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Integrated Anaerobic-Aerobic and Wetland System for Wastewater Treatment and Recycling in Fish Canning Industry

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Fish canning industry is one of the top priority industries in Indonesia that is competitive in international market and essential to food security. It is also an industry with high water consumption due to its water-intensive processes such as thawing and washing that produces large amount of wastewater containing very high load of organic pollutants which must be treated properly before disposal into the environment. This study was conducted using wastewater characteristics from one of the fish canning plants in Bali, Indonesia, that already implemented wastewater treatment using a combination of aerobic treatments with trickling filter and activated sludge. The treatment system has difficulty to achieve a good and stable effluent quality, especially during high load production season. It is necessary to find a better system that can treat the high load of organic content in wastewater and produce a cleaner effluent that can be recycled back into the production process. This study is aimed to develop a model of integrated system comprised of sedimentation, coagulation-flocculation, Upflow Anaerobic Sludge Blanket (UASB) and Modified Ludzack-Ettinger (MLE) that can be used as a base design for further implementation in pilot-scale facility. The integrated system was designed to remove 99 % of BOD, 99 % of oil and grease, 98 % of TSS and 87.8 % of total nitrogen achieving effluent quality of 59.9 mg/L BOD, 0.6 mg/L oil and grease, 27.4 mg/L TSS, and 30.0 mg/L total nitrogen in nitrates form. Compared to the existing treatment system with effluent quality of 351.4 mg/L BOD, 337 mg/L TSS and 111.1 mg/L ammonia, this system could improve the effluent quality significantly by maintaining a hydraulic retention time (HRT) of 55.3 h. Combining constructed wetland with HRT of 28.8 h as water reclamation system to refine the water quality, the nitrogen content could be reduced to less than 10 mg/L to meet the requirement as raw water for clean water production process. The design in this study could be used to replace the existing aerobic treatment system and enable the industry to solve the environmental problems of wastewater disposal and water conservation and expand further the production capacity simultaneously.

1. Introduction

Fish canning industry is a priority industry in Indonesia, the largest archipelago country in the world with sea area of about 5.8 M km^2. This industry is considered to be competitive in the international market, with Indonesia as one of the top global exporters regarding several kind of fishery products including canned tuna. The large population in Indonesia also rely on fishery products as one of the important food sources for the community. Indonesian Ministry of Industry also highlighted national fish canning industry as the positively growing industry that supports the food security during COVID-19 pandemic in 2020 and recommended more governmental stimulus in this industry (Indonesian Ministry of Industry, 2020).

Fish canning industry produces large quantity of wastewater due to its water-intensive processes such as thawing, washing, and retorting which is a process to sterilize fish cans using saturated steam. The wastewater from a fish cannery contains high load of organic pollutants in the form of oil, grease, fish bloods and residues. The wastewater must be treated in wastewater treatment plant (WWTP) properly to meet the specific water quality standards issued by the government for this industry (Indonesian Ministry of Environment, 2014) before disposal to the environment. The organic content in wastewater from fish cannery

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is specified using several parameters according to the characteristics, i.e. biochemical oxygen demand (BOD) for biodegradable compounds, chemical oxygen demand (COD) for organic compounds that are chemically oxidizable, and oil and grease for organic compounds that are extractable using hexane.

The inability to treat wastewater from fish canneries properly will result in the pollution of receiving water bodies such as seas and rivers. The high organic load in fish cannery wastewater can reduce the dissolved oxygen (DO) in water significantly, killing water organisms and producing odorous gases such as hydrogen sulfide from anaerobic reactions. The social and economic problems entailing these phenomena are also very important to be considered and prevented using proper wastewater treatment facilities.

This study highlighted a fish cannery in Bali that has already implemented a combination of trickling filter and conventional activated sludge treatment methods to remove the pollutants in its wastewater aerobically. Biological treatment method is a preferable method in processing wastewater with high organic load, and it is considered economic and environment-friendly if designed properly (Cristóvão et al., 2015a). In a normal operation, the existing treatment system is capable to produce effluent that meets the wastewater quality standards. During peak season with high production load, the organic content in wastewater becomes too high for the conventional system to treat effectively, causing failure in the aerobic reactor tank due to low DO and producing effluent with high total suspended solid (TSS) and sulfide. It is necessary to find a better system that can treat the high load of organic content in the wastewater and produce a cleaner effluent.

The objective of this study is to obtain a feasible design of wastewater treatment system that can be implemented in pilot-scale facility. Most of previous studies are focused on either anaerobic or aerobic treatment methods to reduce the organic content in wastewater from fish cannery. In this study, a design model of new treatment system is proposed using an integrated system of sedimentation, coagulation-flocculation, Upflow Anaerobic Sludge Blanket and Modified Ludzack-Ettinger combining both the advantages of anaerobic and aerobic treatments. This system was evaluated using theoretical calculation based on wastewater characteristics obtained from the fish cannery before treatment as the influent. The possibility of water reclamation using wetland treatment method is also considered. With recycling system, the amount of clean water required by the fish cannery from the environment can be cut significantly, achieving water conservation while reducing the environmental risk by decreasing the wastewater quantity disposed to the environment.

2. Theoretical considerations in system design

Figure 1 illustrated the new wastewater treatment system proposed in this study. This system combines two biological treatment methods, i.e. Upflow Anaerobic Sludge Blanket (UASB) and Modified Ludzack Ettinger (MLE) that have different characteristics and purposes.

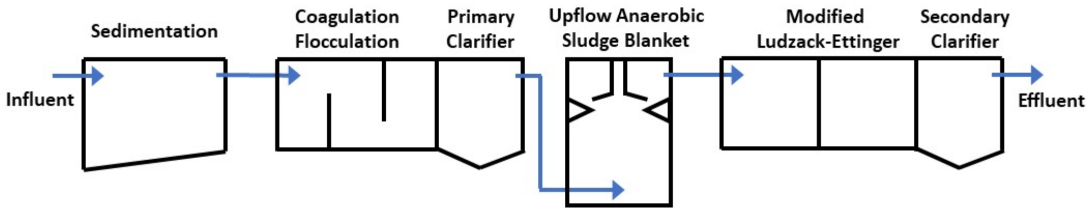

Figure 1: Process scheme of newly proposed wastewater treatment system

UASB along with other anaerobic treatment methods are considered suitable to treat wastewater with high organic loading due to its high energy efficiency and high treatment rate (Ersahin et al., 2011). This method utilizes anaerobic biomasses concentrated in sludge to digest the organic pollutants. The inlet is located at the bottom of the reactor where the wastewater is flowed vertically upward through the sludge blanket as shown in Figure 2. During the contact, biomasses digest and convert the larger organic materials in wastewater into smaller compounds including biogas such as methane that can be collected and used as energy source.

Sunny and Mathai (2013) reported UASB performance of 80-95 % in reducing COD when applied to wastewater from fish processing plant with organic loading of 1-8 kg COD/m^3/d. This result also agrees with Metcalf and Eddy (2014) which stated that UASB can reach 90 % COD removal with high organic loading of 8 kg COD/m^3/d. Khan et al. (2014) studied extensively the full-scale applications of UASB in India and reported removal efficiency ranging between 55 to 70 % on BOD, COD and TSS. Yang et al. (2018) showed that the seeding microorganisms using anaerobic pool sludge of municipal sewage treatment plant could enhance the formation of granular sludge that exhibits a better performance in UASB reactor.

Nitrogen removal is also another important process that is necessary in treatment of fish cannery wastewater containing organic nitrogen and ammonia. In biological treatment, a two-step process of nitrification and denitrification is used to remove the nitrogen pollutants in wastewater. Modified Ludzack Ettinger (MLE) is one of methods that is developed for this purpose (Hollas et al., 2019). Figure 2b shows the process flow of MLE that consists of an anoxic reactor, an aerobic reactor, and a clarifier. The working principle is similar to complete mixed activated sludge with sludge recycling system, except that the bioreactor of MLE is divided into two parts, the anoxic reactor and the aerobic reactor.

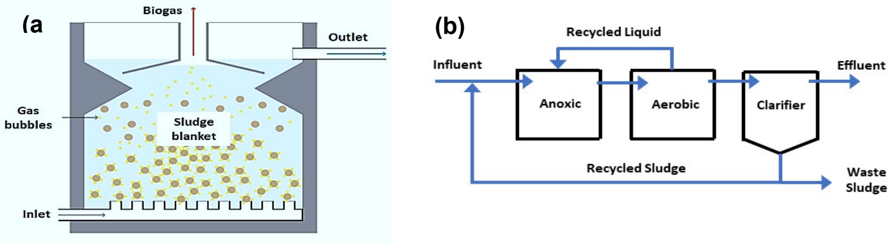

Figure 2: (a) Schematic diagram of UASB and (b) process flow of MLE

The first reactor maintained in anoxic condition is responsible for denitrification process where nitrate (NO_3^-) and nitrite (NO_2^-) are converted into nitrogen gas (N_2) through the activity of anaerobic microorganisms. On the other hand, the aerobic reactor utilizes aerobic microorganisms to convert ammonia into nitrate and nitrite that are recycled back into the anoxic reactor for denitrification process. The removal of organic pollutants will also take place because the anaerobic and aerobic microorganisms require the organic materials as substrate in their metabolisms during denitrification and nitrification processes. By adjusting the internal ratio of sludge and liquid recirculation, the system can be optimized to remove the nitrogen and organic pollutants in wastewater sufficiently.

Hollas et al. (2019) reported removal efficiencies of 88.3 % and 86.3 % for nitrogen and total organic carbon using MLE system to treat wastewater containing swine manure. Ibrahim (2005) showed that MLE has similar performance with conventional activated sludge in BOD removal ranging from 85 % to 95 %.

Sedimentation and coagulation-flocculation were added in the system to reduce the pollutants load in wastewater entering UASB. Observation of the existing treatment system at the fish cannery showed high amounts of solid such as fish scales and bones that must be removed prior to biological treatment processes. According to Cristóvão et al. (2015b), sedimentation could remove 48 % TSS, 75 % oil and grease and 4 % dissolved organic carbon in wastewater from fish cannery at hydraulic retention time (HRT) of 1.5 h, while coagulation with 100 mg/L dosage of $Al_2(SO_4)_3.16H_2O$ could remove 66.5 % TSS, 98.8 % oil and grease and 20.7 % dissolved organic carbon.

Constructed wetland for water reclamation can be designed using subsurface-flow (SSF) wetland that is effective to treat nitrogen in the effluent in the form of nitrates and nitrites. This kind of wetland is composed of soil layer where the wastewater is flowed through and contacted with plants and microorganisms in it as shown in Figure 3.

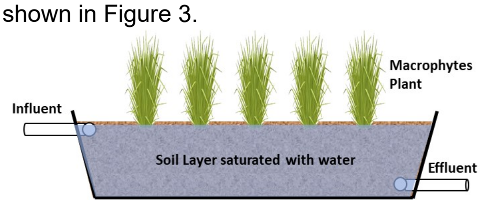

Figure 3: Schematic diagram of subsurface slow constructed wetland

According to Fernando et al. (2019), the removal rates of TSS, BOD and ammonia in municipal wastewater using *Phragmites australis* in vertical subsurface-flow wetland could reach 62.85 %, 75.39 % and 70.70 % at HRT of 1.12 d and hydraulic loading rate of 0.2 m/d. Another study conducted by Leonora and Joana (2020) reported the performance of vetiver floated in a surface-flow wetland to treat swine wastewater with 96.85 % of BOD, 65.01 % of TSS, 96.51 % of nitrate, 55.92 % of phosphorus removal rates after 5 weeks of cultivation.

3. Materials and Methods

The wastewater characteristics used as influent in the calculation of the proposed system was the actual wastewater sampled from the fish cannery in Bali. The wastewater was analysed by certified external laboratory according to standard methods published by APHA (2005) and the result is shown in Table 1 as WWTP influent.

Table 1: Comparison of existing WWTP influent and effluent qualities with standards set for fish cannery

Parameter	WWTP Influent	WWTP Effluent	Standards	Unit	Test Method
pH	6.5	7.5	6 - 9	-	4500-H^+-B
TSS	1,745	337	100	mg/L	2540 D
Sulfide	10	4.6	1	mg/L	4500-S^{2}-D
Ammonia	147.5	111.1	5	mg/L	4500-NH_3-F
TKN (calculated from ammonia)	245.8	185.2	-	mg/L	-
Free Chlorine	4.4	< 0.01	1	mg/L	4500-Cl-B
BOD_5 at 20 °C	7,871.7	351.4	75	mg/L	5210 B
COD_{Cr}	17,358.3	585.6	150	mg/L	5220 B
Oil and Grease	199.5	8	15	mg/L	5520 B
Quantity	-	-	15	m^3/t of raw material	-

Four main parameters, i.e. TSS, oil and grease, BOD and total nitrogen were selected for the calculation and evaluation of the proposed system. The performance of each unit was set according to data from reference studies and shown as removal efficiency for each parameter (Table 2). The nitrogen in effluent from MLE was estimated using the following calculation steps according to Metcalf and Eddy (2014), and a simple trial-and-error iterative calculation method was adopted to find the solution to these set of equations.

First the biodegradable chemical oxygen demand which is the substrate for biomass growth (S_0) was calculated with Eq(1), and soluble BOD in effluent ($S_{e,sol}$) was calculated with Eq(2) and Eq(3) using total BOD (S_e) and suspended BOD ($S_{e,sus}$) in effluent.

$$S_0 = 1.6 \times BOD \tag{1}$$

$$S_{e,sus} = S_e \times 0.68 \times 1.42 \times 0.65 \tag{2}$$

$$S_{e,sol} = S_e - S_{e,sus} \tag{3}$$

Quantity of nitrates and nitrites (NO_X) was determined from Total Kjeldahl Nitrogen (*TKN*) value in Eq(4). According to Henze et al. (2008), TKN value can be assumed to be one fifth of BOD value.

$$NO_x = 0.8 \times TKN \tag{4}$$

The decay coefficient of microorganisms responsible for BOD degradation at certain temperature ($k_{H,T}$) was obtained from Eq(5), assuming decay coefficient at T=20 °C ($b_{H,20}$) is 0.12 g/g/d. The decay coefficient of microorganisms responsible for NH_3 oxidation at certain temperature ($k_{AOB,T}$) was calculated with Eq(6), assuming decay coefficient at 20 °C ($b_{AOB,20}$) is 0.17 g/g/d.

$$k_{H,T} = 0.12 \frac{g}{g.day} \times 1.029^{(T-20)} \tag{5}$$

$$k_{AOB,T} = 0.17 \frac{g}{g.day} \times 1.029^{(T-20)} \tag{6}$$

Biomass production rate P_{bio} was obtained from Eq(7) using wastewater flow rate (Q) of 36.92 m^3/h observed at the fish cannery, and assuming biomass yield (Y) and fraction of biomass that remains as cell debris (f_d) as 0.45 and 0.15. The sludge retention time (*SRT*) is set at 3 d.

$$P_{Bio} = \frac{Q.Y.(S_0 - S_{e,sol})}{1 + k_{H,T}.(SRT)} + \frac{f_d.k_{H,T}.Q.Y.(S_0 - S_{e,sol}).(SRT)}{1 + k_{H,T}.(SRT)} + \frac{Q.Y.(NO_x)}{1 + k_{AOB,T}.(SRT)} \tag{7}$$

NO_x from nitrogen mass balance was determined from Eq(8) using an assumption of nitrogen concentration in effluent (N_e) to meet a certain value of internal ratio.

$$NO_x = TKN - N_e - 0.12 \times \frac{P_{bio}}{Q} \tag{8}$$

Internal ratio (*IR*) was calculated with Eq(9) using NOx value from Eq(8) and returned sludge ratio (*R*) of 0.6.

$$IR = \frac{NO_x}{N_e} - 1 - R \tag{9}$$

The hydraulic retention time (HRT) for sedimentation, coagulation and UASB units are set at 2 h, 0.3 h and 33 h, with influent flow rate at 1030 m^3/d as observed from the fish cannery. HRT for MLE was counted using IR value of 4 and HRT for wetland was set to 1.12 d according to calculation using data from Fernando et al. (2019).

4. Results and discussion

Effluent quality from the existing WWTP was shown in Table 1. Some of the parameters were still over the Indonesian standards for wastewater disposal in fish cannery. The calculation results of the proposed system are shown in Table 2. Using the proposed system, the effluent characteristics can meet the required standards for disposal shown in Table 2. Most of the TSS and Oil and Grease could already be removed from wastewater in sedimentation and coagulation-flocculation units, and UASB could remove the TSS further to a value lower than the standard of 100 mg/L. The important consideration is the effectiveness of secondary clarifier in separating the sludge and the supernatant liquid from MLE effluent which mainly depends on the floc quality. Maintaining a good treatment condition within the design criteria of MLE is very important.

Table 2: Calculation results of integrated anaerobic-aerobic treatment system

Treatment Unit	Parameter	Removal Efficiency	Influent	Effluent	Standards	Unit
Sedimentation	TSS	48 %	1,745	907.4	-	mg/L
	Oil and Grease	75 %	199.5	49.9	-	mg/L
	BOD	4 %	7,871.5	7,556.6	-	mg/L
Coagulation-Flocculation	TSS	66.5 %	907.4	304.0	-	mg/L
	Oil and Grease	98.8 %	49.9	0.6	-	mg/L
	BOD	20.7 %	7,556.6	5,992.4	-	mg/L
UASB	TSS	55 %	304.0	136.8	-	mg/L
	BOD	90 %	5,992.4	599.2	-	mg/L
MLE	TSS	80 %	136.8	27.4	100	mg/L
	BOD	90 %	599.2	59.9	75	mg/L
	Total Nitrogen	87.8 %	245.8	30.0	-	mg/L

The high BOD removal in UASB is one of the important factors that help maintaining the good treatment condition in MLE by reducing the organic load considerably. With a relatively low BOD in wastewater entering MLE, it will be easier to maintain DO within the range of aerobic condition in the aerobic reactor, reducing the occurrence possibility of filamentous microorganisms that could reduce the floc settleability. A low BOD value also means that less amount of organic compound that could compete with the nitrogen nitrification and denitrification processes, increasing the effectiveness of the biomass in removing nitrogen pollutant in the wastewater. In this system, all the nitrogen is assumed to be discharged in the form of nitrates and nitrites after passing through the nitrification process in MLE. In this form, the nitrates can be removed from water using the absorption mechanism by plant or microorganisms in wetland, and then incorporated into the biomass.

Table 3: Calculation results of wetland system for water recycling

Treatment Unit	Parameter	Removal Efficiency	Influent	Effluent	Standards	Unit
Wetland	TSS	62.85 %	27.4	10.2	50	mg/L
	BOD	75.39 %	59.9	14.7	2	mg/L
	Total Nitrogen	70.70 %	30.0	8.79	10	mg/L

Using the research data from Fernando et al. (2019), a wetland with HRT of 1.12 d and area of around 12,000 m^2 is required to reduce the total nitrogen content to meet the standard on raw water for potable use (Indonesian Government Regulation, 2001) as shown in Table 3. Deeper vertical flow wetland with longer HRT could be used to reduce BOD further to meet the standards. A combination of surface-flow and subsurface-flow wetlands may also be an interesting idea to be pursued because surface-flow wetland can be designed to have a short HRT without any restriction on the soil hydraulic conductivity as shown by Salim et al. (2017), reducing the area required for the wetland while maintaining high treatment performance.

With a total HRT of 55.3 h, around 1.2 times of the existing system using trickling filter and conventional activated sludge methods, the treatment performance of the newly proposed system surpassed the existing one as shown in the results of effluent quality from existing WWTP in Table 1 and effluent quality from new system in Table 2. Removal efficiency could be improved for TSS from 81 % up to 98 %, BOD from 96 % up to 99 %, and total nitrogen from 25 % up to 87.8 %. This new system would also be more resilient in facing pollutants load fluctuation during the production due to additional anaerobic and anoxic systems.

5. Conclusion

This study has proposed a new design of wastewater treatment system using an integrated system of sedimentation, coagulation-flocculation, Upflow Anaerobic Sludge Blanket (UASB) and Modified Ludzack-Ettinger (MLE) that can be implemented to improve wastewater treatment of fish cannery in Bali. With a total hydraulic retention time of 55.3 h, the new system could reduce TSS, BOD, oil and grease, and total nitrogen better than the existing one, achieving wastewater quality of 27.4 mg/L TSS, 59.9 mg/L BOD and 30 mg/L total nitrogen. Integration with constructed wetland using hydraulic retention time of 26.88 h and hydraulic loading rate of 0.2 m/d, the total nitrogen could be reduced to 8.79 mg/L, clearing the standards set on raw water for potable use by Indonesian government.

The feasibility of the new design can further be explored in a pilot-scale facility prior to full-scale implementation, where the design optimization of UASB and MLE can be conducted and several types of wetland vegetations can be studied to find the most suitable one for nitrogen removal.

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