Diurnal variation of the water quality parameters in the waste stabilization ponds (WSPs) for water treatment of integrated multi-trophic aquaculture (IMTA) ponds with closed recirculation system

G A Ajie1* and N Setiadewi1
1Research Center for Limnology, Indonesian Institute of Sciences (LIPI), Jl. Raya Bogor Km. 46 Cibinong 16911 Bogor Indonesia

*Correspondence author
Email: ajie@limnologi.lipi.go.id

Abstract. Organic wastes from Floating Fish Cage Aquaculture (FCA) activities have polluted many inland water bodies, from small reservoirs to major lakes in Indonesia. It has become a national priority to restore ecosystem health in Lake Maninjau. The lake has suffered from the harmful effects of approximately 17,000 units of FCA on its surface area. Better FCA practices that would improve its adjacent water quality have been proposed. The FCA should utilize a more excellent net that would confine its waste. Using a connection pump, the wastewater within this net could then be circulated into a wetland system for its water quality improvement. The proposed wetland system consists of a series of Waste Stabilization Ponds (WSP) and Constructed Wetland Compartments. For the initial stage, a study has been conducted to test the performance of the WSP with approximately six days of hydraulic retention time (HRT) to improve water quality from the Integrated Multi-Trophic Aquaculture (IMTA) ponds in the Prototype Laboratory of Research Centre for Limnology-LIPI. Two major problems in IMTA, namely organic deposition and low of dissolved oxygen (DO), especially concerning its diurnal variations in the system, have not been studied yet. Water qualities of the WSP ponds were measured every 2 hours for three days (22-25 May 2019). Water quality parameters measured were pH, conductivity, dissolved oxygen (DO), turbidity, temperature, oxidation and reduction potential (ORP), and total dissolved solids (TDS). A closed re-circulation within the WSP system was then applied for the last two days of the study period. The result showed that DO values in the effluent pond during the day were significantly higher than the night. In the maturation and facultative ponds, DO values difference ranged from 2.5-3 mg/L and 1.1-4.4 mg/L, respectively. The highest DO (5.98 mg/L) was measured in the maturation pond at 3.00 PM and values were lowest almost to 0 mg/L during the first day in the anaerobic ponds. While for turbidity, the highest was observed in the anaerobic ponds for 41 NTU and were decreased to stable values of an average of 5.3 NTU in the maturation pond on the third day. At the end of the observation, marked increase of DO and decrease in turbidity have occurred in the system. A closed recirculation system within WSP can be used as an option to increase the performance of the wetland system.

Keywords: diurnal variation, water quality, waste stabilization ponds, IMTA aquaculture.
1. Introduction
The development of Floating Fish Cage Aquaculture (FCA) in Indonesia's inland waters, e.g. lakes, reservoirs, situ, and others, for the utilization of the ecosystem, has become an increasing trend. At Lake Maninjau, FCA began in 1996 with introduction of only four units which then increased rapidly to 15,000 units in 2008 that had covered almost the entire lake surface [1]. FCA is famous due to the enormous profits that can be obtained in a short time with low capital. It takes only three months to get a net profit of 2.4 million for the total operational costs of 7.9 million rupiahs [2]. This type of aquaculture is also preferred due to the easiness of both maintenance and operational [3] e.g. allow fewer concerns for the water supply during the dry season.

Supporting national fish production, Lake Maninjau can offer its potential use, which is enormous. In 2015, there were more than 62,000 tons of fish production resulted from FCA activities in this lake. However, the environmental burden as the result of FCA is immense. Intensive feeding activities within a large number of FCA in Lake Maninjau have caused degradation in lake water quality [4]. The problem was aroused due to the seemingly high input of nutrients (N and P) and organic materials (OM) from FCA waste into the lake ecosystem [5]. The decline in the water quality of the lake can be seen from its frequently low of dissolved oxygen (DO) in lake surface area [6]. During critical times, DO values were found to be zero [7]. The low DO in the lake water surface might be caused by the excessive oxygen consumption from the microorganisms to metabolize FCA organic waste load. It has triggered many catastrophic mass deaths of fishes in Lake Maninjau. In November 2010 alone, the loss was recorded at 24 billion rupiahs with the fish deaths of 1,657 tons. This anoxic condition has also caused the emergence of toxic sulfides from the bottom of Lake Maninjau [8]. The presence of FCA on the banks of the lake (littoral zone) accompanied by the foul smell of sulfide gas from its surroundings has damaged the lake aesthetics of the Lake Maninjau and subsequently reduced the number of tourists coming to this lake.

Since 2018, the Limnology Research Centre-LIPI has been involved in national priority research projects to contribute not only concepts but also technologies that could support the ecosystem rehabilitation of the Lake Maninjau. It is known that the best practice of FCA that could process its waste before returning the water to the lake ecosystem has been proposed. Lake water in the area of FCA should be contained for then pumped into a wetland system to improve its water quality. The proposed wetland system consists of a series of Waste Stabilization Ponds (WSP) and Constructed Wetland Compartments. For the initial stage, a study has been conducted to test the performance of the WSP to improve water quality within the Integrated Multi-Trophic Aquaculture (IMTA) ponds in the Prototype Laboratory of Research Centre for Limnology-LIPI. Two major problems in IMTA, namely organic deposition and low of dissolved oxygen (DO), could be reduced by applying WSP [9]. However, the information concerning diurnal variations in the system was not available. This research also aims to study the diurnal fluctuations of the water quality in the WSP system using a closed re-circulation system in treating water quality from the IMTA ponds.

2. Methods
WSP consists of a series of anaerobic, facultative, and maturation ponds with a dimension of 1.5 m x 1.5 m x 3 m; 2 m x 5 m x 1.7 m; 2.2 m x 7 m x 0.7 m, respectively. This system was connected through the form of pipes that will allow water flow until a similar surface water level between all of the connected ponds is reached. These connection pipes were also used to draw water from the IMTA ponds to be treated for approximately six days of HRT in the wetland system. The treated IMTA water came from 2 series of Catfish (Clarias sp.) ponds (approx. 1000 fish/pond), which were intensively fed with fish pellets connected with 3 Duckweed (Lemna sp.) ponds with the dimension of 2 m x 5 m x 0.7 m of each (figure 1.) Water qualities from each of the WSP ponds were measured every 2 hours for three days (22-25 May 2019) using pre-calibrated Horriba®U 52 water quality checker and DO meter Pro DO YSI® International. Water quality parameters measured were pH, conductivity, DO, turbidity, temperature, oxidation and reduction potential (ORP) and total dissolved solids (TDS). A closed re-circulation within the WSP system was then applied for the last two days of the study.
periods. In this private re-circulation system, WSP was no longer receiving any additional influents from IMTA ponds, while the effluents were pumped back into the anaerobic ponds with a flow rate of 70 mL/sec.

Statistical analysis was performed using Statistical Analysis for Social Science (SPSS) with 13.0 version. Parametric tests were carried out using a t-test while non-parametric tests were conducted using Wilcoxon test. These tests were applied 95% of confidence interval with P<0.05 concluded as the test statistically significant. The results were presented with the degree of freedom (df) along with results values obtained from each test (Z for Wilcoxon test and t for t-test). Normality distributions of the data were analysed using Shapiro Wilk test. Daytime observation data were obtained during available sunlight for photosynthesis from 7:00 a.m. to 5:00, while the night time data group were measured from 7:00 p.m. to 5:00 a.m.

![WSP-IMTA Layout](Image)

**Figure 1. WSP-IMTA Layout.**

3. Results and Discussion
The Applied WSP system within the IMTA ponds was able to increase DO significantly and reduce the turbidity from highly organic turbid water. Intensive feeding within IMTA has resulted in murky water containing high nutrients and organic compounds. These compounds have led to low oxygen in the water and further organic waste sedimentation in the basin of the ponds. Applied WSP system allows suspended solids to be deposited and further enabled the water to be oxygenated using naturally occurred photosynthesis.

An increase in the daily mean of DO within these three ponds was found during the observation period. The mean DO was lowest in the anaerobic pond for 1.8 ± 1.42 mg/L and was highest for 3.5 ± 1.14 mg/L in the maturation pond. The lowest DO of 0.06 mg/L was found in anaerobic ponds on the 1st day morning, while the highest was found on the 3rd day afternoon (at 03:00 p.m.) in the maturation pond for 5.98 mg/L (figure 2). Using the closed re-circulation system, WSP could significantly increase the DO (t = -2.333, df = 11, P <0.05) within the maturation pond that would later serve as an outlet of the water. A significant difference (t = 3.274, df = 34, P <0.05) between DO at daytime (4.04 ± 1.22 mg/L) and during the night (2.95 ± 0.7 mg/L) in this pond was also found. Photosynthesis and respiration, primarily by phytoplankton, would cause these DO variations [10]. DO would be produced and added to the water due to photosynthesis occurred during the day, while in the night, the available oxygen would be consumed by respiration. It is thus also necessary to measure DO during the night to determine the actual values of the water outlet.
Figure 2. Diurnal DO variations within WSP.

DO values in the anaerobic pond were steadily increased due to the closed re-circulation water system implemented on the 2nd day. With an average flow rate of 70 mL/sec, in just a day, water in the anaerobic pond has been entirely replaced by the water from the maturation pond. The anaerobic ponds within WSP typically have a short retention time between 1-3 days for the biological oxygen demand (BOD) higher than 100g/m3 day. The removal of anaerobic conditions from this pond could be attributed to the dilution of the top DO from the effluent water from the maturation pond. This condition would also imply that the BOD treated within the IMTA water was relatively low in the range of WSP operational standards. This re-circulation water system also created a smaller peak of maximum DO in both the facultative pond and the maturation pond on the 2nd day. These could be happened due to water content from both previous treatment ponds (the anaerobic and the facultative) that have a lower DO value and higher organic matter content mixed with water at the further processing ponds. Although the biological-chemical process that occurs in both ponds, mainly photosynthesis, would then allow re-increase in the peak of DO value in the 3rd day of observation.

Overall, by using closed re-circulation water system in WSP, the DO values tend to raise [11] and the distance between the maximum and minimum peaks were able to be reduced in all of the treatment ponds. Thus, it could create stable DO conditions and better quality of the effluent water.

The treated water became more transparent on the third day (figure 3). The mean turbidity decreased from anaerobic to maturation pond with a value of $12.16 \pm 8.82$ to $5.26 \pm 2.8$ NTU. The closed re-circulation system within the WSP could significantly reduce the turbidity of the water treated ($Z = -2.86, P <0.05$). The decrease in average daily turbidity in the maturation pond of from $4.99 \pm 3.2$ NTU to $4.52 \pm 1.96$ NTU was not significant ($t = 0.387, df = 11, P> 0.05$) because on the beginning of the study water conditions were clear with shallow values in the turbidity. The effluent water turbidity from the WSP treatment could then qualify as the water source for agriculture purposes according to the Indonesian government regulation no.82 year 2001.
Figure 3. Diurnal turbidity variations within WSP.

Turbidity values were highly fluctuated in small dimensions of anaerobic ponds due to input water from both IMTA ponds and the maturation pond. Peak values on turbidity in all WSP ponds during the day after water re-circulation could be attributed to the biomass formed from the photosynthesis of phytoplankton [12][13].

Photosynthesis may also affect the increase values in pH (figure 4). This process would consume acidic CO2 in pond water and increase the pH of the ponds [14]. pH in anaerobic ponds were not initially following the pattern. However, with re-circulation water in WSP, the pH value also increased in this pond as the water flowed from the maturation pond.

WSP pool temperature ranged between 26.9-29.84°C (figure 5). The difference in the average temperature during the day and night for all WSP ponds were not significant. Statistics test results for each ponds were t=1.165, df=17, P>0.05 for anaerobic ponds, t=0.89 df=17 P>0.05 in facultative ponds, and t=1.363, df=17 P>0.05 in maturation pond. The increase of temperature can be triggered by sunlight penetration during the day; however, in the night, the temperatures were maintained by water medium in the ponds.
Figure 4. Diurnal pH variations within WSP.

Closed recirculation system in WSP could have water quality improvement between these ponds affect each other [15]. The water qualities within the WSP were more homogeneous on the third day. Both ORP and conductivity (figure 5 & 6) values pattern showed this tendency. The ORP values tend to increase as more DO was available in the water [16] [17], while conductivities of the turbid water tend to decrease as the water was getting more transparent in the anaerobic pond [17] [18]. Due to TDS (figure 7), values are calculated in measurement tools based on equations that are directly proportional to conductivities. Therefore the homogenous pattern can also be seen in its results. Moreover, size is one of the main limitations of WSP performance. Thus, re-circulating effluent water provides possible alternative to increase WSP capacity in wastewater treatment [19].
4. Conclusion
The research proved that the existence of the WSP system could increase the water quality within IMTA ponds. As an initial stage with the laboratory scale prototype, this system is capable to overcome two major problems within IMTA, which are organic deposition and low of dissolved oxygen. Closed re-circulation system applied can be used as an option to improve the performance of the WSP without increasing its size.
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