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Water Reclamation Using Constructed Wetland in Indonesia Fish Canning Industry

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Wetland is an effective system in water conservation and water reclamation due to its natural water purification capability consisting of several mechanisms e.g. filtration, absorption, adsorption, bioconversion, biodegradation, pathogen neutralization, that can remove inorganic, organic and biological pollutants in water. In Indonesia, fish canning industry is one of the major maritime industries that support the economy and food security and will continue to grow along the years. It is also a water-intensive industry that requires a lot of clean water during the operations and processes. It is a necessity to have a water conservation scheme that can anticipate the growth of this industry. In this study, the implementation of constructed wetland in wastewater treatment plant (WWTP) at one of the fish canneries in Bali, Indonesia, was evaluated using a small-scale vertical-subsurface-flow constructed wetland planted with Typha angustifolia. 10 L of the effluent from WWTP was flowed into the wetland constructed with media composed of sands and gravels, and a hydraulic conductivity of around 0.5 m/h was maintained by sieving the sand and gravel particles into certain size ranges. The liquid was recycled several times to simulate retention times of 24, 48 and 72 h. At 24-h treatment the average removal rate of TSS and COD were 87 %, and 63 %. Further increase of treatment time to 72 h could improve the average removal rate of TSS and COD up to 90 % and 72 %. Around 0.4 ppm of sulfide was also detected in one of the WWTP effluent sample, indicating a possible system failure in the aerobic treatment tank. The wetland could reduce sulfide concentration significantly lower than detection limit of standard analysis method. In conclusion, constructed wetland is a potential method to treat and stabilize the WWTP effluent further for recycling use in the production process. A larger-scale study using subsurface-flow constructed wetland is worthy to be pursued for full scale implementation of water reclamation in Indonesia fish canning industry.

1. Introduction

Wetland is a natural ecosystem composed of many components that can act as water treatment units. It can be considered a full water treatment system by itself, that has an adsorption and filtration unit which is the soil or sediment as the primary treatment and a biological reactor which is the microorganisms or plants that can degrade and absorb pollutants as the secondary treatment. The natural microorganisms in wetland can also help neutralizing pathogenic microorganisms that might enter the wetland along with the influent. Because of these characteristics, wetland can be considered a very effective and energy-efficient natural water purification system that relies mainly on sunlight as the energy source. Many cities around the world preserve nearby natural wetland not only for its biodiversity but also as part of municipality water purification system. When integrated with municipal wastewater treatment system, natural wetland can serve as tertiary treatment to refine the water quality so that it can be reused as raw water to produce clean water for the city uses.
A man-made wetland, so-called constructed wetland, has already been a subject of study since many years ago. US EPA has already established guidelines for municipal wastewater treatment using constructed wetland as early as 1988 (US EPA, 1988). The application of constructed wetland for other type of wastewaters, i.e. agricultural wastewater, domestic wastewater, coal mine drainage, and storm water has also been established as a handbook by USDA cooperating with US EPA and Pennsylvania Department of Environmental Resources (US EPA, 1995).

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There are two types of constructed wetland, the surface-flow (SF) and the subsurface-flow (SSF) wetland. The surface-flow wetland has a free-flowing water layer on top of its soil layer as shown in Figure 1. Vegetation used in this type of wetland could be floating plants such as water hyacinth (*Eichhornia crassipes*) or plants with roots embedded into the soil such as cattail (*Typha angustifolia*) depending on the water level in the wetland.

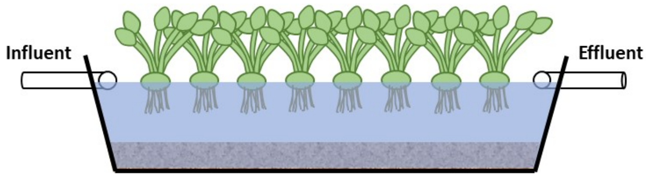

Figure 1: Illustration of surface-flow wetland using floating plants

On the other hand, the water in subsurface-flow wetland is flowed through the soil layer horizontally or vertically from top to bottom as shown in Figure 2. According to US EPA (2000), some of the commonly used vegetations in SSF wetland are cattail (*Typha* spp.), bulrush (*Scirpus* spp.), and reeds (*Phragmites* spp.). In Indonesia, vetiver (*Chrysopogon zizanioides*) is also commonly used in studies and real practices of wetland for example the study conducted by Astuti et al. (2016) on canteen wastewater treatment using vetiver on SSF wetland or the use of vetiver wetland in land revitalization and sewage treatment projects in Indonesia (Vetiver Indonesia, 2007).

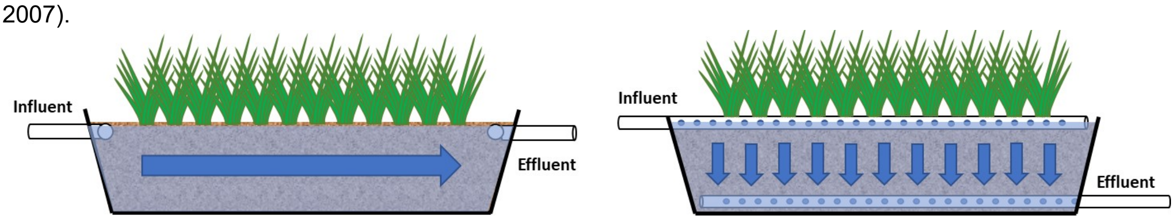

Figure 2: Illustration of horizontal (left) and vertical (right) subsurface-flow wetland

Both types of wetland have their own advantages and disadvantages. SF wetland is more flexible in the flow rate design as no solid layer prevent the movement of the water, resulting in a possibility to design compact wetland with low hydraulic retention time (HRT) as long as the treatment performance can be maintained as shown by Salim et al. (2017). However, maintenance of the system may prove challenging due to the need to remove excess vegetations routinely to prevent septic condition in the wetland.

On the other hand, SSF wetland has the advantage of filtration system due to its soil layer. Pores in the solid media can block particles with size larger than the pores from passing through it. However, the soil porosity that controls the hydraulic conductivity of water must be maintained properly to prevent clogging and reduced efficiency in the system. The plants and microorganisms in the soil could also help improve the treatment efficiency and effectiveness significantly on the removal of organic and inorganic pollutants, either by biodegradation or by absorption into their biomasses.

Despite its frequent uses in sewage and wastewater treatments in Indonesia, the research and implementation of wetland as an integrated system in water reclamation connecting the wastewater treatment and clean water treatment systems has been minimal.

Fish cannery is well-known for its water-intensive processes and operations that consumes a lot of clean water, for example thawing of frozen fish, cutting and cleaning of fish, steam sterilization of canned fish called retorting, and after-production cleaning and washing. In fact, observation of water balance in the fish cannery revealed that thawing and retorting cover more than 50 % of daily water usage in this industry that could reach more than 1000 m^3/d. A successful application of water reclamation system in fish cannery will have two positive impacts on the environment, the reduction in fresh water intake from external source leading to water conservation and the reduction in wastewater discharge to the environment that could help minimizing environmental pollution.

This study is aimed to assess the performance of vertical SSF wetland in refining the effluent quality of wastewater treatment plant in a fish cannery in Bali for recycling use. The data collected in this study will be important in designing and implementing a full-scale integrated wastewater and water treatment system using wetland as its tertiary treatment to refine the quality of effluent for recycling use.

2. Experimental methods

The wastewater used in this study as influent was sampled from the effluent of wastewater treatment plant in a fish cannery in Bali. The parameters of water quality that were analyzed are pH, temperature, total suspended solid (TSS), chemical oxygen demand (COD), ammonia and sulfide concentrations.
The SSF wetland used in this study was composed of several layers of gravel and sand as shown in Figure 3. The bottom layer was coarse gravel with particle diameter of 20.1 to 50 mm, and the main layer of sand with diameter of 1 to 2.5 mm was positioned on top of it between two layers of fine gravel with diameter of 2.6 to 20 mm. The influent was introduced into the wetland using a perforated pipe placed on top of the solid media, and the effluent was collected after it passed through coarse gravel layer at the bottom.

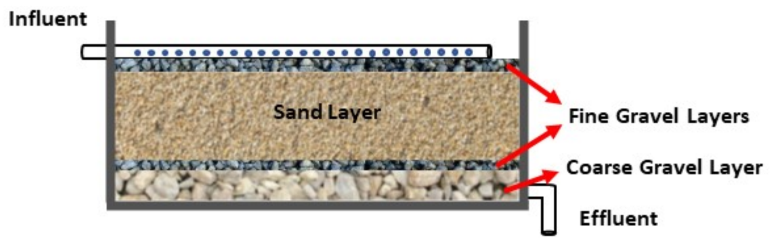

Figure 3: Schematic diagram of SSF wetland in this study

The solid media was placed in a brick vessel with dimensions of 60 cm, 39 cm and 40 cm for its length, width and height. The thickness of each layer was 1.4 cm for both layers of fine gravel, 12.9 cm for sand layer and 4.3 cm for the layer of coarse gravel. Hydraulic conductivity tests were also carried out to observe the change of the media conductivity when vegetation was planted on it.
The vegetation used in this study is cattail that is commonly found in Bali. It is selected due to the fast-growing characteristic that requires large quantity of nutrients for its growth. 2-month-old plants with height averaging at around 1.5 m were used for the experimentation because it is considered that these plants were still in growing state and can provide a relatively high absorption rate and good treatment performance.
Prior to experimentation in the constructed wetland, acclimatization of the vegetations were conducted to prevent shock loading to the vegetations using another vessel where they are placed and contacted with diluted concentration of wastewater that were increased daily until reaching the actual pollutants load as shown in Table 1. The acclimatization was conducted for 9 d in total, and the actual experimentation in the constructed wetland using full load (100 %) of wastewater started at day 10. No additional substrate or nutrient was added for the vegetation growth during the acclimatization step and the actual experimentation.

Table 1: Volume ratio for wastewater dilution in acclimatization step

Day	Clean Water	Wastewater
1	90 %	10 %
2	80 %	20 %
3	70 %	30 %
4	60 %	40 %
5	50 %	50 %
6	40 %	60 %
7	30 %	70 %
8	20 %	80 %
9	10 %	90 %

In the experimentation of treatment using the constructed wetland, the wastewater was flowed and recycled back from effluent tank to influent tank to simulate a hydraulic retention time (HRT) of 72 h or 3 d in total for each run. At the start of each run, wastewater filled in a 10-L vessel was also observed simultaneously as a control test without any wetland treatment. 6 units of cattails were evenly spaced inside the wetland with roots reaching 9-cm depth from the top layer.
pH, TSS and COD were measured at the start of experimentation run and also in every 24 h. Ammonia and sulfide concentrations were measured at the beginning (0 h) and at the end (72 h) of the run.
The experimentation was replicated five times and the pH, TSS and COD values were shown as average values in the next section.

3. Results and discussion

Table 2 shows the wastewater quality sampled from the effluent of wastewater treatment facility in the fish cannery. The pH, TSS and COD were shown as a range of values as they were measured from 5 different samples taken at different days. It can be seen that the wastewater treatment facility produced effluent with fluctuated quality that actually depended on the production load during the sampling day. This result also suggested that optimization and capacity increase of the treatment facility is required to meet the wastewater quality standards set by Indonesian government that requires TSS and COD to be less than 100 and 150 mg/L (Indonesian Ministry of Environment, 2014).

Table 2: Effluent quality from fish cannery wastewater treatment facility

Parameter	Value	Unit
pH	8.04 - 8.48	-
TSS	495 - 1570	mg/L
COD	306 - 600	mg/L
Sulfide	0.438	mg/L
Ammonia	29.215	mg/L

The results in Figure 4 shows that after planting vegetation in the wetland media, the hydraulic conductivity decreased slightly from the average of 0.54 $m^3/m^2/h$ down to 0.49 $m^3/m^2/h$. This decrease could be attributed to the reduction of void space inside the sand layer due to vegetation roots. It may also because of the increased water retention ability by vegetation roots as stated by Leung et al. (2015). In overall, there was no decrease in hydraulic conductivity after repeating the test up to ten times, meaning the media was stable enough for experimentation with long HRT.

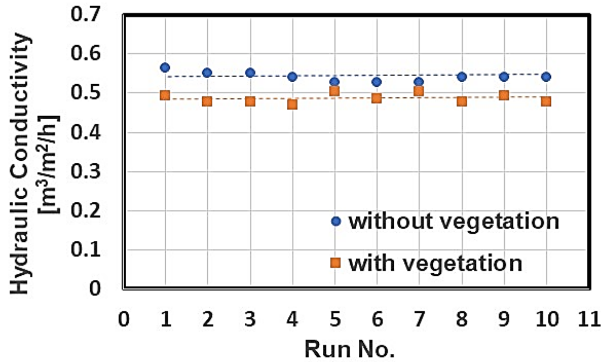

Figure 4: Hydraulic conductivity test results of wetland media

During the acclimatization step, the vegetations were able to receive increasing load of wastewater without any observable damage to the biomasses. Instead, it could be concluded that the vegetations flourished well in the prepared condition as four new sprouts were observed after the 9-d acclimatization period.
pH changes in wetland effluent and in control tank without any treatment during the experimentation are shown in Figure 5.

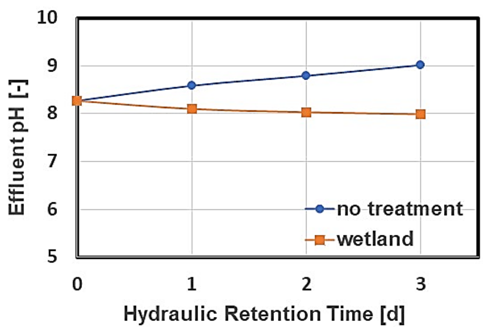

Figure 5: pH changes in wetland effluent and in control tank

pH value of wetland effluent showed a slight decrease toward neutral pH during the 3-d run, while the pH of liquid in control tank without any treatment showed a slight increase to over 9. This result suggested the wetland ability to neutralize and stabilize the pH of wastewater, and maintain it within the standard pH range of 6 to 9 according to regulation set by Indonesian Ministry of Environment (2014). In SSF wetland, solid media such as sand or soil layer could be playing a major role as a buffer to capture ions responsible for basicity in wastewater, while releasing proton to lower the pH (Western Australia DPIRD, 2018).
On the other hand, the increase in control tank pH may be attributed to reduction of nitrates and nitrites into ammonia, a basic gas, in anaerobic condition. The relatively high ammonia content in the influent as shown in Table 2 suggested a high total nitrogen content as well that also includes nitrates and nitrites.
Figure 6a shows the average removal efficiency of TSS in wetland effluent and in control tank during the 3-d runs. Almost 90 % of TSS has already been removed by the wetland in the first 24 h compared to the control tank, and no significant increase was observed after that.

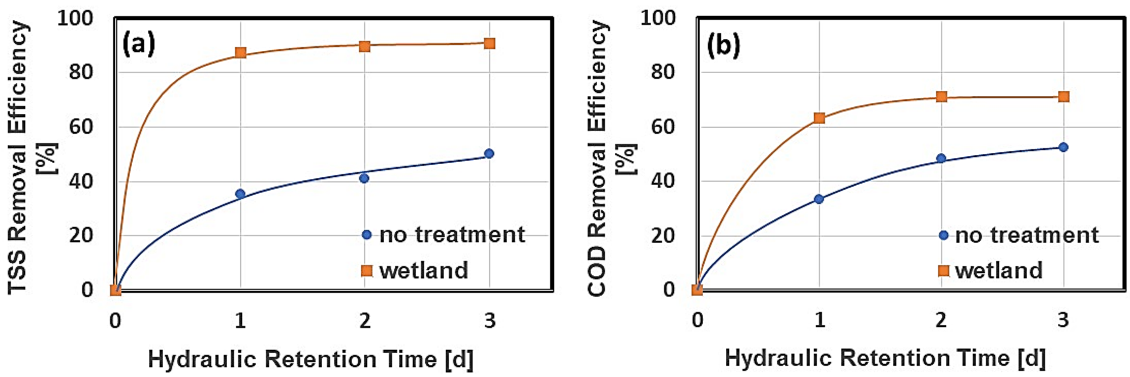

Figure 6: Removal efficiency of (a) TSS and (b) COD in wetland effluent and in control tank

The main mechanism that took place in the wetland to remove TSS is the filtration by solid media. It is likely that the residual TSS in the wetland effluent is composed of particles with size smaller than the pores of solid media. The use of wetland media with smaller particle size should be able to improve the removal efficiency of TSS, although a certain minimum value of hydraulic conductivity must be maintained to design a feasible treatment system in terms of HRT and wetland area. Considering the maximum removal efficiency of around 90 % and the TSS value that must be met for reuse as raw water in clean water production, which is less than 50 mg/L according to regulation (Indonesian Government Regulation, 2001), an influent with TSS value no more than 500 mg/L must be maintained in the wetland treatment system for water reclamation.
The average removal efficiency of COD in wetland effluent was also higher than in control tank as shown in Figure 6b. The COD removal in wetland reached around 63 % in the first 24 h and increased up to 72 % after 48 h. However, the efficiency is still too low to achieve water reclamation for potable or, in the case of fish cannery, food-grade industrial use that should meet a standard regulated value of no more than 10 mg/L according to Indonesian Government Regulation (2001). This could be related to several factors such as the low density of vegetations used in this experimentation and the relatively high initial COD value in the influent.
A study conducted by Al-Baldawi et al. (2015) showed that the use of compost in the media could increase the treatment performance of wetland achieving 86 % of COD removal efficiency. The review on wetlands treatment efficiency on septage conducted by Tan et al. (2015) showed that COD removal of more than 80 % could be achieved with an optimized vertical-flow wetland. Learning from these previous studies, an optimization of the treatment conditions should be explored further using several factors such as vegetation density, vegetation type, and initial COD concentration in the influent.
COD removal in control tank also showed an increase up to 50 % after 3-d run. The organic pollutants in the wastewater can degrade through anaerobic digestion which is what could be occurring in the control tank during the experimentation. Although, the lack of management of inhibiting factors such as ammonia build-up, pH changes and oxygen transfer may be the reasons of low removal efficiency in control tank.
Sulfide and ammonia measurements were also conducted in one experimentation run on the influent and the effluent of wetland after 72-h treatment. In aerobic treatment process such as conventional activated sludge treatment that is used in the fish cannery wastewater treatment plant, there should be no sulfide detected in the effluent if the system operates properly. However, 0.438 mg/L of sulfide was detected in the sampled effluent, indicating an anaerobic condition may exist in the system that causes reduction of sulfate into sulfide. After wetland treatment, the sulfide could not be detected anymore using analysis equipment with detection limit less

than 0.1 mg/L. It means that the wetland effluent clears the standard regulated value of 0.1 mg/L according to Indonesian Government Regulation (2001) on raw water for potable use.

On the other hand, ammonia concentration increased from 29.215 mg/L up to 141.39 mg/L after 3-d wetland treatment. The cause of this increase is unclear yet because all the procedures and other test results such as TSS and sulfide reductions suggested that the wetland condition was aerobic. Other studies also reported ammonia removal capability using SSF wetland, for example Sikora et al. (1995) that showed a removal rate of 0.6 g NH_4-N/m^2/d using *Typha sp.* on SSF wetland. Overall, it is very important to maintain the aerobic condition in wetland to prevent the ammonification of other nitrogen species in the wastewater, for example by aerating the wetland or maintaining certain depth and pore size of the media that still enables the oxygen transfer to the bottom part of the wetland.

At the end of the experiments, the original plants are in a good condition and 28 new sprouts have been observed in the wetland, meaning that the vegetations could flourish well in the wetland conditions with only the wastewater as its nutrients source.

4. Conclusion

The subsurface-flow wetland in this study could refine the effluent quality of wastewater treatment plant in a fish cannery in Bali. The pollutants in terms of TSS and COD were substantially removed from wastewater with removal efficiency of 90 % and 72 %. The strict standard of sulfide in raw water for potable use could also be met after wetland treatment that reduced the sulfide concentration from 0.438 mg/L down to non-detectable range. Further study using pilot-scale wetland is worthy to be pursued and can be focused on the optimization of the wetland operational conditions, i.e. the vegetation type and density, hydraulic retention time, media depth and pore size, and initial pollutant load in the influent, prior to full-scale implementation of the wetland for water reclamation.

References

Al-Baldawi I.A.W., Abdullah S.R.S., Suja F., Anuar N., Idris M., 2015, Phytoremediation of contaminated ground water using *Typha angustifolia*, Water Practice and Technology, 10(3), 616-624.

Astuti A.D., Lindu M., Yanidar R., Kleden M.M., 2016, Performance of Multilayer Filtration Type Vertical Subsurface Constructed Wetland using Vetivera Zozanoides in Removal of BOD and COD from Canteen Wastewater, Jurnal Penelitian dan Karya Ilmiah (Journal of Research and Scientific Work), 1(2), 91-108. (in Indonesian language)

Leung A.K., Garg A., Ng C.W.W., 2015, Effects of plant roots on soil-water retention and induced suction in vegetated soil, Engineering Geology, 193, 183-197.

Salim C., Rachmania A., Dewi R., 2017, Surface-flow wetland for water reclamation at Batamindo Industrial Park, MATEC Web of Conferences, 101, 04007.

Sikora F.J., Tong Z., Behrends L.L., Steinberg S.L., Coonrod H.S., 1995, Ammonium removal in constructed wetlands with recirculating subsurface flow: Removal rates and mechanisms, Water Science and Technology, 32(3), 193-202.

Tan Y.Y., Tang F.E., Saptoro A., Khor E.H., 2015, Septage Treatment Using Vertical-Flow Engineered Wetland: A Critical Review, Chemical Engineering Transactions, 45, 1531-1536.

US EPA, 1988, Constructed Wetlands and Aquatic Plant Systems for Municipal Wastewater Treatment, US Environmental Protection Agency <nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=30004626.TXT> accessed 30.06.2020.

US EPA, 1995, A handbook of constructed wetlands, US Environmental Protection Agency <nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100CHM3.TXT> accessed 30.06.2020.

US EPA, 2000, Wetland: Subsurface Flow, US Environmental Protection Agency <www3.epa.gov/npdes/pubs/wetlands-subsurface_flow.pdf> accessed 30.06.2020.

Vetiver Indonesia, 2007, Post-tsunami reconstruction in Aceh, Vetiver Indonesia <www.vetiver-indonesia.com/projects.htm> accessed 30.06.2020.

Western Australia DPIRD, 2018, Soil pH buffering, Western Australia Department of Primary Industries and Regional Development <www.agric.wa.gov.au/soil-acidity/soil-ph?page=0%2C1> accessed 12.08.2020.