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Process Performance and Nutrient Removal in Fish Processing Wastewater Using a Membrane Bioreactor (MBR) Unit for Reuse for Irrigation

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Abstract:
This study investigated the removal of nitrogen and phosphates in fish processing wastewater through process optimization of a membrane bioreactor (MBR) treatment unit. Raw process wastewater was collected from the Makindi fish farm and was pre-filtered through a mesh of 0.8 mm. The experiment was conducted at a lab scale using commercial Polyethersulfone (PES) membranes submerged in the MBR unit. The pre-filtered wastewater sample was added into a denitrification (anoxic) tank. The process was conducted through continuous recirculation between the aeration and the anoxic tank to enhance the removal of nitrogenous compounds. The recirculation flow rate was 10L/h. A hydraulic residence time (HRT) of approximately 22-25h was maintained, and the aeration rate in the aerobic tank was 100L/min. Aluminum sulphate AI2(SO4)318H2O was added continually into the anoxic tank and with constant stirring to enhance the removal of phosphates. A removal rate of 85±2% for NH4+-N, 84±1% for NO3- -N, and 69±3% for PO43--P was obtained. The nutrient concentration in the effluent was successfully reduced to an acceptable level with both nitrogenous compounds and phosphate concentrations obtained within the range of < 30 mg/L and ≤ 5 mg/L as per the WHO guidelines for wastewater reuse for irrigation. The results showed a successful process optimization that can be applied to ensure optimized performance of the MBR unit thus improve its effectiveness for the treatment of fish processing wastewater. The study therefore recommends process optimization as a tool for effective removal of nutrients in the MBR system thus making it a potential recycling approach for treatment of fish processing wastewater for reuse for irrigation purposes.

Keywords: MBR Technology, Fish Processing, Wastewater, Performance, Nitrogen, Phosphates

INTRODUCTION

Kenya's fish industry contributes to over 0.5% of the country's gross domestic product (GDP) per year (Munene & Wanjiku, 2020). It is estimated that Kenya's fisheries provide fish as a rich source of protein to over 4.2 billion people (Fondo & Ogutu, 2021). Kenya's fish industry is prominent in Kisumu town along the Lake Victoria shores (Njiru, Van der Knaap, Kundu, & Nyamweya, 2018). The region dominates the country's fishing industry and is a host to large and small-scale fish trades (Abila & Kisumu, 2005). With the massive urbanization, pupation growth, and industrialization there have been major infrastructure constraints to wastewater treatment systems in Kisumu City (Musungu, Lalah, Jondiko, & Ongeri, 2014). The most common wastewater treatment systems used in Kenya include lagoons, maturation ponds, and in some cases offsite treatment where wastewater is collected and transported to treatment plants (Musungu et al., 2014). These types of treatment systems however have insufficient removal of nutrients such as nitrates and phosphates, and they require large land areas and have long residential time (Gukelberger et al., 2020). The need for efficient wastewater treatment systems with small footprints is growing especially for fish industries in cities such as Kisumu (Martin, Hongtao, & Fengting, 2016). Most industries have poorly managed wastewater disposal systems which have resulted in continued nutrient loading and eutrophication of Lake Victoria. This harms the water bodies within the environs now characterized by large floating mats of water hyacinth that cover a massive part of the Lake Victoria shores and rivers draining to the Lake (Ongore, Aura, Ogari, & Nyamweya, 2018). Further, there has been a negative impact on the chemical and physical properties of soil in the region attributed to the disposal of untreated effluent to unmanaged wetlands around the lake (Habibi, 2019). These present a need for the treatment of wastewater before discharge or reuse. Figure 1 shows mats of hyacinth resulting from continued nitrification of the lake that has resulted to eutrophication and invasion of water hyacinth plant along shores of Lake Victoria.

Figure.1 Mats of water hyacinth along shores of Lake Victoria

The MBR uses both physical and biological processes to treat the wastewater. The incoming influent is introduced in the wastewater bioreactor tank seeded with bacteria-rich activated sludge (Mburu et al., 2020; Mburu et al., 2019). The process involves a biodegradation process of organic compounds occurring in the aeration tank and subsequent simultaneous separation of the biomass and the treated effluent through a filtration process (Saadia, Shamim, Francesco, Alberto, & Jan, 2015). The filtration is conducted using microfiltration or ultrafiltration membranes (Galiano et al., 2015). The bioreactor also called the aeration tank is installed with diffusers that produce cross-flow current for the MBR scrolling thus limiting fouling and supplying air for the biological degradation process (Naghizadeh, Mahvi, Mesdaghinia, & Alimohammadi, 2011). The system has low sludge production and does not require sedimentation or clarification tanks for further treatment of the resultant effluent (Deowan, Galiano, Hoinkis, Figoli, & Drioli, 2013). The MBR treatment system has a reduced footprint, produces high-quality effluent that exceeds the capacity of waste stabilization ponds (WSP) and Activated sludge process (ASP), and has a shorter residential time (Gukelberger et al., 2020). It can allow the reuse of treated water, and the capital cost is mainly dependent on plant size and the cost of equipment (Figoli et al., 2014). The MBR was tested for the treatment of fish processing wastewater at a laboratory scale in JKUAT using the immersed membrane bioreactor (MBR) unit (Mburu et al., 2019). The

Ultrafiltration polyethyl sulphone (UF/PES) membrane modules studied showed good performance for water permeability during pilot testing but were found to have significant fouling problems (Mburu et al., 2019). This has also been observed in other studies where the author (Oulad, Zinadini, Zinatizadeh, & Derakhshan, 2019) investigated the influence of operating parameters on the fouling behavior of modified nanofiltration membranes (Oulad et al., 2019). In follow-up work, a novel low-fouling membrane was prepared by coating the surface of a PolyetherSulphone (PES) membrane with a Polymerisable Bicontinuous Microemulsion (PBM) and tested using the MBR unit (Mburu et al., 2020). The results showed improved performance and ability to resist fouling (Mburu et al., 2020). In a similar study, polyethersulfone (PES) ultrafiltration membranes were coated with O-carboxymethyl chitosan/ Fe_3O_4 and tested for antifouling performance (Rahimi, Zinatizadeh, & Zinadini, 2014). The results showed improved flux for the modified membrane (Rahimi et al., 2014). The drawback observed from the MBR pilot testing study on the inefficient removal of nutrients is yet to be investigated (Mburu et al., 2019). This study is a follow-up work where the MBR operational process parameters were optimized to intensify the removal of nitrogen compounds and phosphates in fish processing wastewater.

MATERIALS AND METHODS

The Lab-scale MBR unit used for this experiment constituted two PES flat sheet membrane modules immersed in a 97L Polyvinyl chloride (PVC) aeration tank. The unit was installed with two permeate suction pumps with a speed control of 0.2 to 2 L/h, each connected to a permeate line for each module. Each permeate line had a manometer and an analog rotameter with a volume flow of 0.5 to 5 L/h connected to it. Air was supplied to the aeration tanks through diffusers by an air pump with a flow volume of 100 L/min. The diffusers were installed below the membrane modules to create a cross-flow current for the MBR scrolling to limit fouling. The MBR unit had sensors to measure pH, temperature, and conductivity along the two permeate lines. The reactor tank had a float switch to control the water levels. A 70L PVC denitrification tank with a digital stirrer was connected to the aeration reactor tank via a recirculating pipe to allow recirculation between the aeration tank and the denitrification tank. The aeration tank was fitted with an outlet valve for permeate collection and another valve fitted at the bottom for sludge removal. A computer for data recording and storage was connected to the MBR unit to facilitate monitoring the process parameters. Figure 2 illustrates a schematic diagram for the lab-scale MBR unit used in this work.

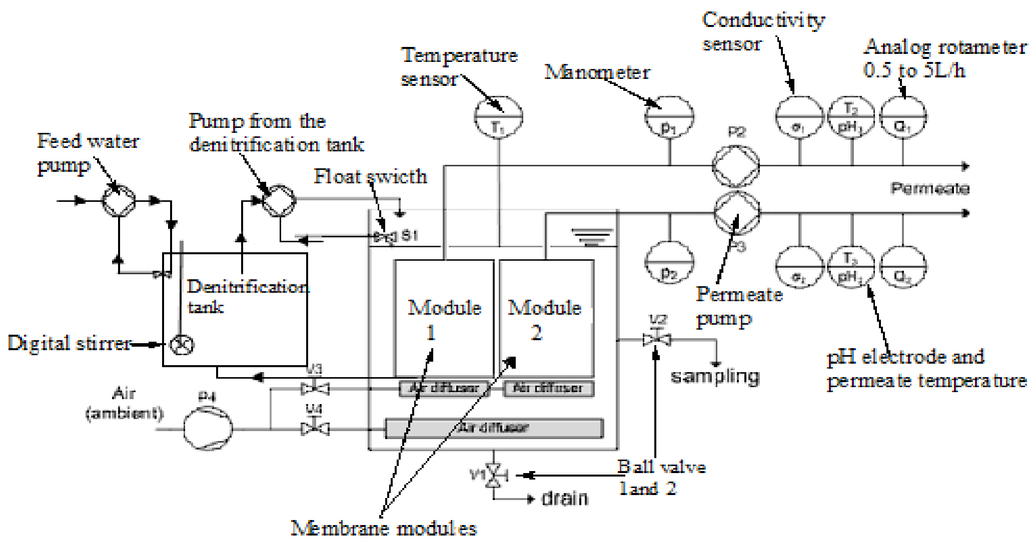

Figure 2: Lab-scale Membrane bioreactor (MBR) unit

The membranes used in this study were assembled into modules by Martin Membrane Systems Company (Germany). Table 1 illustrates the technical specifications for PES membrane modules used.

Table 1: Technical specification for membrane modules from Martin Membrane Systems

Technical data	Martin CUBE Mini membrane module
Active layer	PES
Support layer	PET/PES
MWCO (kDa)	150 kDalton
Pore size (µm) / Pore size (µm) norminal-maximal	0.035-0.1
Membrane area	5 panels of 0.09 m^2 each, total 0.45m^2
Gaps between the membranes	6mm
Water permeability (L/ (m^2 h bar)	> 280

Samples of fish processing wastewater were collected from Makindi fish farm located 20.6 km from JKUAT and were analyzed for various physico-chemical parameters before treatment. Two PES membrane modules were immersed in the MBR reactor tank filled with clean water. Proper functioning of the MBR unit was ensured and the clean water was discharged. The reactor was subsequently seeded with about 5L of bacteria rich activated sludge and a pre-filtered fish processing wastewater sample pumped through a fine screen with 0.8 mm perforated strainer was fed to the tank and was filled to the mark. The sequential test for the PES membrane modules was conducted by recirculating the wastewater between the denitrification tank and the aeration tank at a rate of 10L/h and hydraulic retention time (HRT) of 27.4 h -31.7h. In the aeration tank, the fish processing wastewater was treated by microorganism that metabolized the biodegradable organic matter into biomass, carbon dioxide and water. In denitrification tank micro-organisms metabolized nitrates into nitrogen gas. The treated water was sacked through the membrane modules by the permeate pumps during filtration process and was subsequently collected through an outlet valve into clean sample containers for analysis. A portion of it was returned in the aeration tank to dilute the MLSS and enable a slow adaption of the activated sludge. The rest of the treated water was collected in clean containers for other use. The experiment was conducted continuously in the MBR unit during the experimental period. However, breaking intervals were applied to allow removal of excess sludge and cleaning of the membrane modules. Cleaning process was conducted in a separate tank using 12% sodium hypochlorite solution and by rinsing with 50% citric acid, hydrogen peroxide diluted to 100mg/L and with clean water. Excess sludge produced during the experimental period was used as manure in surrounding farm. Data collection was done only

RESULTS AND DISCUSSION

Characterization of the fish processing wastewater conducted to confirm its quality before treatment. These results are shown in Table 2.

Table 2: Fish processing wastewater characteristics

Parameter	Unit	Wastewater quality Range
TDS	mg/L	232±116
pH	pH scale	6.6±0.3
Conductivity	µS/cm	633±0.2
PO_4^{-3}-P	mg/L	12±5.2
NO_3^--N	mg/L	20.3± 11

NH_4^+-N	mg/L	25.8±12.3
Temperature	˚C	25±1

Mean ± std. deviation, where n=17

Table 2, presents the results from the various tests conducted for the fish processing wastewater samples used in the MBR experiment. The results showed high levels of the tested parameters in the wastewater samples. The concentration of nitrate-nitrogen NO_3^--N was in the range of 20.3±11mg/L and 25.8±12.3 mg/L for ammonium-nitrogen NH_4^+-N. Phosphates (PO_4^{3-}-P) concentration was in the range of 12±5.2 mg/L. The pH varied from 6.58 to 6.96±0.5 with a conductivity range of 633±0.2. The TDS range was 232±116ppm and the temperature of the feed was in the range of 25±1˚C.

Nitrogenous Compounds and Phosphates Removal Rate Using the PES Membrane Module

The following are results for removal efficiency for nitrogenous compounds (NH_4^+-N and NO_3^--N) in the MBR system during treatment of the fish processing wastewater.

During the startup experiment, the removal of NH_4^+-N and NO_3^--N was low with concentration in permeate ranging between 5.5 – 12.3 mg/L for NH_4^+-N and 6.1-20.6mg/L NO_3^-–N respectively. The results showed a significant rise in the nutrients regressively until day 70 of the experiment (See Fig.3).

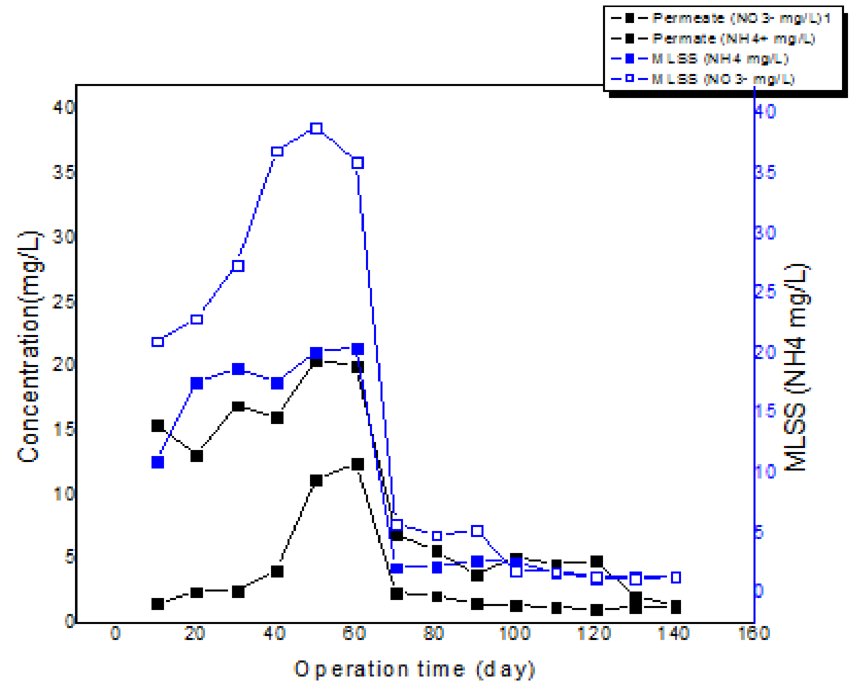

Figure 3: Removal of N-NO³ and NH_4^+ in the MBR experiment

The rise in nitrogenous compounds noted in the effluent could have been caused by continued accumulation of the nutrients in the bioreactor due to incomplete nitrification process and ineffective removal from the treatment system. Afterward, an upfront denitrification (anoxic) tank was installed to allow the recirculation between the aeration and anoxic tank. The recirculation flow rate of 10L/h and a hydraulic retention time (HRT) of 22h -25h were maintained throughout the experiment with alternating aeration in the aerobic tank at a rate of 4mg/L. The NO_3^- -N and NH_4^+-N in permeate were successfully lowered to 3.1 to 5.7mg/L and 0.3 to 2.8mg/L respectively. This showed a successful application of optimal conditions in the treatment system, a technique that can be applied to ensure optimized performance of the MBR unit.

Figure 4 presents the results obtained for the removal efficiency of phosphates (PO_4^{3-}-P) in the treated effluent.

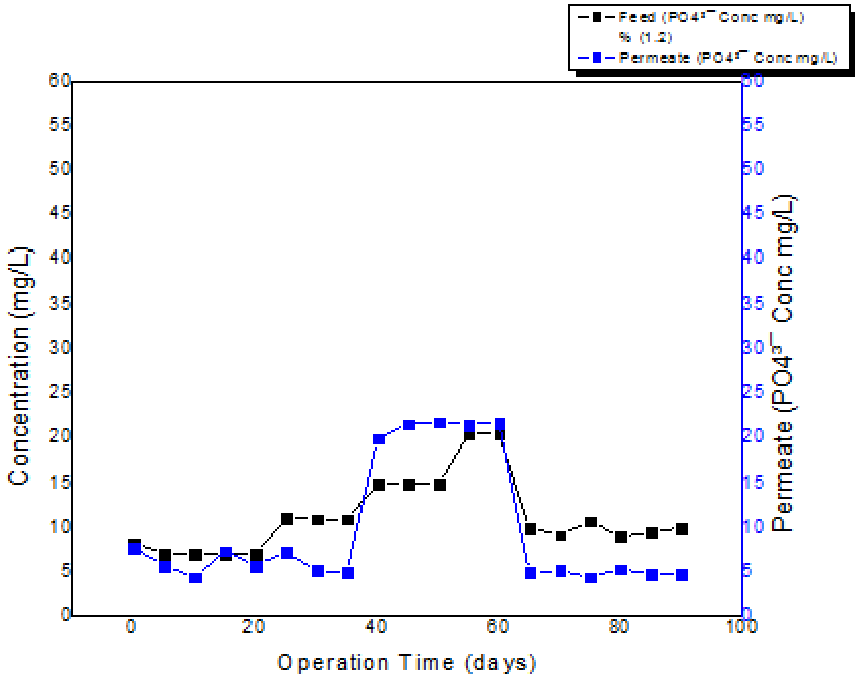

Figure 4: Removal of phosphates in the MBR experiment

As can be seen in Figure 4, there was an increase in PO_4^{3-}-P between day 40 and 60 in the effluent with the concentration level ranging between 4.5 to 21.8mg/L. The results signified inefficient removal and continued accumulation in the treatment system. Phosphates are difficult to eliminate through filtration since they occur in a dissolved state as phosphate ions. To remove the phosphates, it was necessary to use a coagulant commonly applied in other water treatment methods as a booster to the MBR system. This informed the use of 55.2 mg/L of Alum as Aluminum sulphate $Al_2 (SO_4)_3 \cdot 18H_2O$, which was added continually into the anoxic tank and with constant stirring for 30 minutes. The PO_4^{3-}-P ions were successfully coagulated and settled with the sludge at the bottom of the reactor. Consequently, the concentration in permeate was lowered to 3.4 to 5.1mg/L which is a significant reduction in a short time. The level of PO_4^{3-}-P in permeate was brought to below 5mg/L a level that is within the recommendations of the WHO standards. The intensified performance was attributed to the application of chemical coagulant $Al_2 (SO_4)_3$ for treatment of wastewater. These facilitates in neutralizing the negative charge of PO_4^{3-}-P thus causing them to get attracted to each other and form large particles of insoluble phosphoric complexes that remain in the activated sludge and are removed with surplus sludge. Application of coagulants has also been confirmed by (S. Bouhadjar, S. Deowan, F. Galiano, A. Figoli, & J. Hoinkis, 2016; S. I. Bouhadjar, S. A. Deowan, F. Galiano, A. Figoli, & J. Hoinkis, 2016). Extreme amounts of nitrates and phosphates in water bodies lead to enrichment of water bodies with nutrients that support the growth of aquatic weeds thus causing extreme fluctuation of dissolved oxygen, eutrophication and death of aquatic life (Kevin, et al., 2015). The process thus was approved to be sufficient in achieving low levels of nutrients in the treated effluent from fish processing effluent.

CONCLUSIONS

An intensified process for removal of nitrogenous compounds (NH_4^+-N, NO_3^--N) and phosphates (PO_4^{3-}-P) was developed through process optimization in the MBR unit. The nutrient concentrations were lowered to an acceptable range of <5 to 30 mg/L and ≤ 5 mg/L as stipulated by WHO guidelines for wastewater reuse for irrigation. Therefore, the process was succefully optimized and showed better performance thus effective for the treatment of fish processing wastewater for reuse for irrigation.

RECOMMENDATIONS

The study therefore recommends process optimization as a tool for effective removal of nutrients in the MBR system thus making it a potential recycling approach for treatment of fish processing wastewater for reuse for irrigation purposes.

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