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An Effectiveness of Horizontal Subsurface Flow Constructed Wetland to Improve Fish Pond Water Quality

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ABSTRACT: Fish is one of the sources of protein. Fish is one of the largest commodities from aquaculture. Fish farming is one of the economic supports for the community, especially around the waters in Indonesia. Aquaculture in Indonesia uses river water and tidal seawater as the main water source. Changes in water quality due to pollutants in the water can affect the quality of pond water. Horizontal Subsurface Flow Constructed Wetland (HSSF-CW) technology can increase the efficiency of organic matter removal. The aim of this study were to identify the water quality of fish pond and performance of HSSF-CW technology in improving fish pond water quality. The media in reactors were gravel and sand with plants (*Bruguiera gymnorrhiza* and *Avicennia alba*). Dimension of reactor were 65x60x40 cm^3 and it were made from *polymethyl methacrylate*. There were 10 reactors, namely K1 (without plants and without flow rate), K2 (without flow rate), A1Bg (raw water+4 $mL.min^{-1}$+*B. gymnorrhiza*), A2Bg (raw water+8 $mL.min^{-1}$+*B. gymnorrhiza*), A1Aa (raw water+4 $mL.min^{-1}$+*A. alba*), A2Aa (raw water+8 $mL.min^{-1}$+*A. alba*), B1Bg (effluent+4 $mL.min^{-1}$+*B. gymnorrhiza*), B2Bg (effluent+8 $mL.min^{-1}$+*B. gymnorrhiza*), B1Aa (effluent+4 $mL.min^{-1}$+*A. alba*), and B2Aa (effluent+8 $mL.min^{-1}$+*B. gymnorrhiza*). The reactor were operated continuously with flow rate (4 $mL.min^{-1}$ and 8 $mL.min^{-1}$). Analysis of Total Suspended Solid (TSS) used gravimetry method and salinity used argentometri titration. The spectrophotometers analysis were conducted to determine of COD, PO_4^{3-}, NH_4^+, and NO_3^-. In conclusion, the largest removal efficiency of raw fish pond water on COD, TSS, PO_4^{3-}, NH_4^+, and NO_3^- parameters were obtained in reactor A1Aa (83.86%), A1Bg (89.53%), A2Bg (24.06%), A1Aa (84.83%), and A2Aa (93.77%). The greatest removal efficiency of effluent pond on COD, TSS, PO_4^{3-}, NH_4^+, and NO_3^- parameters were obtained in reactor B1Bg (85.46%), B1Bg (91.21%), B2Bg (92.29%), B2Aa (86.81%), and B2Bg (96.84%).

KEYWORDS: fish pond water, efficiency removal, constructed wetland

I. INTRODUCTION

Pond is an artificial pond found in water areas (beaches, lakes, and rivers) filled with water and utilized as a means of aquaculture. Fish pond cultivation is one of the economic supports for the community, especially the areas around the waters in Indonesia. Data obtained by the Aceh Marine and Fisheries Service (2021), Indonesia ranks 8th in its position as a major exporter of fishery products. The export value of Indonesian fishery products in the January to June 2021 period reached USD 2.6 billion, an increase of 7.3% compared to the same period the previous year. Some types of biota cultivated in ponds include fish, shrimp, seaweed, salt, and so on. Fish is one of the largest commodities cultivated in ponds. Fish species that are often cultivated in Indonesian ponds are milkfish (*Chanos chanos*), tilapia (*Oreochromis niloticus*), tilapia (*Oreochromis mossambicus*), catfish (*Pangasianodon hypophthalmus*), catfish (*Clarias batrachus*), grouper (*Epinephelus fuscoguttatus*), and white snapper (*Lates calcarifer*) (Widianarko & Hantoro, 2018).

There are several types of water used, including freshwater, brackish (a mixture of freshwater and seawater), and seawater. Most of the water in the pond comes from the sea at high tide. generally, pond management is done manually (naturally) by utilizing the tides. In addition to seawater, ponds also require fresh water to compensate for too high salt levels during evaporation.

The quality of water parameters for aquaculture commodities needs to determine the level of suitability for cultivated commodities. In addition to supporting the growth process in pond fish, effluent or pond waste also needs to be analyzed for waste quality before being discharged into the environment. Water quality analysis can be determined using biological and chemical indicators. Biological indicators are correlations of community behavior in nature with the environment. Chemical indicators are carried out by analyzing COD and DO (Nuraini et al., 2019). Water quality parameters that are generally used to see the level of water suitability for aquaculture include temperature, salinity, depth, brightness, pH, DO, NO_3^- dan PO_4^{3-} (Awanis et al., 2017). Improving water quality in ponds can be done by CW treatment (Raharjo et al., 2015).

Constructed wetland (CW) is a technology consisting of media, vegetation, and water resembling natural wetlands used for water treatment. Treatment using CW is easy to implement, not only because the technology is simple but also because the operational costs are cheap. CW system maintenance is also relatively cheap. CW can tolerate fluctuations in flow and pollutant concentrations (Halverson, 2004; Munazah & Soewondo, 2018). Based on the type of flow CW has 2 types of systems, namely surface flow (SF-CW) and subsurface flow (SSF-CW) (Choudhary et al., 2014; Rito, 2017). The mechanism of removal of contaminants or pollutants in CW using physical-chemical interactions such as filtration and sedimentation of suspended solids, filtration of organisms (bacteria, viruses, and parasites), decomposition of organic carbon material, nitrogen, absorption of organic matter by plants. The removal efficiency of organic matter in HSSF-CW is more effective (Cheng et al., 2010). HSSF-CW can improve pollutant removal and produce high-quality effluent (Merino-Solís et al., 2015). The removal efficiency of COD and TSS using HSSF-CW technology was 95% and 93% (Sa'At et al., 2017).

Factors that influence the performance of HSSF-CW are macrophytes, media, microorganisms, and temperature. Macrophytes in CW have been widely studied to be one of the main factors affecting water quality in CW systems and provide support in the form of nutrient transformation through physical, chemical, and microbial processes (Vymazal, 2013). Plants serve to help accelerate the process by providing a good environment for the growth of microbial populations in the rhizosphere and can transfer oxygen to the roots and the soil layer so that aerobic alternation (anoxic and anaerobic zones) is formed which can result in different microbial growth and can eliminate most pathogens (Munazah & Soewondo, 2018).

The media used in constructed wetlands processing consists of soil, sand, and gravel. The function of the media in the CW system is as a living place for plant growth, a breeding ground for microorganisms, and a place for physical processes (sedimentation). The media used in CW is very helpful for the accumulation of organic matter, phosphorus, sulfate, arsenate, and the removal of pathogens (Stanković, 2017). CW systems have adsorption and sedimentation processes in the media. There are two stages of the adsorption process which are adsorption on the substrate surface and diffusion into the filter media. The adsorption process takes place faster because of the macropore diffusion movement resulting in smaller barriers (Singh & Walker, 2006).

Microorganisms that can develop in CW systems are aerobic heterotrophic microorganisms because treatment with microorganisms can run faster than anaerobically. The temperature of the water affects the quality of the wastewater effluent because it affects the detention time of wastewater in the reactor and the activity of microorganisms in wastewater treatment. The suitable temperature for constructed wetlands using cattail plants is 20-30°C.

Table 1: Water quality of Wonorejo River

Parameter	Value	Standard[4]
COD ($mg.L^{-1}$)	213,3[1]	25
TSS ($mg.L^{-1}$)	310[1]	50
DO ($mg.L^{-1}$)	4,09[1]	4
PO_4^{3-} ($mg.L^{-1}$)	0,063[2]	0,015
NO_3^- ($mg.L^{-1}$)	0,316[2]	10
NH_4^+ ($mg.L^{-1}$)	0,674[2]	0,2
pH	6,9[3]	6-9
Salinity ($mg.L^{-1}$)	6000[3]	-

Note: [1] *Wulandari & Ratni, 2024*
[2] *Arofah et al., 2021*
[3] *Pribadi et al., 2023*
[4] *GR No.22/2021 Concerning implementation of environmental protection and managemen*

The water quality analysis of Wonorejo River that has been carried out can be seen in **Table 1**. The results of the water quality analysis were compared with the quality standards of Government Regulation (GR) No.22 of 2021 Appendix IV concerning class 2 surface water for fisheries. The data showed that the parameters COD, TSS, PO_4^{3-}, dan NH_4^+ exceed the standard limits. The use of river water that was not meet these standards as raw water for aquaculture can affect the development of cultured fish. Therefore, river water needs to be treated first before it is used as raw pond water. Therefore, this study aims to identify the water quality of fish ponds and the performance of HSSF-CW technology in improving pond water quality.

II. MATERIALS AND METHOD

A. *Fish pond water sampling (raw fish pond and effluent pond water)*

Water sampling was conducted in Wonorejo Fish Pond with coordinates 7°18’44” S 112°49’29” E. The sampling location of this study was shown in **Figure 1**. Water sampling was at the inlet of the pond. Inlet and outlet channels on extensive or traditional ponds were the same. The samples were raw water and effluent ponds. Raw water was obtained from Wonorejo River water which was supplied once every 15 days into the fish pond. This condition was for ± 3 months of the hatchery process until harvest. the water in pond was added river water continuously 2 times a month. Pond effluent was obtained when disposing of pond water waste during the harvest period. Water samples were stored in sample bottles and stored at 4°C for preservation. These pond water samples were analyzed for water quality such as COD (SNI 6989.02-2019), TSS (SNI 06-6989.3-2004), PO_4^- (SNI 06-6989.31-2005), NO_3^- (SNI 6989.79-2011), NH_4^+ (SNI 06-6989.30-2005), DO (SNI 06-6989.14-2004), pH (SNI 06-6989.11-2004), and salinity (SNI 6989.19-2009).

Figure 1: Study Area

B. *Preparation artificial fish pond water*

This study used artificial fish pond water due to the large

amount of water used and the difficult distribution of water transportation locations. Artificial water was made by adding some chemicals to make water conditions similar to chemicals to make water conditions similar to conditions. Artificial water was made by adding clay, glucose, NH_4Cl, KNO_3, and KH_2PO_4 to adjust the parameters of TSS, COD, ammonium (NH_4^+), nitrate (NO_3^-), and phosphate (PO_4^{3-}) content in water. Salinity adjustment was conducted by adding pro-analysis *sodium chloride* (NaCl) (Chhim et al., 2019).

C. *Experimental setup*

This study used horizontal subsurface flow constructed wetlands (HSSF-CW) to improve pond water quality. The reactor used in this study can be seen in **Figure 2.** The HSSF-CW reactor with the addition of media were arranged with gravel (2-4 mm) 10 cm high and 7 cm sand 55 cm long. The reactor was operated continuously with flow rate (4 $mL.min^{-1}$ and 8 $mL.min^{-1}$). Acclimatized plants were planted at a density of 15 $plants.m^{-2}$. The plants were mangroves with *B. gymnorrhiza* and *A. alba* species. Both types of plants were used due to they were suitable for living on gravel media with stagnant water suitable for constructed wetland subsurface type. The ages of mangroves were 3 months so they have tight and compact roots. There were 10 reactors. The configuration of the reactor is as follows :

1. K1 (control without plants+without flow rate)
2. K2 (control without flow rate)
3. A1Bg (raw water+4 $mL.min^{-1}$+*B. gymnorrhiza*)

4. A2Bg (raw water+8 mL.min^{-1}+*B. gymnorrhiza*)
5. A1Aa (raw water+4 mL.min^{-1}+*A. alba*)
6. A2Aa (raw water+8 mL.min^{-1}+*A. alba*)
7. B1Bg (*Effluent*+4 mL.min^{-1}+ *B. gymnorrhiza*)
8. B2Bg (*Effluent*+8 mL.min^{-1}+ *B. gymnorrhiza*)
9. B1Aa (*Effluent*+4 mL.min^{-1}+*A. alba*)
10. B2Aa (*Effluent*+8 mL.min^{-1}+*A. alba*)

Improving pond water quality in this study begins with the acclimatization process followed by the organic matter removal stage. The acclimatization stage functions so that plants can adapt to the new environment. The initial adaptation process of plants was conducted by moving plants to the planting media in CW and then adding tap water for 3 days. After 3 days, the plants can adapt and then add artificial water. The process of adding artificial water was carried for 1 week to make plants adapt to the new environment. During the acclimatization process, temperature, pH, and plant condition were observed. The purpose of plant maintenance in the acclimatization process is to stabilize and adjust the wetland environment to start the biofilter process (Muhajir, 2013). The plant acclimatization process at HSSF-CW reactor was conducted for 1 week (Rozman et al., 2021). The operating HSSF-CW reactor was conducted for 16 days. The output of the HSSF-CW was analyzed for water quality every 4 days for 16 days (Chen et al., 2021).

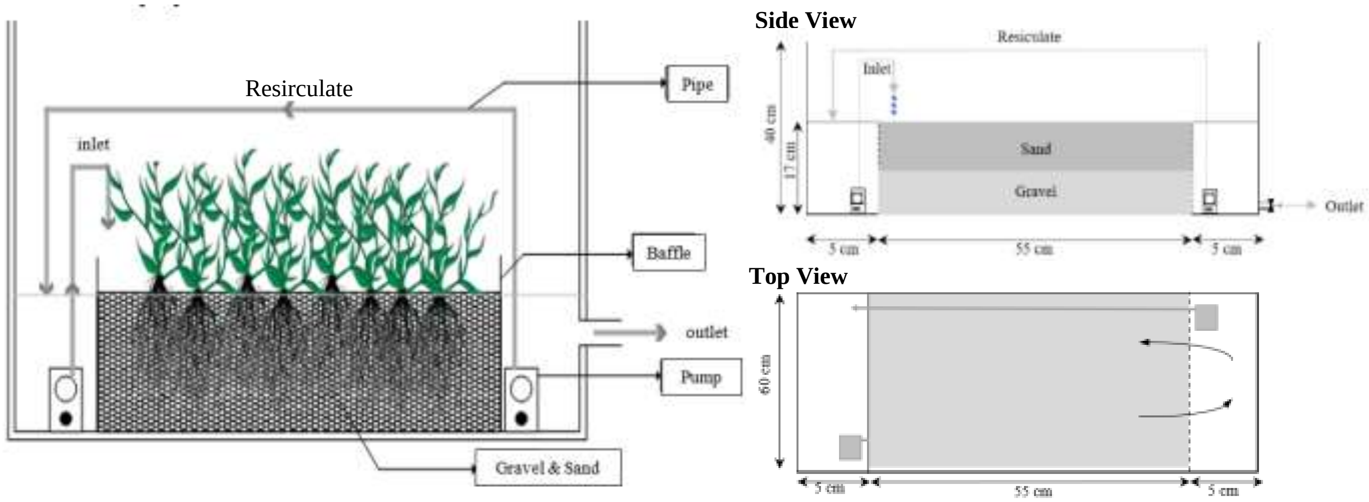


Figure 2: Lay-out reactor HSSF-CW

III. RESULTS AND DISCUSSION

A. Identification and characterization of fish pond water

Parameters DO, NO$_3^-$, pH, and salinity in raw water and effluent Wonorejo Pond meet the quality standards (**Table 2**). While other parameters such as COD, TSS, PO$_4^{3-}$, and NH$_4^+$ were exceed the maximum limit of quality standards. Respectivelt, COD in raw water and effluent samples amounted to 176 mg.L^{-1} and 446 mg.L^{-1}. COD in pond effluent was greater due to the accumulation of fish feces, feed residues, and microbes.

The high COD value can be caused by the high content of organic matter in the aquifer. The organic matter can be of natural origin as well as waste from agriculture, households, and industry. High COD values indicate a significant amount of organic matter in all forms both biologically degradable and non-biologically degradable that seeps into groundwater (Islam et al., 2019; Michalopoulos et al., 2016). The high COD value occurred, it possible that the dissolved oxygen content was sufficient to help bacteria in decomposing organic waste. COD value can be used as an indicator of the total content of organic substances (biodegradable and non-biodegradable) (Koda et al., 2017). River water entering ponds can carry a variety of pollutants such as oil, heavy metals, detergents, and organic matter. Thus, it can threaten the life in the pond.

Sources of organic matter can come from both inside and outside the pond waters themselves. Pollutants originating from within the pond waters were referred to as autochthonous. Autochthonous pollutants such as the decay of dead organisms by detritus, periphyton activity, macrophytes, and phytoplankton. Pollutants originating from outside the pond's water body are referred to as allochthonous, including organic matter carried by water flow from the surrounding area (Allan & Castilo, 2007). In this case, the quality of water in the pond is one of the determining factors for success in fish farming in ponds.

Table 2: Water quality of fish pond water

Parameter	Raw fish pond	Standard[1]	Effluent pond	Standard[2]
COD ($mg.L^{-1}$)	176	25	446	40
TSS ($mg.L^{-1}$)	114,96	50	207,82	200
DO ($mg.L^{-1}$)	3,87	4	3,13	4
PO_4^{3-} ($mg.L^{-1}$)	0,11	0,015	0,93	0,1
NO_3^- ($mg.L^{-1}$)	3,04	10	4,97	75
NH_4^+ ($mg.L^{-1}$)	6,78	0,2	7,18	0,1
pH	6,95	6-9	8,7	6-9
Salinity ($mg.L^{-1}$)	26.614	-	15.379	5.000 - 35.000

Note: *[1] GR No.22/2021 Concerning implementation of environmental protection and management*

[2] Minister of Marine Affairs & Fisheries Decree No.28/2004 Concerning shrimp cultivation in ponds

An increase in water temperature by 10°C can cause an increase in oxygen consumption by aquatic organisms by 2-3 times. However, an increase in temperature was often accompanied by a decrease in dissolved oxygen levels so the presence of dissolved oxygen was unable to meet the oxygen needs of aquatic organisms to carry out metabolic processes and respiration. Increased temperature also causes an increase in the decomposition of organic matter by microbes (Effendi, 2003). There was a relationship between dissolved oxygen and temperature in water. The salinity values of raw water and effluent ponds are 26.614 $mg.L^{-1}$ and 15.379 $mg.L^{-1}$. In general, the salinity value of pond water was in the salinity limit range of fish farming. The salinity allowed for vannamei shrimp cultivation based on KEPMEN No.28 Tahun 2004 was in the range of 5-35 ppt and optimum in the range between 15-25 ppt (Ferreira et al., 2011).

B. HSSF-CW treatment efficiency

1. COD removal

The COD values in the raw water samples and pond effluent can be seen in **Table 1**. COD removal in the HSSF-CW system hat has been done on 10 reactors can be seen in **Figure 3(a).** Reactor K1 (without plants + without flow rate) and K2 (without flow rate) have an insignificant difference in the COD removal process. This is because the removal that occurs due to the physical process in the form of filtration in the CW media used to remove organic matter trapped between the media by microorganisms (Ariany et al., 2020). which grows in gravel and sand media is more influential than bacteria derived from plants (Khairudin et al., 2015).

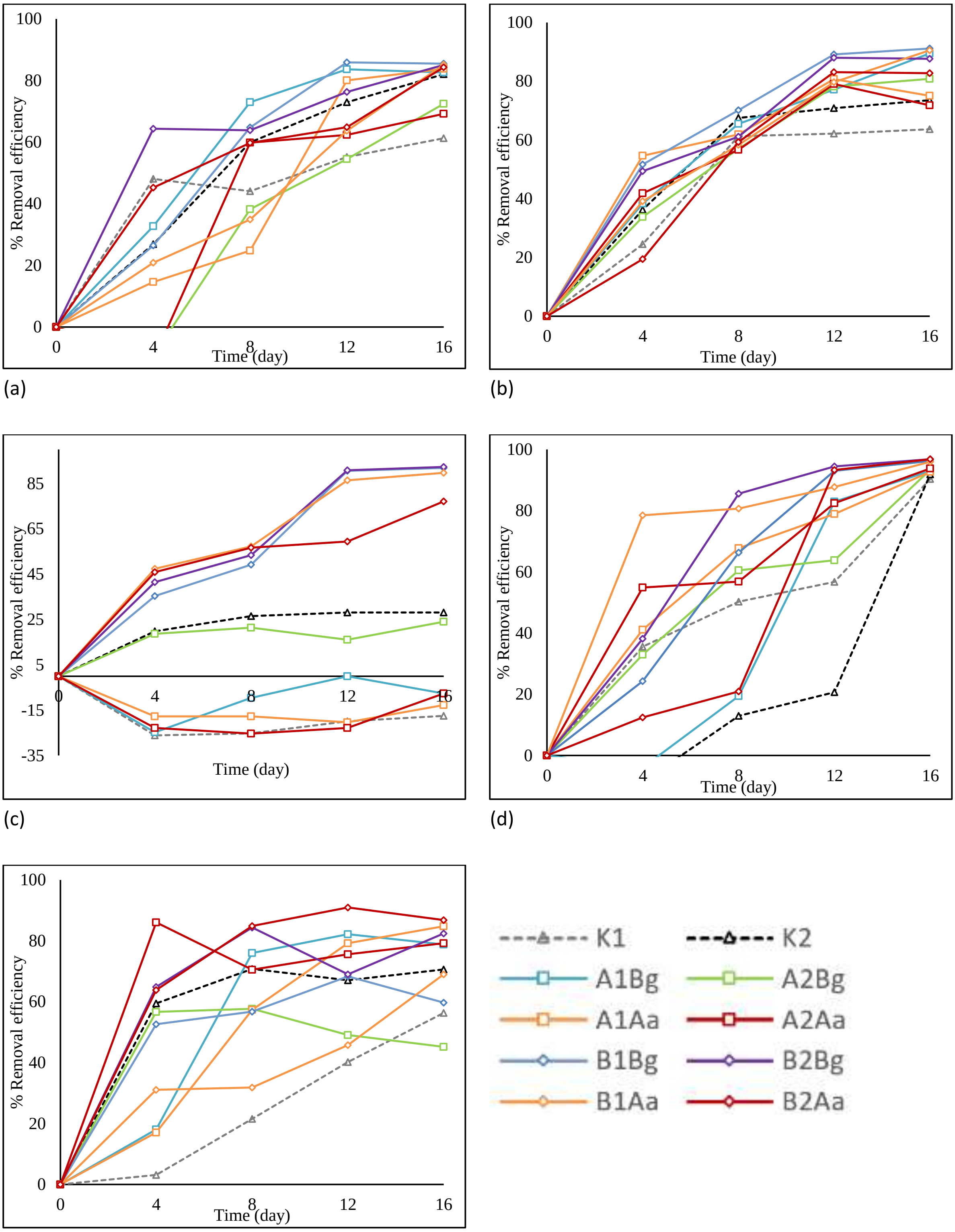
Changes in COD values in reactors A1Bg to B2Aa can be seen in **Figure 3(a).** The COD value during the reactor running for 16 days decreased. The COD value during the running of the reactor for 16 days decreased. The lowest COD removal efficiency in the pond raw water sample was found reactor A2Aa (69.20%). The largest COD removal efficiency in raw pond water was obtained in reactor A1Aa (83.86%). This condition occurred due to *A. alba* plants do not absorb glucose as a nutrient well. Nutrients needed by plants function for the development of microorganisms that will degrade organic matter in waste (Jacoby et al., 2017). The lowest COD removal efficiency in the pond effluent sample was found in reactor B2Aa (84.31%). COD removal efficiency in reactor B1Bg was the greatest, it reached 85.46%. The amount of COD removal efficiency was influenced by several things such as bacteria or microorganisms that grow in the reactor. The pump aeration factor in the reactor also affects the magnitude of the increase in COD removal (Rahmawan et al., 2023).

The magnitude of COD removal efficiency were influenced by several things such as bacteria or microorganisms that grow in the reactor. The pump aeration factor in the reactor also affects the magnitude of the increase in COD removal (Rahmawan et al., 2023). COD removal efficiency in pond effluent was greater than in raw water. This could be due to the ability of nutrient absorption in plant roots. Reactor B1Bg (using plants *B. gymnorrhiza*) while the raw water obtained the greatest efficiency in A1Aa (using plants *A. alba*). Nutrient absorption affects microbial activity that develops in the roots. The two types of plants have different microbial species that can affect the microbes that work to reduce COD in water.

Treatment using subsurface-constructed wetlands (SSF) can increase COD removal optimally for 1 month (Samsó et al., 2015). While COD in water represents organic content such as nitrogen and phosphate which affects the solid content. The carbon content in the CW system was used by microorganisms and used for the mineralization process in aerobic bacteria during the respiration process (Zemanová et al., 2010). Some factors that affect COD removal were ambient temperature, pH, plant age, and contact duration. High ambient temperature can affect the photosynthesis process. The photosynthesis process carried out by plants in the CW system can increase the absorption of organic matter in plants. The optimal temperature for aquatic plant growth is 25-30°C (Azzahra et al., 2015).

2. *TSS removal*

TSS during the reactor running process is shown in **Figure 3(b).** The TSS analysis results show that the concentration of dissolved solids has decreased. The TSS content decreased due to the filtration process in the media and root tissue in the media (Rahmani & Handajani, 2014). TSS levels began to decrease and comply with quality standards on day 8. The decrease in TSS concentration can also be influenced by the contact time of wastewater with microorganisms attached to the media (Rizki et al., 2020). Treatment with HSSF-CW with variations in plant species in CW and flow rate can increase TSS removal efficiency. The largest removal efficiency is in reactor B1Bg (91.21%). This is



(a) (b) (c) (d) (e)

Figure 3: Removal efficiencies (a) COD, (b) TSS, (c) PO_4^{3-}, (d) NO_3^-, and (e) NH_4^+ in fish pond water

because the flow rate used in the B1Bg reactor of 8 mL.min^{-1} affects the settling speed in the water. The settling speed is also influenced by contact time. The longer the processing time, the greater the efficiency of TSS reduction in synthetic water. The removal efficiency increases when the settling time increases (Wijayanto et al., 2019).

The TSS content decreased due to filtration, adsorption, and sedimentation mechanisms. The filtration mechanism occurred because the HSSF-CW media functions as a filter. The CW media used was very helpful for the accumulation of organic matter, phosphorus, sulfate, and arsenate, and for removing pathogens (Stanković, 2017). The adsorption mechanism affects the TSS content because the plant roots in the HSSF-CW system allow colloids and suspended solids in the water column to attach to the roots (Kasman et al., 2018). Sedimentation occurs when the remaining or unsuccessful organic substances will settle to the bottom of the media (Jaelani et al., 2018). TSS content in the form of solids can cause turbidity, blocking the entry of sunlight into the water which will interfere with the photosynthesis process and reduce dissolved oxygen levels (Sofiyullah & Munawwaroh, 2021).

3. *PO_4^{3-} removal*

Orthophosphate levels in the raw water artificial effluent and pond effluent before treatment were 0.101 and 0.935 mg.L^{-1} **Figure 3(c)**. Orthophosphate levels in both types of water samples exceeded the quality limit. The highest removal efficiency occurred in the B2Bg reactor which amounted to 92.29%. Phosphate removal with constructed wetland technology using *C. alternifolius* plants was found to be 93.25% (Azzahra et al., 2015). However, the treatment that has been carried out cannot reduce orthophosphate levels to meet the quality standards of raw water and pond effluent.

Reactors with a combination of raw water samples experienced an increase in removal efficiency. However, the removal efficiency of PO_4^{3-} on day of 8 onwards decreased. The PO_4^{3-} level of the raw water fluctuated during the 16 days of treatment. The PO_4^{3-} levels of reactors A1Bg, A2Bg, A1Aa, and A2Aa at the end of treatment were found to be 0.101 mg.L^{-1}; 0.051 mg.L^{-1}; 0.079 mg.L^{-1}; and 0.076 mg.L^{-1}. This fluctuation in PO_4^{3-} levels made the removal efficiency minus. This could be due to the plants being saturated. So the absorption of PO_4^{3-}- nutrients for plant needs was not going well. This condition occured because PO_4^{3-} levels have increased. The influencing factor was the condition of the media and plants that are saturated. Plants were saturated so they do not absorb nutrients. In addition, the continuous reactor can cause concentration saturated. The removal of PO_4^{3-} in CW was occured due to the mechanism of adsorption and sedimentation (Azzahra et al., 2015). The highest removal efficiency in effluent water occurred in reactor B2Bg which reached 92.29%. After treatment with HSSF-CW technology can reduce orthophosphate levels in water. However, the treatment that has been done cannot reduce orthophosphate levels to meet the quality standards of raw water and effluent ponds.

Orthophosphate is an important parameter to consider in CW systems. Orthophosphate is required in the biogeochemical cycles that occur in CW systems and is a nutrient required by microorganisms. In CW orthophosphate is present in the form of organic compounds and inorganic phosphate compounds. The phosphate cycle is fundamentally different from the nitrogen cycle. No valences are exchanged during biotic assimilation of inorganic P or organic decomposition of P by microorganisms (Vymazal, 2013).

The series of CW reactors had several concentration increases at several sampling points. An increase in nutrient concentration in a CW from a low concentration (*oligotrophic*) to a high concentration (*eutrophic*) can result in an increase in phosphorus in plant tissues (Kadlec & Wallace, 2009). Phosphate in the water entering the reactor was rapidly absorbed by bacteria, periphyton, and plants. Plants influence the degradation process of pollutants in HSSF-CW. Microbes attached to the roots are very important for the process of pollutant transformation and nutrient cycling in CW, especially the N and P cycles. Plants also transfer oxygen from outside through stem tissue to the roots. Excess oxygen conditions for plants can be utilized by microorganisms (heterotrophs) for microbial cell metabolic processes or degradation of pollutants which are nutrients for microbes.

4. *NO_3^- and NH_4^+ removal*

The composition of N in water treatment can be in various forms such as nitrite (NO_2^-), nitrate (NO_3^-), ammonium (NH_4^+), N bound by organic or inorganic materials (N-organic) (Putri et al., 2014). Nitrate content at high concentrations in water can stimulate unlimited algae growth so that water lacks dissolved oxygen which can cause fish death (Pribadi et al., 2016). Treatment with HSSF-CW technology that has been carried out can reduce nitrate levels in water **Figure 3(d).**

The data in **Figure 3(d)** can be used to compare the ability of reactors without plants (K1) and with plant reactors (K2). The efficiency of nitrate reduction in the K1 and K2 reactors was found to be 90.69% and 91.86%, respectively. The reactor with plants has a higher nitrate removal efficiency than the reactor without plants. This proves the role of plants can help reduce nitrate levels in water (Li et al., 2013). Plants play a role in the efficiency of nitrate removal (Vymazal, 2013).

The largest NO_3^- removal efficiency was occurred in the B2Bg reactor. The B2Bg reactor obtained good efficiency due to the denitrification process and absorption by plants as a nutrient source. Nitrate removal in CW showed the denitrification process. The denitrification process occurs due to anaerobic conditions at the bottom of the CW. This condition was very helpful for heterotropic species of bacteria such as Pseudomonas, Arthrobacter, acinetobacter, or bacillus in converting nitrate into nitrogen gas (Gunawan et al., 2013). Anaerobic conditions in CW are oxygen-deficient conditions. Thus, nitrogen reduction occured through the conversion of NO_3^- and NO_2^- into N_2 gas carried out by denitrifying bacteria. The high denitrification process in the anaerobic zone was characterized by low concentrations of NO_3^- and NO_2^- at the end of the process (Fajariyah, 2017).

The NO_3^- cannot be directly utilized by plants until it is reduced to ammonia. This reduction was catalyzed by enzymes in 2 processes. The first process occureds in the cytoplasm by nitrate reductase (NR) which converts NO_3^- into nitric acid (HNO_2). The second process occureds in the chloroplasts (shoots) or proplastids (roots) by nitrite reductase (NiR) which converts HNO_2 into NH_4^+. NO_3^- reduction process occured in both roots and shoots. The uptake and reduction of NO_3^- and the reductive ratio in roots and shoots depend on plant species, carbohydrates in the plant, and nitrate reductase (NRA) activity as well as environmental conditions such as NO_3^- concentration, media pH, complementary ions, light, and ambient CO_2 concentration (Li et al., 2013).

Groundwater pollution mainly by NO_3, NO_2^-, NH_4^+, and PO_4^{3-} were strongly affected by surface contamination sources such as domestic sewage effluents and fish farming and agricultural activities near the wells (Vetrimurugan et al., 2013). High ammonia concentrations will result in increased feed conversion but slowed growth and can irritate the gills of shrimp which results in disrupting shrimp breathing (Wyk et al., 1999).

Treatment with HSSF-CW technology is proven to reduce ammonium levels in raw water and pond effluent. Ammonium levels in raw water and effluent exceeded the quality standards of **Figure 3(e).** However, treatment with HSSF-CW technology can reduce the levels of raw water and effluent ponds. Ammonium removal was influenced by plants in CW. Reactor K1 (without plants) had a lower NH_4^+ removal efficiency than the other reactors. This is due to the role of plants in the CW system. Plants will take some of the ammonium in the water for nutritional needs. Therefore, ammonium in the water will decrease in concentration. The decrease in NH_4^+ occurs through the process of adsorption by the media, aerobic microbial activity, and uptake by plants, and the high decrease in NH_4^+ indicates that the nitrification process runs very well (Fajariyah, 2017).

Roots were the main organ for the absorption of NH_4^+ and NO_3^-. Both forms of N ions can passively enter the root epidermal wall through the symplast and apoplast. Then vertically the two ions enter the simplest cortex towards the endodermis. The ions in the endodermis enter the xylem or are stored in vacuoles. Once in the xylem, NH_4^+ and NO_3^-. are transported to the shoots through transpiration (Li et al., 2013).

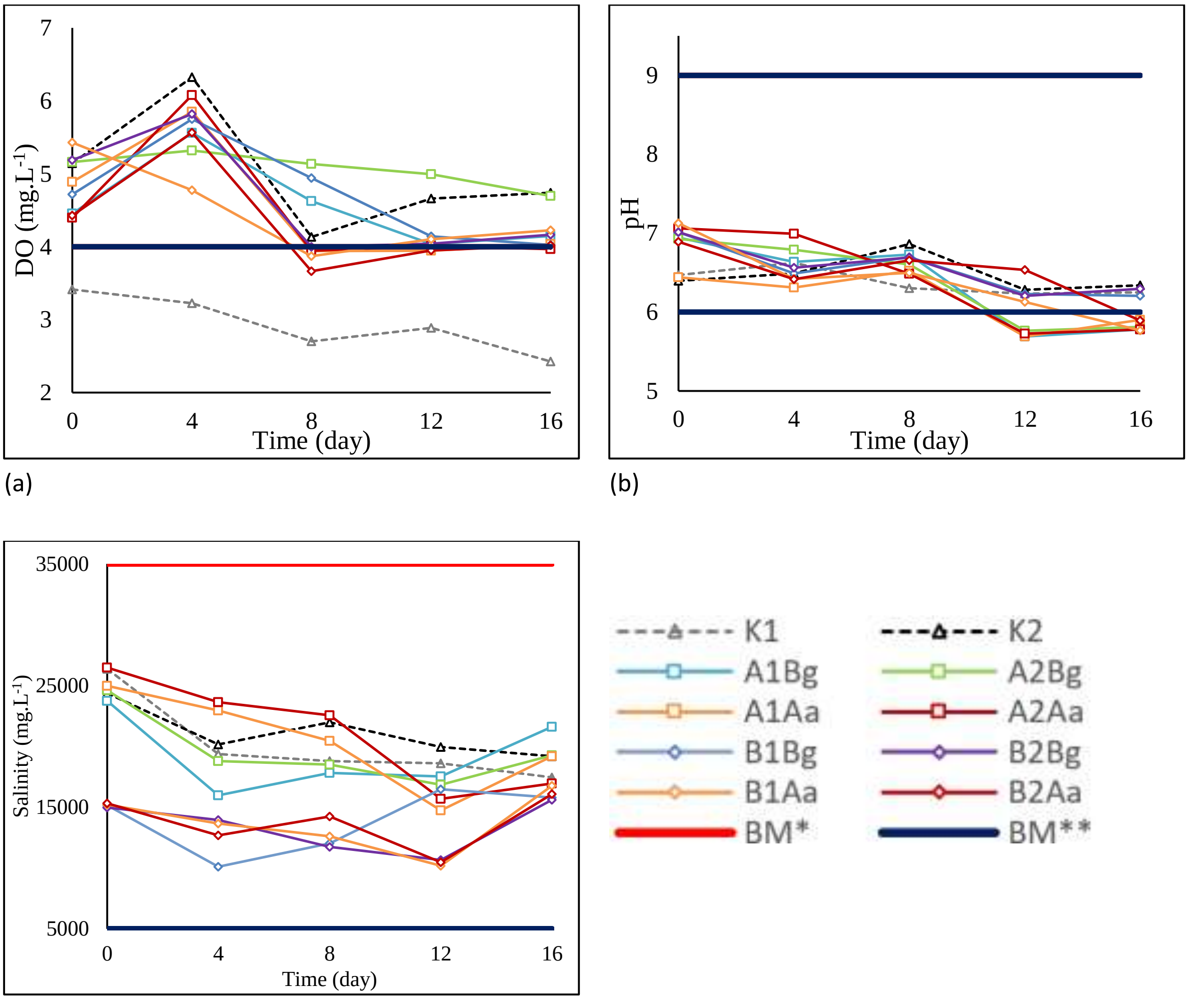
Overall, it can be concluded that NH_4^+ reduction is influenced by the nitrification process that occurs under aerobic conditions. Plant uptake, aerobic microbial activity, and the media used in CW can support the reduction to occur better. The uptake ability of plants was influenced by the physiological characteristics of plants such as roots. The condition of more fibrous and long roots provides more space for microorganisms in the roots so that it can provide a high oxygen supply and increase microbial activity in the nitrification process.

5. DO

Dissolved oxygen content or DO during treatment with HSSF-CW technology can be seen in **Figure 4(a).** DO in K1 was lower than the other reactors. This study showed that the K1 reactor (without flow rate) has a DO of 2.42 mg.L^{-1}. This was because the K1 reactor was not powered by a pump which creates an aeration factor in the CW system. The effect of aeration can make oxygen conditions in CW increase. This was due to the air injection from the pump which increases the dissolved oxygen content in the wastewater in the reactor (Hidayah et al., 2018).

Aeration was made by air supply from a pump. An active pump will stabilize the dissolved oxygen content. DO in K1 for 16 days tends to decrease due to the absence of aeration. DO was useful for increasing the activity of microorganisms so that they can decompose organic matter (Metcalf & Eddy, 2003). The decomposition process by microorganisms can reduce the DO content in the water. The higher the organic matter, the more oxygen was needed by microorganisms, causing a decrease in dissolved oxygen in these waters even in anaerobic conditions (Hidayah et al., 2018). The low oxygen concentration was influenced by the groundwater level, the concentration of organic matter in the aquifer, the biological consumption of oxygen in the soil, and the oxidation-reduction potential in groundwater (Ouyang et al., 2020).

The purpose of aeration itself was for oxygen enrichment in ponds, to neutralize the activity of bacteria, and to reduce CO_2 levels and decomposition of organic material that may cause odors. Aeration can increase the carrying capacity in an aquaculture system, where dissolved oxygen is a limiting factor. Oxygen content greatly affects growth and feed efficiency. If the dissolved oxygen concentration was low, the cultivated animals can not eat well, their growth can be inhibited, they will be susceptible to disease, and may even die. Aeration is required to supplement natural food sources. Oxygen was necessary for the production of all species of fish and crustaceans. Aeration was an effective way to increase the value of dissolved oxygen in a water body (Das & Mukherjee, 2003).



(a)

(b)

(c)

Figure 4: Concentration of (a) DO, (b) pH, and (c) salinity during operation of HSSF-CW

6. *pH and salinity*

Treatment with the HSSF-CW technology did not show any major changes in the pH and salinity of the raw water **Figure 4(b).** pH and salinity conditions during treatment with HSSF-CW technology. Changes in temperature, pH, and salinity that exceed quality standards can adversely affect the distribution pattern of biota, especially benthic/bottomwater organisms (Bochert et al., 1996). Changes in pH in wastewater indicate that there has been microorganism activity that degrades organic matter. The degradation of proteins and N-organics into ammonium (NH_4^+) can raise the pH to alkaline (Polprasert, 1989).

The relationship between salinity and temperature was that if the temperature drops, the salinity also tends to decrease. This condition occurred due to the effect of evaporation when the temperature increases. Salinity can directly affect water quality (Jóźwiakowska et al., 2020). The relationship between temperature and pH was that temperature can increase the rate of chemical reactions in water including acid-base, so that when the water temperature rises, the pH of the water can also tend to increase. Reactors A1Aa, A2Aa, B1Aa, and B2Aa tend to have low salinity. This condition occurred due to *A. alba* plant can absorb water with high salinity levels. *A. alba* plants are secreter mangroves that have a salt gland structure (salt gland). Salt glands in secreter mangroves function to secrete liquid Na^+ and Cl^- (Onrizal & Kusmana, 2009).

IV. CONCLUSION

This study investigated that the quality of raw water and effluent of Wonorejo Fish Pond still do not meet the quality standards on several parameters namely as COD, TSS, PO_4^{3-}, and NH_4^+. The values of COD, TSS, PO_4^-, NO_3^-, NH_4^+, DO, pH, and salinity in the raw water samples are 176 $mg.L^{-1}$; 114,96 $mg.L^{-1}$; 3,87 $mg.L^{-1}$; 0,11 $mg.L^{-1}$; 3,04 $mg.L^{-1}$; 6,78 $mg.L^{-1}$; 6,95; and 26.614 $mg.L^{-1}$. Respectively, while the pond effluent samples were 446 $mg.L^{-1}$; 207,82 $mg.L^{-1}$; 3,13 $mg.L^{-1}$; 0,93 $mg.L^{-1}$; 4,97 $mg.L^{-1}$; 7,18 $mg.L^{-1}$; 8,7; and 15.379 $mg.L^{-1}$. HSSF-CW treatment with plant variations (*B. gynorrhiza* and *A. alba*) and flow rate (4 $mL.min^{-1}$ and 8 $mL.min^{-1}$) could increased the removal efficiency of organic matter in pond water. The largest removal efficiency of raw fish pond water on COD, TSS, PO_4^{3-}, NH_4^+, and NO_3^- parameters were obtained in reactor A1Aa (83.86%), A1Bg (89.53%), A2Bg (24.06%), A1Aa

(84.83%), and A2Aa (93.77%). The highest removal efficiency of effluent pond on COD, TSS, PO_4^{3-}, NH_4^+, and NO_3^- parameters were obtained in reactor B1Bg (85.46%), B1Bg (91.21%), B2Bg (92.29%), B2Aa (86.81%), and B2Bg (96.84%). Technology HSSF-CW treatment was proven to improve the water quality of fish ponds so that it can be used for pond water needs.

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