured in a LOVIBOND MD600 photometer at 660 nm. The detection range for this test is 0 – 50 mg/L NH_3-N. The concentration of phosphate was evaluated by the HACH standard 8048 method. The reagent used was the PhosVer®3 Powder Pillows and as with nitrate the spectrophotometry was performed on the HACH DR2800 but at 880 nm. This method for phosphate measurement is consistent with USEPA methods 365.2 and Standard Method 4500-P-E. This test has a given range of detection between 0.02-2.5 mg/L PO_4^{3-}.

2.4.2. Measurement of COD concentration

Concentration of COD in the wastewater sample was measured using the dichromate/H_2SO_4 method, Lovibond 131 with the COD VARIO tube test kit in a MD600 photometer set to 610 nm. The detection range is 0-1500 mg/L. This procedure for measurement of COD is compliant with the recommended Standard Methods of the American Water Works Association

2.4.3. Measurement of turbidity

For the measurement of turbidity, collected samples were shaken vigorously in a centrifuge tube. A 10 mL glass cuvette was filled with the well mixed water to the marked level. The outside of the cuvette was gently wiped with a Kimwipe before insertion into the measurement unit. The turbidity of the sample is evaluated using a HANNA turbidity meter.

2.4.4. Determination of MLVSS

The centrifuge tube is shaken vigorously to ensure the water sample is well-mixed. 50 mL samples of the wastewater were passed through a 47 mm diameter weighed Whatman™ glass microfiber filter unit using a vacuum air compressor. Any residues collected on the filtered were placed in a drying oven set to 105°C for 1 h or until a constant weight (no additional fluctuations) was achieved. This measured gain in the mass of microfiber filter indicates the amount of total suspended solids present in the sample. After weighing the dry filters, they were ignited in a muffle furnace at 550 °C for 30 min, or to a constant weight. Any remaining weight represents the weight of fixed solids while the weight that was lost following the ignition process are the volatile solids. The procedure used in this MLVSS test was performed following standards set in APHA 2540D and APHA 2540E.

2.5. Percentage change

The change in parameters following filtration and subsequent phytoremediation is presented as percentage change. This is calculated using the equation:

$$\%\ change = 100 \times \frac{(final\ value - initial\ value)}{|initial\ value|} \tag{1}$$

3. Results and discussion

3.1. Physical treatment

The initial water quality of the collected fish farm wastewater is shown in Table 1. The concentration of measured nitrates and phosphates were lower than the limit of sewage discharge for Standard A bodies, at 10.00 mg/L and 5.00 mg/L respectively for enclosed bodies of water [19]. Standard A applies to discharges into any inland waters within catchment areas which is the most stringent limit. (Standard A represents the most minimal amount of pollutant that can be present in inland catchment waters) The pH value of 7.89 was in the range of discharge limit standard A as well of 6.00 to 9.00 but for ammonia, the initial value of 36.30 mg/L was well above the standard A of 5.00 mg/L ammonia-N. The same were observed for the COD level measured at 248.00 mg/L, MLVSS at 220.00 mg/L and turbidity at 203 NTU which was well above the Standard A limits. From the initial analyses only nitrate, phosphate and pH meet the Standard A discharge limit while the ammonia-N, COD, turbidity and MLVSS were above the discharge limit.

In this study, the wastewater was filtered through three different membranes with pore sizes of 20 µm, 3.0 µm and 0.2 µm and the quality of the wastewater was monitored. From Table 1, nitrate concentration remained unchanged at 0 mg/L, but phosphate decreased gradually by 21 %, 61 % and 64 % as the membrane pore size was reduced from 20 µm to 0.2 µm. Similar trends were observed for ammonia and phosphate remediation: there was less ammonia and phosphate present at the end of treatment when pre-filtered with membranes with smaller pores. Filtered wastewater showed higher concentrations of ammonia, perhaps due to bacterial activity in the sample. Previous studies have shown that bacteria liberated organic suspended solids into water-soluble ammoniacal nitrogen during the day-long delay period between experiment set-up and filtered water testing [20]. The experimental pre-filtration steps also appeared to significantly reduce COD, turbidity, MLSS and MLVSS. Reduction as high as 88 %, 91 %, 88 % and 91 % for COD, turbidity, MLSS and MLVSS respectively were obtained when filtered through membranes with 0.2 µm pores. The filtration and removal of suspended solids greatly improved all subsequent tested parameters, as these properties are directly related. The removal of suspended solids improves turbidity of the wastewater, and their absence also reduces the COD measured. The MLSS and MLVSS which measures the presence of suspended solids and volatile organic matters also improved as those matters were partially removed via filtration as well [21].

Based on the results of Table 1, the smallest membrane pore gave the best reduction of all the wastewater parameters monitored. However, there was a reduction in the filtered wastewater volume since smaller pores are easily clogged by particulates present in the wastewater (Table 2). The larger pore size membrane of 20 µm and 3.0 µm were able to filter up to 3.1 and 1.8 times the volume of wastewater corresponding to 25.0 L/m^2 and 18.0 L/m^2, before clogging would become significant and the membrane would need to be cleaned. The smallest membrane pore would require the most frequent cleaning.

Table 1
Chemical analyses of initial and filtered fish farm wastewater by different membrane pore size and comparison to Standard A discharge limits.

Parameter	**Initial**	**Standard A**	**Microfiltration membrane pore size**		
			20 µm	3.0 µm	0.2 µm
Nitrate-N (mg/L)	0.00	20	0.00	0.00	0.00
Phosphate (mg/L)	1.17	5	0.93	0.46	0.42
Ammonia-N (mg/L)	36.30	10	49.00	40.20	38.50
COD (mg/L)	248.00	20	166.00	145.00	81.00
pH	7.89	6.0-9.0	7.93	7.97	7.94
Turbidity (NTU)	203.00	5	95.30	53.60	19.10
MLSS (mg/L)	220.00	50	140.00	80.00	40.00
MLVSS (mg/L)	188.00	n/a	132.00	62.00	22.00

Table 2
Comparison of membrane filtration rates.

Properties of filtration	**Microfiltration membrane pore size**		
	20 µm	3.0 µm	0.2 µm
Average filtered amount (L)	0.043	0.025	0.013
Diameter (m)	0.047	0.047	0.047
Average filtration rate (L/m^2)	25.0	14.0	8.0
Filtration rate ratio	3.1	1.8	1.0

In this study, the physical pre-treatment was designed to reduce inorganic and organic matter that phytoremediation is unable to remove. Therefore, the 20 µm membrane was chosen for its ability to reduce the water turbidity by more than 50 %. It gives a balance between high filtration volume with respect to reduction in MLSS and MLVSS (both more than 60 %) when compared to smaller pore size membranes of 3.0 µm and 0.2 µm. It also prevents the excessive removal of beneficial bacteria which can help the plants during the bioremediation of the wastewater.

3.2 S. polyrhiza cultivated in fish farm wastewater

3.2.1. Ammonia removal

The ammonia concentration in the wastewater was observed to decrease significantly from day 0 to day 8 and then decrease gradually until the end of experimentation for both control and filtered wastewater (Figure 1). The initial concentration of filtered was at 46.2 mg/L and by day 14 it had dropped to 1.4 mg/L with removal efficiency of 97 %. As for the control run, the decrease in concentration was from 50.2 mg/L at day 0 to 0.25 mg/L at the end of the experimental period achieving a removal efficiency of 99.5 %. The initial rapid ammonia decrease by *S. polyrhiza* was due to its preference of ammonia rather than other types of nitrogen sources and thus it was taken up rapidly. Duckweed plantlets will absorb and make use of all the readily available ammoniacal nitrogen before moving on to assimilate other forms of nitrogen such as nitrate [22]. Duckweed appeared to grow more quickly in the presence of ammonium rather than with nitrate. The final ammonia level for filtered and control was low enough to qualify for standard A [19] with a permissible discharge limit of 5 mg/L ammonia-N into any enclosed water body.

3.2.2. Nitrate removal

Nitrate was not initially detected in the wastewater sample. However, its concentration gradually increases during the experiment; at a higher rate for the filtered wastewater as compared to the control (Figure 2). The filtered water achieved peak nitrate concentration of 23.0 mg/L at day 10, however its concentration drops to 9.4 g/L at the end of the experiment. The nitrate concentration in the control, on the other hand, didn't show any drop and achieved a concentration of 24.3 mg/L at the end of the experiment.

The presence of nitrate is governed by nitrification, denitrification as well as the plant and microbial uptake [23]. Nitrification will increase the nitrate level while the other two processes lower the nitrate concentration. The result showed that the rate of nitrification was higher than the rates of combination of other two processes which caused an accumulation of nitrate in the water samples. Nitrification is a two-step biological process in which one type of autotrophic bacteria, ammonia oxidizing bacteria (AOB) converts ammonium (NH_4^+) or ammonia (NH_3) into nitrite (NO_2^-) following which, a second type of bacteria, nitrite oxidizing bacteria (NOB) oxidizes nitrite to nitrate (NO_3^-). Nitrification is further supported by the optimum reaction temperature of 25-35 ºC and a pH of 7.5-8.0 [23]. Additionally, the observed increased nitrification rates are supported by the higher dissolved oxygen concentration in the wastewater likely from the continuous circulation of the wastewater by the water pump

This reduction in nitrate concentration during the last days of the experiment period may be attributed to the nitrogen uptake preference of *S. polyrhiza*. By day 10, the ammonia concentration in the wastewater had dropped to a very low level (<10 mg/L) and at that level, plants metabolize nitrate as their nitrogen source [24]. However, in the control system where the wastewater was not filtered, the presence of a higher amount of organic matter and microbial communities, the nitrification process was more extensive. It seems that the plantlets were fully assimilating the nitrate liberated into the water body as a result of bacterial degradation. The nitrate concentration reached a plateau instead of the drop as seen in filtered water.

3.2.3. Phosphate removal

In Figure 3, the phosphate concentration was found to decrease over the 14 day experimental period. The initial differences of phosphate content in the wastewater samples between the filtered and the control system were significant. Phosphate levels measured 2.7 mg/L in the control group and 0.8 mg/L in the filtered wastewater. However, both systems were able to achieve a significant drop in phosphate concentration by day 2 and generally the concentration was not observed change much after that. On the last day the control group had a concentration of 0.4 mg/L and the filtered wastewater system was determined to be 0.3 mg/L with a removal efficacy of 87 % and 67 % respectively.

The reason for this reduction in phosphate concentration in the phytoremediation system was uptake for utilization by *S. polyrhiza* plantlets. The plantlets are highly efficient at removing elements required for growth such as phosphate. Phosphate is categorized as a major plant nutrient element and it is commonly considered that plants absorb most of their required phosphate as orthophosphate ions, $H_2PO_4^-$. The secondary orthophosphate ion, HPO_4^{2-} is also absorbed but in smaller proportions. Phosphate is needed for the building of biochemical structural components like nucleic acid, phytates and phospholipids. Satisfactory supply of phosphate is crucial in early life of plants as it is important in laying down the primordium for the reproductive parts of the plants. Phosphates are also important for seed formation and root growth High-energy phosphate bonds are essential for plant's respiratory and photosynthetic processes and they are necessary for the transfer of energy during certain metabolic processes that are fundamental to life itself [25]. Therefore, its importance contributed to the substantial uptake from the wastewater within the first two days of the experiment.

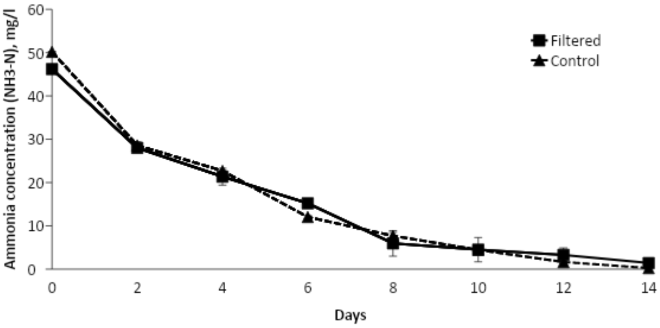

Fig. 1. Ammonium concentration profile for control and filtered wastewater subjected to phytoremediation using *Spirodela polyrhiza*.

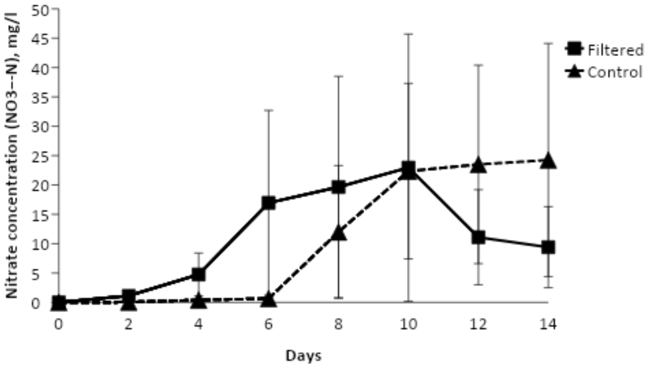

Fig. 2. Nitrate concentration profile for control and filtered wastewater subjected to phytoremediation using *S. polyrhiza.*

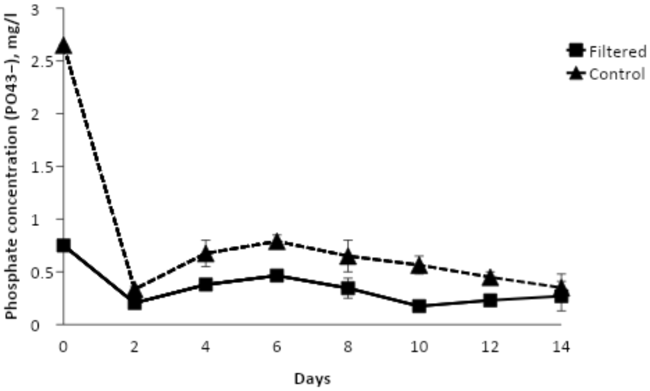

Fig. 3. Phosphate concentration profile for control and filtered wastewater subjected to phytoremediation using *S. polyrhiza*.

3.2.4. COD removal

It can be observed from Figure 4 that the concentration profile of COD differs significantly with the control system for the first 2 days. The filtered wastewater COD remains almost unchanged throughout the entire experiment, averaging around 117 mg/L. The control group drops from 343 mg/L on the initial day to 185 mg/L before gradually falling to 124 mg/L on the last day of the experiment. These results indicate that the COD value results from the suspended solids that are present in the wastewater. Removal of these suspended solids effectively reduces the COD while the plants and the microorganisms in the water can stabilize the COD profile via decomposition of the organic matters in the water [18].

3.2.5. Turbidity

In the case of turbidity, both filtered and control systems proved to be highly efficient in improving the clarity of fish farm wastewater (Figure 5). In the filtered system, the turbidity went down from 110 NTU on day 0 to 25 NTU on day 14. The control unfiltered system decreased from 249 NTU on day 0 to35 NTU on day 14.. The filtered system achieved a removal efficiency of 77 % while the unfiltered control had a removal efficiency 86 %. Unfiltered water appeared darker green in the circulation pump of the containment unit due to the presence of microalgae and suspended solids (Figure 5B) compared to the filtered sample (Figure 5C).

Turbidity was used as a general indicator of water clarity. During regular operations, total duckweed cover is expected to suppress the growth of algae and reduce sedimentation formed by floating algae, producing a clearer wastewater. In the filtered system, most of the suspended solids were removed by the membrane and therefore a lower turbidity level was obtained than the control system. When placed in a phytoremediation system, the presence of plantlets was able to limit the subsequent algal growth which further reduces the turbidity of the wastewater. This result was achieved through the simple mechanism of shading as a dense layer of floating plants on top of wastewater prevents sunlight from passing through to the wastewater and stimulating algal growth [26]. Furthermore, the microbial communities in the wastewater are also known to be able to degrade and solubilize the organic matters present and effectively reduces the turbidity as well. Furthermore, *S. polyrhiza* plantlet roots provide surface area for the suspended solids to attach, thereby effectively reducing the wastewater turbidity [22].

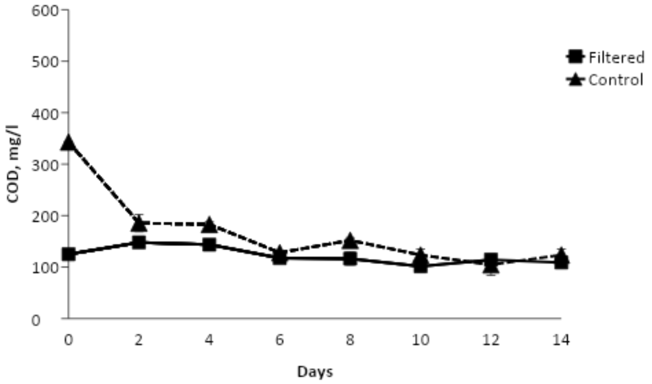

Fig. 4. COD profile for control and filtered wastewater subjected to phytoremediation using *S. polyrhiza*.

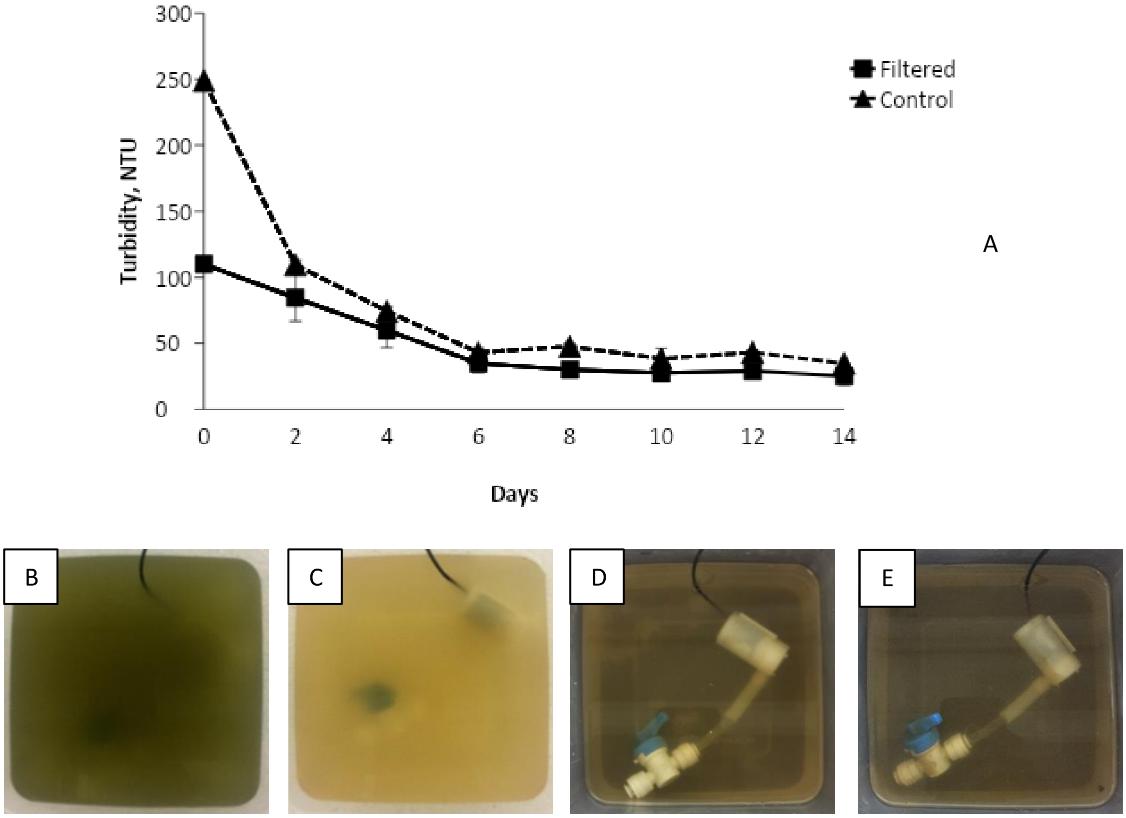

Fig. 5. Effect of phytoremediation on turbidity value throughout the experiment (A). The difference in opacity of the internal circulation pump observed from the top view of the pre-treated fish farm wastewater (B) unfiltered at day 0 (C) prefiltered with 20 µm membrane at day 0 (D) unfiltered at day 14 and (E) prefiltered with 20 µm membrane at day 14.

3.2.6. MLVSS

Figure 6 and 7 shows the initial day 0 and final day 14 values of MLSS and MLVSS respectively. The initial concentration of total suspended solids for the filtered system began at100 mg/L and by day 14 was reduced to 20 mg/L. The removal efficiency was 80%. The control began at 240 mg/L and by day 14 was reduced to 70 mg/L with a removal efficiency at 71%. The initial concentration of volatile suspended solids for the filtered system began at 84 mg/L and by day 14 was reduced to 12 mg/L with a removal efficiency of 86%. The control concentration at day 0 was 222 mg/L and by day 14 it was reduced to 51 mg/L with a removal efficiency of 77%.

The MLVSS results obtained correlate with the turbidity results, since turbidity depends on the amount of total suspended solids in wastewater. For the filtered system, the final value of suspended solid during day 14 which was lower than control is related with the final value of turbidity from Figure 5 which is lower than the control as well. As mentioned previously in *section 3.2.3* the removal of total suspended solids was mainly caused by *S. polyrhiza's* widespread root system and this was likely the reason for the observed decrease of total suspended solids in the filtered wastewater as well [22]. Meanwhile, for the control group the final effluent value corresponds with the final turbidity value as well.

3.3. Biomass growth

The initial fresh weight of *S. polyrhiza* was 6 g/L for both filtered and control system and by the end of the experiment on day 14 the total weight of the filtered and control system were 30 g/l and 28 g/l respectively (Figure 8). Duckweed species have the capability to grow extremely rapidly and can double in total biomass within a period of two days under ideal levels of nutrients, sunlight intensity and temperature. The results from this experiment showed that *S. polyrhiza* can accumulate a biomass 5 times its initial fresh weight and have a doubling time of about 2.8 days. This indicates that the wastewater effluent rich in nutrients were able to support a healthy growth of the duckweed [2,27].

4. Conclusions

The experimental results reveal that membrane filtration can significantly reduce the turbidity of the fish farm wastewater (up to 90%) when using a filter with a pore sizeof 0.2 micrometers This eventually leads to a much lower COD, MLSS and MLVSS reading for the wastewater. The dissolved nutrients however were not significantly affected by the physical filtration. Filtered fish farm wastewater does have a head start in terms of monitored wastewater parameters but given enough time, unfiltered wastewater eventually catches up in terms of the nutrient removal performance. A significant difference was observed in the nitrate concentration whereby nitrification in unfiltered wastewater was significantly higher than the uptake of the duckweed at the end of the experiment. As a conclusion, membrane filtration is able to significantly reduce the turbidity and indirectly reduces the COD, MLSS and MLVSS of the wastewater and thereby shortening the time required for completion of the phytoremediation process.

Acknowledgements

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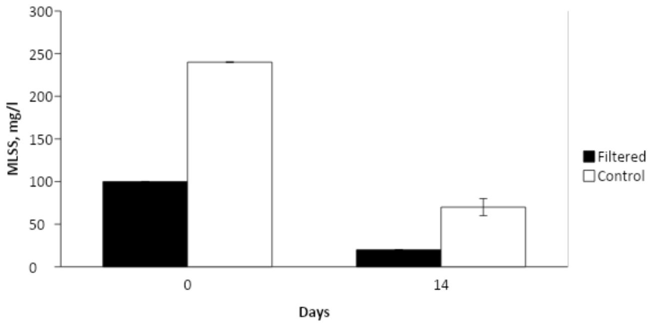

Fig. 6. Effect of phytoremediation on MLSS value throughout the experiment.

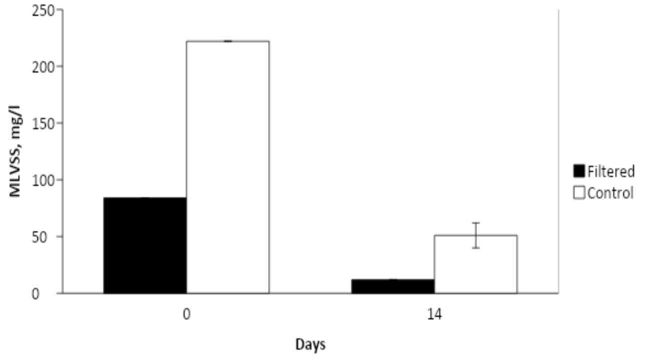

Fig. 7. Effect of phytoremediation on MLVSS value throughout the experiment.

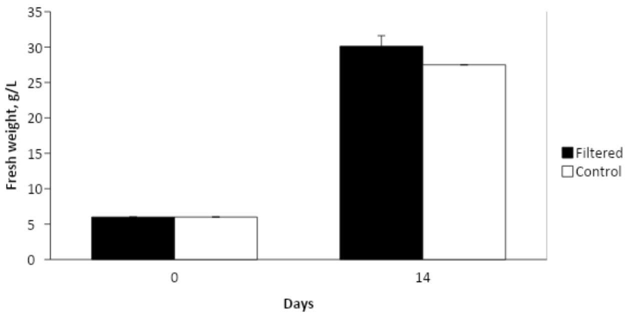

Fig. 8. Effect of phytoremediation on fresh weight value throughout the experiment.

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