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Canteen Wastewater and Gray Water Treatment Using Subsurface Constructed Wetland-Multilayer Filtration Vertical Flow Type with Melati Air (Echindorus paleafolius) at Senior High School

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Abstract – Domestic wastewater needs to be treated because it can pollute the environment, either water bodies, ground water, or soil. One alternative to treat domestic wastewater is using subsurface constructed wetland methods. This method has advantages, among others, like cheap, simple technology and can be applied to the area of ample land. In this research, subsurface constructed wetlands-multilayer filtration with vertical flow type using Melati Air (E.*paleafolius*) in field scale to treat domestic wastewater from canteens and gray water toilet of Senior High School at Bekasi with treatment capacity for 2261 L/day. Subsurface constructed wetlands-multilayer filtration with vertical flow type is an advanced treatment in this research. For preliminary treatment the collecting and aeration tank is used. Performance of subsurface constructed wetland-multilayer filtration with vertical flow type was able to achieve effluent COD parameters of 40 mg/L (standard 100 mg/L) from an average influent of 350 mg/L with removal efficiency of 90%, while BOD was successfully degraded to 33.00 mg/L (quality standard 30 mg/L) of an average influent concentration of 350 mg/L. In addition, the parameters analyzed are total nitrogen, the total phosphate succeeded to meet the quality standard. Based on the results of laboratory analysis, the reactor is able to treat organic loading of 500-700 kg BOD5/Ha/D compared to previous research which is range from 40-300 kg BOD/Ha/D. Similarly, the value of K in this study ranged from 0.35-0.57 m/day for BOD and 0.37-0.45 m/day for COD compared to precious research which is 0.055-0.16 m/day for BOD and 0.027-0.16 m/day for COD.

Keyword: Subsurface Constructed Wetlands; Multilayer Filtration; Organic loading; Removal Efficiency; Melati Air (*Echindoruspaleafolius*

Introduction

Senior High School as an educational institution has activities that generate wastewater especially domestic wastewater from canteen, from bathroom: grey water toilet and black water. Black water commonly treated in septic tank, meanwhile canteen wastewater and grey water discharged directly to drainage or water body. Generally, grey water contains high turbidity, and high concentrations of phosphorus, low total suspended solids, oils and greases, surfactants (Chrispim and Nolasco, 2017; Irham *et al.*, 2017). Conventional wastewater treatment plants need high investments and operating costs. These systems are not suitable solutions for rural communities and villages. Constructed wetlands (CWs) proved to be a kind alternative for such wastewater treatment that offer low operation and maintenance costs since no mechanical equipment or external energy supply is required (Abou-elela *et al.*, 2013). The CW with willow (Salix *babylonica*) to treat household domestic wastewater in rural villages in northern China has achieved high overall removal efficiencies for BOD5, TSS, NH4-N, and TP: 96.0%, 97.0%, 88.4% and 87.8% (Wu *et al*, 2011)

Vertical Flow CW proved to be more efficient than Horizontal Flow CW not only in COD, BOD removals but also for nitrification. The vertical flow allows the penetration of more oxygen, beside its small size and long detention time (Abou-elela *et al.*, 2013) and (Vymazal, 2010).

In developing countries, the use of non-conventional plant species as emergent plants in constructed wetlands may add aesthetics and economic benefits besides treating wastewater (Zurita, Anda, and Belmont, 2009). One of ornamental plants is Melati Air (E. *paleafolius*) that grows in the tropics, include in Indonesia. This plant is not sun-resistant throughout the day, because it can make the leaves turn into yellow, if the location of the cultivation got excessive sunlight, it needs to apply a condition that supports it. Propagation is done by separation of till shoot buds at the base of the stem of the plant.

The purposes of this study are to apply of subsurface constructed wetland multilayer filtration (SCW-MLF) type of vertical flow method in the field-plant scale using Melati Air (E. *paleafolius*) and to investigate the performance of domestic wastewater treatment from canteen and grey water toilet using subsurface system constructed wetland multilayer filtration vertical flow type, after going through preliminary processing on collecting and aeration tank.

Materials and Methods

Experimental Setup

The wastewater treatment unit was located at a Senior High School in Bekasi and consisted of collecting tank (capacity 112.5 L) and aeration tank (capacity 237.5 L) as prelimenary treatment process, then wastewater flowedto subsurface constructed wetland multilayer filtration type vertical flow (SCW-MLF) for advanced treatment. The dimensions of SCW-MLF are (4.5 m x 2.5 m x 1.4 m) as can be seen at Figure 1.

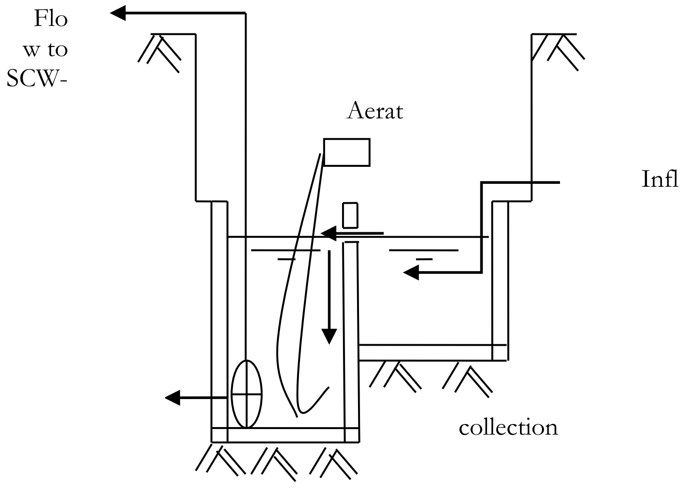

Figure 1. Flow Chart of Field Plant SCW-MLF withMelati Air (*E. paleafolius)*

The field plant was equipped with pump due to topography of the site and water distribution. The depth of the reactor also being adjusted to surface water level and the depth of existing drainage system. The SCW-MLF with *E. paleafolius* unit was designed with vertical flow type and the total filter depth is 1.1 m and consists of soil 90% and quartz sand 10% that was filled to a depth of 20 cm followed by a 30 cm layer ofgravel, a 40 cm layer of sand, and a 30 cm layer of gravel.

Water analysis

Wastewater from bathroom (especially grey water) and canteen is treated in this field plant. The result of wastewater analysis can be seen at Table 1.

Water samples analysis were determined for pH, Chemical oxygen demand (COD), total Kjedal nitrogen (TKN), total phosphorus (TP),oil and grease according to the Standard Methods (APHA, 2012). Removal efficiency was calculated by the percentage of removal in concentration for each pollutant as follows: removal efficiency = (1 − Ceff/Cinf) × 100%, where Cinf and Ceffconcentrations of the influent and effluent in mg/L

Table 1.Measured Parameters and Analysis Method

No	Parameters	Unit	Effluent Standards*)
1.	BOD	mg/l	199 – 2160
2.	COD	mg/l	352 – 2564.77
3.	Total Nitrogen	mg/l	17.55 – 63.70
4.	Total Phosphat	mgl	0.177 - 1,905
5.	Oil and grease	mg/l	80.6– 466
6.	pH	-	6.8 – 7.4

Source :)* Ministry of Environment and Forestry's Standard for wastewater Nr. P.68/2016

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Area Constants

Calculation of Area Constants according to Moshiri (1993)

$$A = \frac{Q}{K} \times \ln \frac{Ci}{Ce} \quad \text{.......(1)}$$

A = Constructed wetland Area (m^2); Q = flowrate of influent (m^3/day); Ce = concentration of efluent (mg/L); Ci = concentration of influent (mg/L); K = Contants of Area (m/day).

Organic loading rate (kg/Ha/day) were calculated as below:

$$\text{Organic loading rate} = \left[\frac{(Ci - Ce)\ mg/L \times 1000}{10^6} \right] \times \frac{Q}{A} \quad \text{.......(2)}$$

Results and Discussion

Acclimatization of Melati Air (*Echindoruspaleafolius*) and its Displacement to the Reactor

The acclimatization of *E.paleafolius*is based on the hypothesis that each plant has tolerance to the concentration of contaminants carried by domestic wastewater. In order to avoid the death of the plant at the reactor, an acclimation treatment with combination of 50% wastewater and 50% distilled water and 75% wastewater and 25% distilled water is carried out, in order to enable the *E. paleafolius*planted in the reactor to adapt with wastewater before finally receiving treatment with 100% wastewater. Besides, in order to identify durability of the plant, the process of planting without acclimatization or direct treatment with 100% wastewater is conducted after 100 *E. paleafolius*plants are planted at the reactor.

Acclimatization process was implemented for 3 days involving acclimatization media containing 50% and 75% domestic wastewater. Acclimatization is conducted on the physiology of plant with 8 cm average of height. Before the acclimatization process began, 120 *E. paleafolius*plants are normalized on a particular container for a week before finally moved into acclimatization container. After most of the *E. paleafolius*have been treated through the acclimation process, there are only 2 plants in the reactor which are died by the next week and they are directly replaced with new ones without having the acclimatization process. *E. paleafolius*are planted in a reactor with about 3 to 5 cm depth with the distance of each plant reaches 30 cm. The growth media for the *E. paleafolius*in the reactor is lateosol soil that is less fertile with a mixture of 10% sand. Sand in this case serves as a bulking agent which expands the porosity which leads to the water absorption area increases and prevents clogging. Figure 2 as presented below shows the process of planting *E. paleafolius*plants gradually until finally it reaches 100%, and it also illustrates the final condition of the plant.

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Figure 2. Process (a) Normalization, (b) Acclimatization 50% and (c) Acclimatization 75%, on Domestic

Wastewater from E. p*aleafoliu*s plants.

The height of each *E. paleafolius*at the reactor is less evenly distributed at 1 to 3 months of the treatment, especially for those which are placed in the middle, compared to the plants grown at the edge of the reactor. However, after the 4th month, the plants' growth has indicated the same height because they obtain similar portion of the sun shine after the roof covering the reactor during the study opened. By the initial plants' height in the reactor at about 10 cm, the plants' height at the final stage of the treatment has reached about 70 to 80 cm with an average width of leaves is 15 cm. In general, it can be said that *E. paleafolius*plants are plants that can be used for biological treatment in subsurface constructed wetland reactor, because it is proven that this plant can live, grow, bloom, produce new seedlings and more importantly, they are able to remove the contaminant or pollution in domestic wastewater.

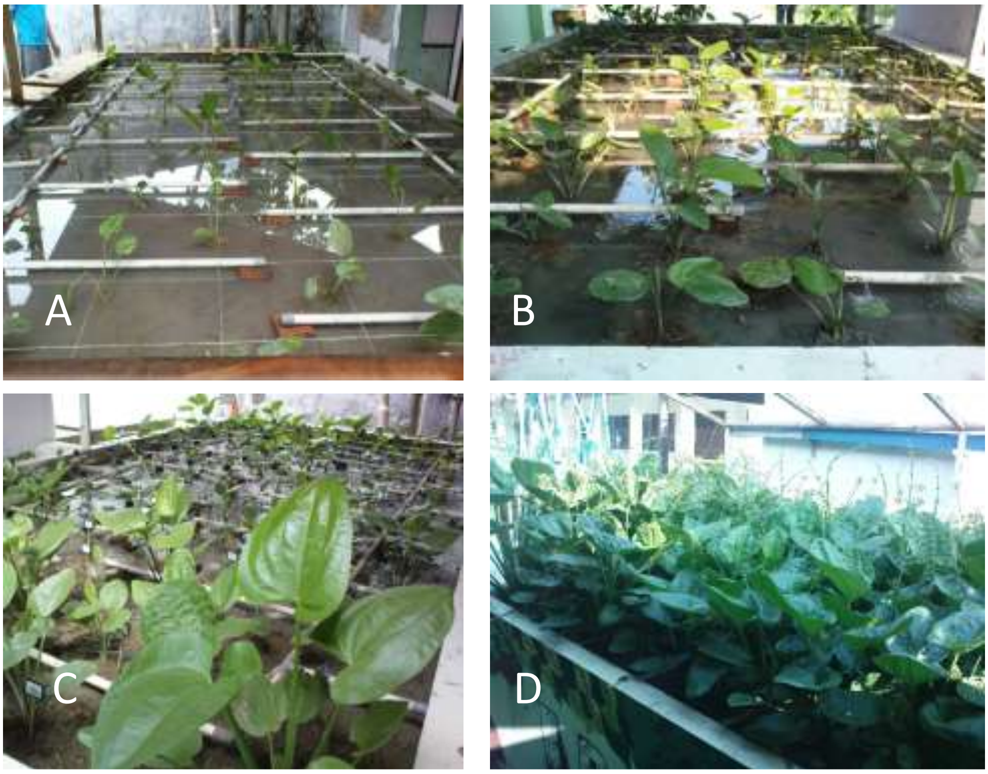

Figure 3. (A) The incremental water planting of the *E. paleafolius*in the Reactor, (A) age 1 week, (C) Age 1 month and (D) Age 4.5 month, in *SubsurfaceConstructed Wetland Reactor*.

The Role of *E. paleafolius* in Contaminants Removal

The domestic wastewater comes from canteen and gray water toilet is processed using SCW MLF with selected plant species (*E. paleafolius*plants) and longer retention time of the wastewater (for about 2 days), which is considered as sufficient time for the plants to absorb nutrients that are part of the organic wastewater removal itself. Meanwhile, the optimum pH conditions are maintained to achieve ideal conditions for plants to perform their metabolic activities.

There are about 120 *E. paleafolius*that are treated in 11.25 m^2 reactor, by giving 30 cm distance among each plant so that the process of removal of the contaminants in wastewater will be well distributed, because the plants have fiberous roots that can approximately reach 15 cm horizontally and 20-30 cm vertically. The roots of the plant act as an effective biofilter, because the roots of plants are used as the growing media of microorganisms. The plants take oxygen from the air and distribute the oxygen to their roots, so that the microorganisms around the roots of the plant use the existing oxygen for supporting their metabolism. The growing microorganism is indicated by the enzyme produced, these enzymes will break the chains of the hydrocarbon in the wastewater into simpler forms so that it will be easier for plants' roots to absorb hydrocarbon compounds for their growth.

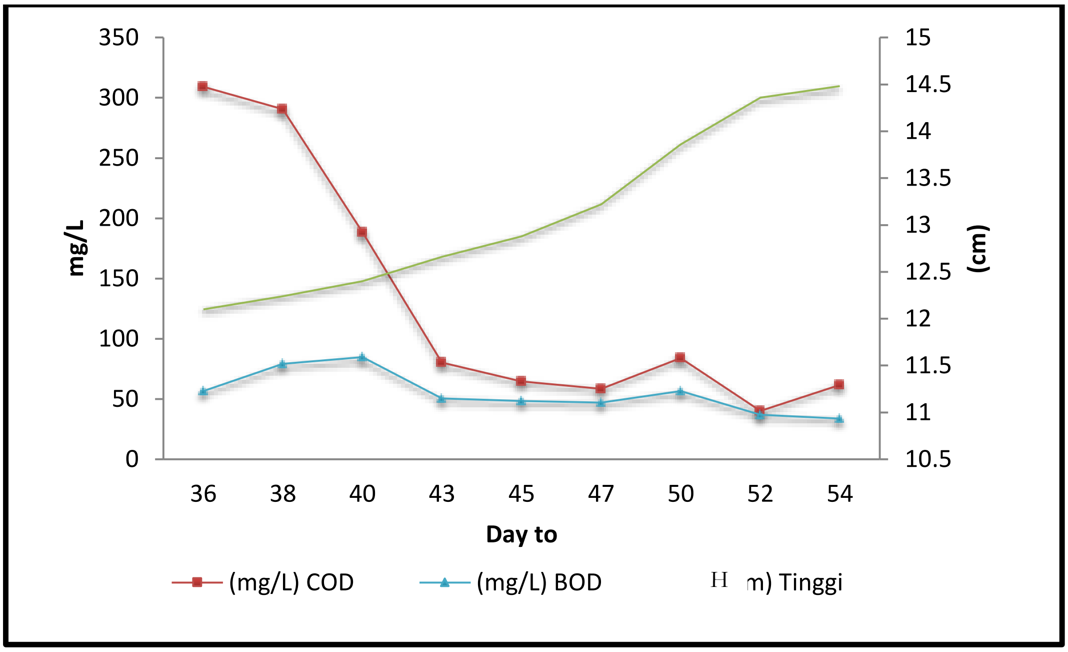

Figure 4. Curve of Relation removal COD and BOD concentration (mg/L)with plant growth from high rectangle as indicated.

Those biological processes provide significant contribution on the removal of pollutants in domestic wastewater such as COD, BOD, total nitrogen, total phosphate and oil and grease which can be seen from the removal efficiency achieved at the reactor outlet after being analyzed in the laboratory. The lowest COD, BOD removal efficiency before planting of *E. paleafolius*in the reactor is only 34.14%, 8.72% compared with after *E. paleafolius*planting reaches 50.73%, 59.03%. The highest COD, BOD removal efficiency before planting *E. paleafolius*was 88.86%, 82.89% while the highest removal efficiency after planting was 95.23, 93.25% on the 47th day.According to research by Abdelhakeem, Aboulroos, and Kamel, (2016) the average removal efficiencies of chemical oxygen demand (COD), biological oxygen demand (BOD), total suspended solids (TSS), ammonium (NH4) and total-P (TP) were 75%, 84%, 75%, 32% and 22% for the planted CW using Phragmites*australis* compared to 29%, 37%, 42%, 26% and 17%, respectively, for the unplanted CW.

The Relationship between Removal Concentration Parameter and *E. paleafolius*Growth

In this study, the indication of the plants' growth and development are observed from the height of the plants, the new leaf bud and total number of leaves on one observed plant as well as measurements on environmental physical factors such as air temperature and air humidity. This study focuses on identifying the relationship between the removal concentration (mg/L) of the pollutants in domestic wastewater and the observed plant growth. In this study there are only 5 samples of *E. paleafolius*observed deeply and they are considered as the representatives of a total of 120 plants.

Data from the results of the observation of the height rates among the 5 plants treated as samples for this study and their relation to the COD and BOD concentrations are presented in Figure 5 as follows. Based on results illustrated in Figure 5, it can be seen that, *E. paleafolius*plants show increased height (cm) which indicates that the plants are growing. The height of *E. paleafolius*plants increases by the time, along with COD and BOD concentration (mg/L) removal. As the age of the plants increase, the COD and BOD concentration is also increasing.

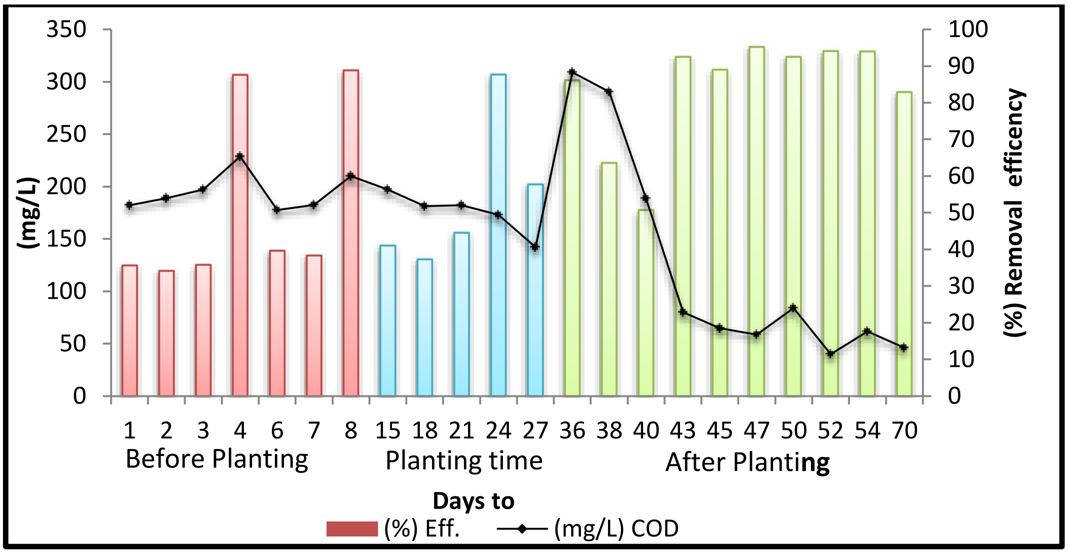

Figure 5 Graph of COD removal efficiency against COD Concentrations in mg/L on Subsurface Constructed Wetland Reactor

Figure 5 also shows that the average height of the 5 *E. paleafolius*plants treated as samples for this study is 12.1 cm after 12th days of 100% planting or simultaneously with the 36th day of domestic wastewater sampling on the reactor effluent. The average height of the plants in the end of the observation, lasted for 4 weeks observed period, is 14.48 cm or it is exactly at the 54th day of the domestic wastewater sampling on the reactor effluent. Thus, the average height of the plants increases by 2.38 cm.

The concentration of COD in the effluent reactor of the plants with 12.1 cm height average reaches 309.06 mg/L. The COD removal remains stable in the 13.86 cm average height of the plants with COD concentration in the effluent is 58.51 mg/L on 47th day. Thus, it can be concluded that the average increase of plants' height by 0.15 cm/day within 12 days.The concentration of BOD in the effluent reactor of the plants with12.1 cm height average is at 56.6 mg/L. The steady decrease of BOD concentrations was started on the 40th day until the 47th day with BOD concentration at 84.80 mg/L (on average plant height of 12.4 cm) and stopped at mean plant height of 13.22 cm with BOD concentration of 47 mg/L.

Removal Efficiency of BOD Concentration

The results of organic loading COD are presented in Table 2 as follows.The data presented in Table 2 figures out that none of the samples showed increased concentration level of the reactor effluent. To make it understandable, the following illustration (as presented in Figure 5) shows the removalefficiency of COD concentration with the removal COD concentration at mg/L.

In Figure 5, it is clearly presented that the removal efficiency of COD concentration in the reactor is getting higher and constant as the concentration of COD mg/L has been successfully removed. The lowest efficiency before planting the *E.paleafolius*plants in the reactor conducted is 34.14%. However, after the plants are grown, the efficiency reaches 50.73%. The highest efficiency before attaching the plants is 88.86% while the highest efficiency after the attachment of the plants reached 95.23% on the 47th day of the treatment.

The removal percent fluctuations on the sample tend to be stable on 43rd to 70th day. During the period, the COD concentration after the removal is successfully conducted has reached and fulfilled the standard of quality (80 mg/L) ranging from 80.17 mg/L to 40 mg/L. Thus, the plants provide significant contribution in COD concentration removal compared to other non-plants reactor. The non-plants reactors were only able to remove the COD concentration rate by 51.42% compared to the reactor using *E. paleafolius*plants which reached 84.04% rates. Thus, it can be concluded that the plants are able to remove COD concentration with 38.81% higher compared to the reactor without and before the plantation of the plants are conducted. Whereas, using periodical planting of the plants, the removal efficiency do not showed significant difference from the previous (before the plants are planted). This is influenced by the metabolic process of this plant that has not yet reached its peak.Song et al., (2015) using SCW research ammonia and COD removal rates reached 56% and 64%,

Table 2. Organic load kg COD/Ha/Day

COD in	COD out	mg/L	kg/L	kg/m^3	m^3/day	kg/day	Ha	kg/ha/day
670.97	40	630.97	0.0006	0.6310	2.261	1.4266	0.001125	1,268.1095
1017.4	61.61	955.79	0.0010	0.9558	2.261	2.1610	0.001125	1,920.9255
268.85	46.14	222.71	0.0002	0.2227	2.261	0.5035	0.001125	447.5976

From the results of the analysis, it can be concluded that this subsurface constructed wetland reactor using multilayer filtration with vertical flow type is able to remove organic load at 450 to 1200 kg COD/Ha/ Day on the 52nd to 70th day, during the period the effluent COD is at steady state.Chang, Wu, Dai, Liang, and Wu, (2012)treated domestic wastewater using Typhaorientalis and Arundodonax var. versicolor and has mean organic removal rate of 44.3 gr/m^2/day or 443 kg/Ha/day for COD.

Removal Efficiency of BOD Concentration

The results of laboratory analysis of BOD parameters for 70 days, as presented in Table. indicates that none of the samples indicate increased concentration level on the effluent reactor. However, the percentage of efficiency has gradually increased by the age of the plant in the constructed wetland reactor. To make it easier to read, Figure 3 show the percentage of BOD efficiency with the removed BOD concentration in mg/L.

As illustrated on the graph (Figure 6), it can be clearly seen that the percentage of BOD removal on the reactor is higher and constant along with the successfully removed BOD concentration which reaches mg/L. The condition has been more frequently occur after *E. paleafolius*plants are attached in the reactor. The lowest efficiency which reaches 8.72% occurs during the pre-planting stage of the plants at the reactor, this is resulted from low influent BOD concentration which reaches only 172 mg/L, while the average concentration removed reaches about 146.29 mg/L. The lowest removal efficiency in the reactor after the plantation of the plants was 59.03% which is very high compared with the non-plants reactor. Meanwhile, the highest removal efficiency in non-plants reactor reaches about 82.89% compared to reactor after the plantation which reaches 93.25% at 47th day.

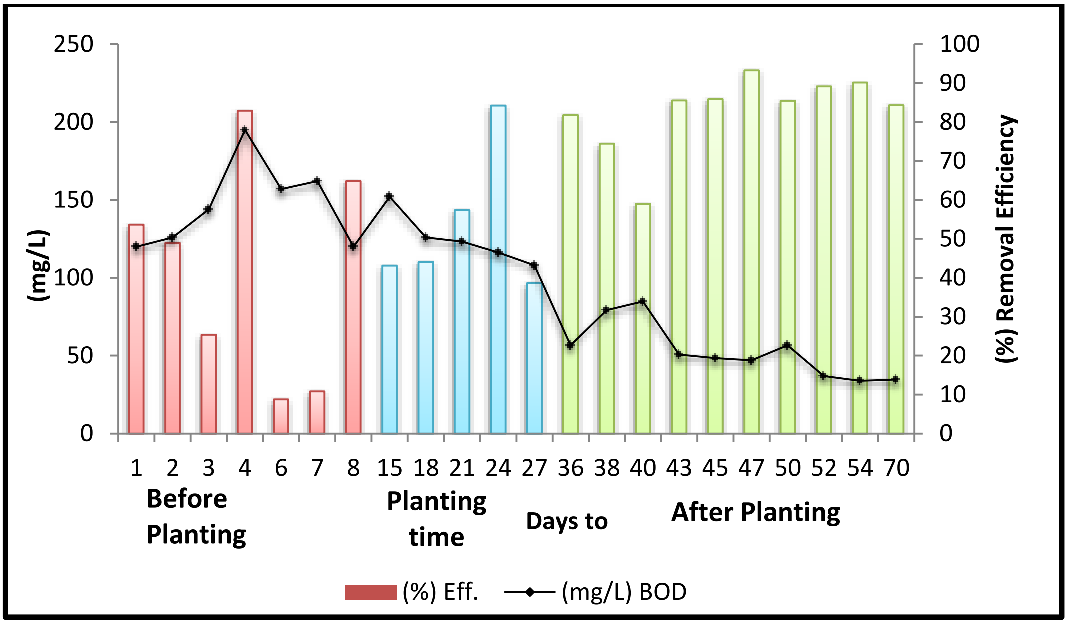

Figure 6 Graph of BOD removal efficiency against BOD Concentrations in mg/L excluded on Constructed Wetland Multilayer Filtration

The removal efficiency fluctuations of the sample tends to be stable at the 43rd to 70th day. During the period, the concentration of BOD that has been successfully removed has reached and fulfilled the standard of quality (50 mg/L) which ranges from 50.16 mg/L to 33.8 mg/L. Therefore, it can be said that the plants have a significant role in removing BOD concentrations compared to non-plants reactors. The non-plants reactors are only able to remove BOD at 42.18% compared to the reactors using *E. paleafolius*plants which reaches removal BOD average at 82.91%. Thus, it can be concluded that *E. paleafolius*plants are able to remove BOD by 49.13% higher than other reactors without the plants and prior to plantation of *E. paleafolius*plants. Obtaining the removal efficiency, it indicates that the biological treatment using *E. paleafolius*plants is more efficient to remove BOD concentrations in domestic wastewater compared to remove COD concentration which reaches 38.81%.

From the results of this analysis, it can be concluded that the constructed wetland reactor is able to remove the organic load with the capacity of 500-700 kg BOD/Ha/Day on the 45th to 70thday as during the period the effluent BOD is found at steady state.

Removal Efficiency of Concentration of Total Nitrogen and Total Phosphorus

Results of the laboratory analysis on the parameters of total nitrogen and total phosphorus for 70 days, are presented in the following table. Results of laboratory analysis of total nitrogen and total phosphorus at the subsurface constructed wetland multilayer filtration reactor with vertical flow type shows that the percentage of total nitrogen concentration is relatively good and constant and there is no increase in reactor effluent, while total phosphate in some samples has obtained increased concentration. The explanation related to this will be discussed deeply after Figure 7, presenting the removal efficiency of total nitrogen and total phosphorus on the concentrations of the two parameters has been presented as follows.

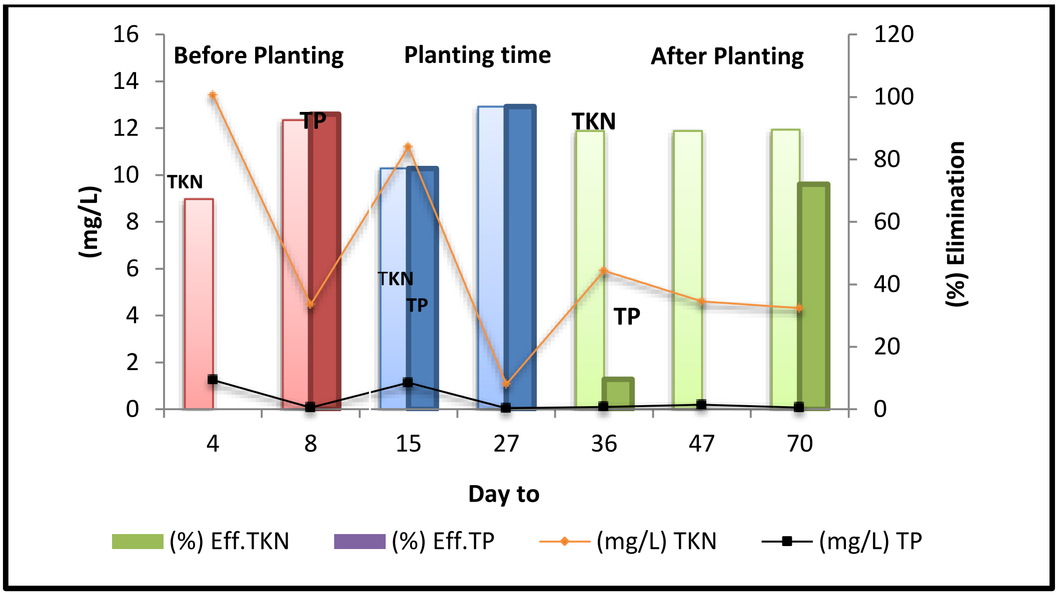

Figure 7 Graph of Total Nitrogen and Total Phosphate removal efficiency to second concentrations parameters (mg/L)are excluded on Constructed Wetland Reactor

Figure 7 shows that the average removal efficiency of total nitrogen reaches 85.35%. Vymazal, (2007) mentioned that removal of total nitrogen in studied types of constructed wetlands varied between 40 and 55% with removed load ranging between 250 and 630 g N/m/year depending on CWs type and inflow loading.The result confirms different findings on the percentage of removal concentration before and after the planting of *E. paleafolius*plants. Total nitrogen shows relatively quick decrease concentration on effluent reactor after 100% *E. paleafolius*plants conducted. Within only 12 days, this parameter has removed to 1.065 mg/L over the standard of quality (5 mg/L). This condition is different from other parameters that require longer period of time to meet the standard of quality.

This condition is caused by nitrogen which plays as one of the essential macro nutrients that are needed by plants to support their growth. Biological nitrogen can easily decompose biomass of the plants by the help of microorganisms, the result of nitrogen fixation will be returned to the atmosphere through denitrification process. This causes the concentration of nitrogen dissolved in the water will be small, so that the total nitrogen concentration of the reactor effluent based on laboratory analysis is very low.

Different from the total nitrogen, the total phosphorus from 2 laboratory analyses on the sample shows increased concentrations in the reactor outlet, but it still meets the standard of quality required. The increase of total phosphate concentration at the reactor outlet is resulted as phosphate decomposition produced by plants with the help of microorganisms is turned into the salt solution which later will sediment into mineral materials. However, the total concentration of phosphate in some sampling period, shows high removal efficiency up to 96.90%. The removal efficiency of total phosphate cannot be calculated because it has a very fluctuated and non-constant removal efficiency.

Removal Efficiency of Oil and Grease Concentration

The results of laboratory analysis of oil and grease parameters for 70 days, are presented in the following table. The results of laboratory analysis of oil and grease in the constructed wetland reactor shows good results and no increase in concentration of reactor effluent has been identified. Figure 5 below shows the removal percentage of oil and grease to the oil concentration within the mg/L removal.

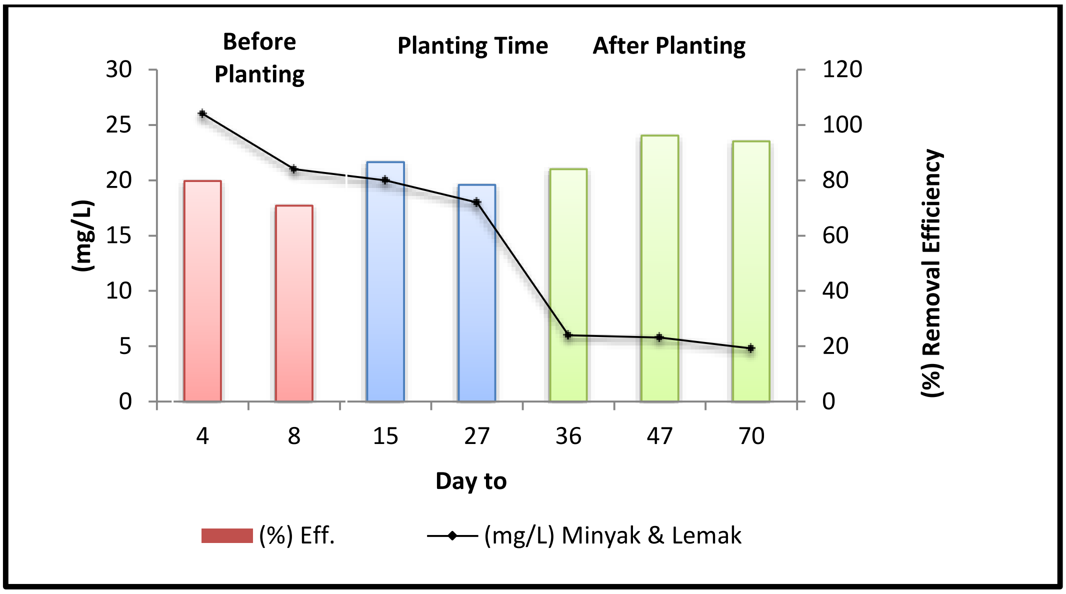

Figure 8 Graph ofOil and Grease removal efficiency to its effluent concentration (mg/L) on Constructed Wetland

The removal efficiency of oil and grease to its concentration in mg/L shows a very stable decline compared to other parameters. Although from the results of analysis of the previous treatment units shows that the concentration of oil and grease in domestic wastewater is quite high, with both physical and biological treatment in the constructed wetland reactor, the process of decomposition of oil and grease is quite effective. The removal efficiency rates of oil and grease is equal to 84.21%. The difference on the removal efficiency between reactor constructed wetland without plants and after the plantation of E. paleafoliusplants reaches about 17,66%. Thus, with the plants attached to the reactor, the removal efficient of oil and grease compared to other reactors without plants media is found more effective.

Oils and grease in domestic wastewater have simpler chains that can be easily decomposed biologically by plants with the help of microorganisms. Oils and grease are organic compounds that are included in the carbon element needed by plants as nutrients supporting their growth.

Conclusions

Subsurface constructed wetland-multilayer filtration with vertical flow type was proven be able to achieve effluent COD concentration of 40 mg/L (standard 100 mg/L) from an average influent of 350 mg/L with removal efficiency of 90%, while BOD was successfully degraded to 33.00 mg/L (quality standard 30 mg/L) of an average influent concentration of 350 mg/L. In addition, the parameters analyzed are total nitrogen, the total phosphate succeeded to meet the quality standard according to Ministry of Environment and Forestry's Standard for wastewater Nr. P.68/2016. Based on the results of laboratory analysis, the reactor is able to treat organic loading of 500-700 kg BOD5/Ha/Day. Similarly, the value of K in this study ranged from 0.35-0.57 m/D for BOD and 0.37-0.45 m/day for COD compared to precious research which is 0.055-0.16 m/D for BOD and 0.027-0.16 m/day for COD.

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