Role Of Vetiveria Zizanioides Plant (AKAR WANGI) In Field-Scale Subsurface Constructed Wetland-Multilayer Filtration With Vertical Flow

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Abstract: There are currently more than 176 high schools in DKI Jakarta with no wastewater treatment plant in the canteens. Canteens wastewater contains high organic compounds which must be treated before discharging into the body of the water. A subsurface constructed wetland (SCW) multilayer filtration (MLF) system with vertical flow (VF) field plants was planned, implemented and operated at the High School in South Jakarta. The field-scale of the SCW-MLF was planted with Vetiveria zizanioides and the other plants free (MLF). These were operated at a hydraulic load of 6.9 m³/day, and the organic loading rate was between 1.43 and 8.3 kg BOD/day. Research has shown that the removal efficiencies in SCW-MLF for COD, BOD, TKN, and TP were 70.5%, 75%, 62.6%, and 54.3%, respectively. Also, the COD and BOD organic loading at SCW-MLF were between 917.08 – 4,126.84 kg COD/Ha/day and 309.78 – 850.73 kg BOD/Ha/day, respectively. Based on the results, the SCW-MLF unit was more efficient compared with MLF in COD, BOD, oil and grease removals, TKN, and TP parameters. Besides, a two-sided t-test was used to identify any significant differences in the mean efficiencies of the two units, with p < 0.05. In conclusion, SCW-MLF has proven to be more effective in the treatment of wastewater from canteens which complies with the Ministry of the Environment and Forestry's Standard for wastewater Nr. P.68/2016 for COD, BOD, and TKN.

Index Terms: Subsurface Constructed Wetlands, Multilayer Filtration, Organic loading, Removal Efficiency, Vegetation

1. INTRODUCTION

There are over 176 high schools in Jakarta, but most of them do not have a wastewater treatment plant (WWTP). As a consequence, the wastewater produced is discharged directly into the receiving water bodies. The wastewater generated comes not only from toilets or bathrooms but also from the canteen/cafeteria. And the ones from canteens usually contain high-organic contents which need to be treated before being discharged into the water bodies [1]. A constructed wetland (CW) is the controlled system used in achieving this through natural processes which involve treating the wastewater with vegetation, media, and microorganisms [2]. CW is widely used in most countries around the world as advanced treatment of both domestic and non-domestic wastewater, but not for canteens with high organic compound concentrations. The application of these wetlands is useful in developing countries as effective treatment systems considering the fact that they are sustainable with simple technology which involves low operational costs [3]–[6]. Research has been carried out on CW to treat wastewater with low concentrations of heavy metals[7] and does not combine it with multi-layer filtration during wastewater treatment in the canteen. Also, researches have shown that vertical wetlands achieve up to 99% removal of its COD while treating domestic [8]. Therefore, there is need to study the treatment of wastewater from canteens by combining constructed wetlands with multilayer, which is considered as an alternative means of such treatment but with simpler technology and also in terms of cost, cheaper on manufacturing, operation, maintenance, as well as more natural [9]. Use Vetiveria zizanioides has the ability to reduce dissolved P after three weeks by 99 % and N after five weeks by 74 %. According to Wu et al. (2001), IHCW used the willow-planting method (Salix babylonica) to achieve a very high overall removal efficiency for BOD5, TSS, NH4-N, and TP which were put at 96.0%, 97.0%, 88.4% and 87.8% respectively [10]. High average removal efficiencies of 94.9%, 99.1% and 52.7% were also achieved in the biochar-amended aerated VFCW for COD, NH4-N and TN, respectively [11]. The purpose of this study was to assess the potential for vertical flow of Vetiveria zizanioides in sub-surface multilayer wetland filtration (SCW-MLF) in the treatment of high organic wastewater. Also evaluated was the efficiency of plant-subsurface constructed wetland multilayer filtration (SCW-MLF) versus unplant multilayer filtration (MLF). And based on the performance data, the constants of the removal rate were calculated, and Vetiveria zizanioides ‘growth rates were measured. Furthermore, the objective of this study is to document for the first time that Vetiveria zizanioides can be used in multi-layer filtration systems for high organic wastewater treatment.

2. METHODOLOGY/ EXPERIMENTAL

2.1. Experimental Setup

The wastewater treatment unit designed in this study was located at a senior high school in Selatan, Jakarta using a combination of collecting and aeration tanks in the preliminary treatment process, which then flowed in parallel to a biofilter tank (Multilayer filtration-MLF) and subsurface constructed wetland multilayer filtration type in the form of vertical flow (SCW-MLF) for advanced treatment as shown in Figure 1.

![Image](https://www.ijstr.org)
The reactor depth was adjusted to the surface water level and the current drainage system depth. Then the SCW-MLF with Vetiveria zizanioides unit was equipped with the model of vertical flow and a detention time of 17.76 hours. Also, the SCW-MLF and MLF were designed with the same surface loading rate.

2.2 Water analysis
The water samples used were collected from the sampling point and immediate analysis was conducted to study the dissolved oxygen (DO) and pH. Also, The chemical demand for oxygen (COD), total Kjedal nitrogen (TKN) and total phosphorus (TP) were determined by standard methods [12]. More so, the removal efficiency was calculated using the formula shown below:

Removal Efficiency = \( (1 - \frac{C_{eff}}{C_{inf}}) \times 100\%
\)

Where \( C_{inf} \) and \( C_{eff} \) are the influent and effluent concentrations measured in mg/L, besides, environmental factors such as temperature and humidity were measured.

2.3 Area Constants
The area constants were calculated in accordance with the formula stated by Moshiri (1993)

\[
A = \frac{Q}{K} \times \ln \left( \frac{C_i}{C_e} \right)
\]

Where:
- \( A \) = Area of constructed wetland (m²);
- \( Q \) = Flow rate of influent (m³/day);
- \( C_i \) = Concentration of influent (mg/L);
- \( C_e \) = Concentration of effluents (mg/L);
- \( K \) = Area constants (m/day).

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

\[
= \left[ \frac{C_i - C_e \times 1000}{10^6} \right] \times \frac{Q}{A} \]

3. RESULTS AND DISCUSSION

3.1 Subsurface Constructed Wetland Multilayers Filtration with Vetiveria zizanioides Unit (SCW-MLF)
Figure 2 and 3 show the result using SCW-MLF in vertical flow with Vetiveria Zizanioides for the treatment of COD, BOD, TKN, and TP in the wastewater from the canteen.

The set up in Figure 2 effectively removed the COD and BOD parameter. Considering the result, the removal efficiency of COD treatment in steady-state was between 64.29 and 80%. Also, it has an organic loading rate between 971.08 and 4126.84 kg COD/ Ha/day. More so, the COD concentration of the effluent was 83 mg/L, which was compiled with the quality standard of domestic wastewater Nr. P.68/2016 based on the recommendation of the Ministry of Environment and Forestry. However, the standard of COD concentration is 100 mg/L. Based on observation as well as the water analysis, it was observed that the plant has a quite significant effect in terms of reducing BOD. The analysis result on day-30 on which the effluent standard was 30 mg/L. Also, the highest BOD concentration in the outlet was on day-2 which was 382.55 mg/L, and the lowest of 26 mg/L was on day-30. Research conducted by Molle (2012) showed that excellent performance of the BOD, COD and SS recirculating VFCW has an average outlet level of 14, 73 and 19 mg/L respectively [13]. Also considering Figure 2, the BOD treatment efficiency at steady state was between 61.2 and 70.8%. During a high concentration of 225 mg/L on day-24, the treatment efficiency was 61.2%, while at a low concentration of 94 mg/L, the efficiency was 70.8%. More so, the SCW-MLF type vertical flow with Vetiveria Zizanioides has organic loading rates between 309.78 and 850.73 kg COD/ Ha/Day, which were much higher compared to the organic loading rate of CW for Domestic wastewater according to Moshiri (1993) at 150 kg BOD/ Ha/Day [14]. Also, a research conducted by Astuti et al., (2017), which used E. paleafolis in treating wastewater from canteen recorded the removal rates of 450 to 1200 kg COD/ Ha/Day and 500 to 700 kg BOD/ Ha/Day [15]. Result of analysis of TP and TKN on the outlet of SCW-MLF type vertical flow with Vetiveria Zizanioides shown in Figure 3.

Based on the result, the removal efficiency of TP on SCW-MLF vertical flow with Vetiveria zizanioides was between 45.71 to 76.54%, while that of TKN was between 10.37 to 77.13%. This result shows that the unit was effective in reducing the two parameters, which is in line with the research conducted by Zheng et al. (1997) that The Vetiveria Zizanioides has the capacity to be used to treat high concentrations of dissolved N and P in a eutrophic stream, with removal efficiency of dissolved P at 99% after three weeks and removal efficiency of dissolved N at 74%
after five weeks. This finding is an indication that SCW-MLF vertical flow with Vetiveria Zizanioides is very effective in removing these two organic matters from the wastewater. The plant reduced TKN and TP by using both parameters as a nutrient for its growth and reproduction. These substances are transformed into the organic and inorganic matter by the microorganism through decomposition and synthesis process. A study by Fu et al. (2017) also obtained removal rates of 91.5% for NH4 + N, 94.5% for NO3 + N and 92.8% for TN [16 ].The removal of TP in SCW-MLF vertical flow with Vetiveria zizanioides was possible due to soil adsorption, plant absorption, as well as the removal process, carried out by the microorganisms in the roots and stem of the plant. The phosphorous is usually converted into orthophosphate before being absorbed by the plant. And this transformation is commonly affected by some abiotic factors in the environment such as sunlight and air medium; as well as some biotic factors such as microbes and plant. The removal of TN in SCW-MLF vertical flow with Vetiveria Zizanioides was possible due to processes such as ammonification followed by nitrification, assimilation, fixation and denitrification. The nitrogen fixation process converts gaseous N into its organic form by particular microorganism with the nitrogenase enzyme. The reaction can take place in aerobic and anaerobic conditions such as water surface, in sedimentation, plant rhizosphere leaves the surface as well as the stem. However, nitrogen assimilation is a process in which plant takes in N after its inorganic form is converted to organic nitrogen usable by plant tissue. Plant use a large amount of nitrogen during the growth phase. The dissolved oxygen on the outlet of the treatment unit was in the range of 3.02 to 3.36 mg O2/L, which indicates the process was aerobic. The pH of the SCW-MLF outlet with Vetiveria zizanioides was between 6.5 and 7.6, which is an indication that the average pH condition was optimum and a supporting factor in bacterial growth.

The organic loading rates of phosphate was between 0.66 to 17.08 kg/ha/day or 0.24 to 6.15 ton/ha/year, while that of nitrogen removed was between 3.09 and 60.18 kg/ha/day or 1.12 to 21.66 ton P/ha/year. And according to some researchers, Vetiveria zizanioides has the potential to remove 54 Ton P/ha/year and 102 ton N/ha/year. Chang et al. (2012) used Typha orientalis and Arundo donax var Versicolor to treat domestic wastewater, and findings showed a mean mass removal rate for COD of 44.3 gr / m2/day or 443 kg / ha / day; 1.27 gr/m2/day or 12.7 kg/ha/day for TN; and 0.39 gr/m2/day or 3.9 kg/ha/day for TP [17].

3.2 Multilayers Filtration Unit (MLF)

The main goal of MLF treatment was to assess the efficacy of Vetiveria Zizanioides on SCW-MLF. The MLF unit is designed with the same setting and layer without any plant. The attached growth process is also known as biofilter method in which microbes mass grow attached to the medium. The medium used in the MLF unit is similar to those in SCW-MLF vertical flow with Vetiveria zizanioides. Based on Figure 4, the COD removal concentration in the MLF unit at steady state (day-21 to day-30) was between 20 to 40% which is an indication that a biological treatment occurred in this unit although with lower efficiency compared with SCW-MLF vertical flow with Vetiveria Zizanioides unit. Its removal efficiency declined due to the high input loading and the outlet in steady-state was between 749 and 166 mg/L. The standard required by the regulation of the Ministry of Environment and Forestry Nr. P.68/2016 which is 100 mg/L. The figure also shows that the BOD concentration removal in MLF unit at steady state (day-21 – day-30) was between 15 and 48.51% and the concentration of MLF BOD outlet at steady-state was between 181 and 62 mg/L. However, this concentration is higher than regulation which is 30 mg/L. In addition, the MLF unit has COD organic loading rates between 9.24 and 545.41 kgBOD/Ha/day.

The removal efficiency of TP concentration in MLF was between 0.56 and 41.08%, while that of TKN was between 2.56 and 33.33%, as shown in Figure 6. In general, the treatment efficiency in MLF unit fluctuated with a declining trend and lower when compared with SCW-MLF vertical flow with Vetiveria zizanioides. Also, the dissolved oxygen rate of 3.69 to 4.02 mg O2/L indicates that the process was in the aerobic flow. More so, the pH was between 6.7 and 7.3, which is the optimum average pH condition and a supporting factor in bacterial growth.

3.3 Effect of Vetiveria Zizanioides to the Efficiency of Canteen Wastewater Treatment

The removal of COD in SCW-MLF vertical flow with Vetiveria Zizanioides unit was 69.24% - 80%, while in MLF unit without plant ranges was 20% - 40.7%. Also, the BOD removal in SCW-MLF vertical flow with Vetiveria
Zizanioides unit was 61.2% - 70.8% while in MLF unit without plant was 15% - 48.51%. The comparison of COD between the outlets of the aeration tank, SCW-MLF vertical flow with Vetiveria Zizanioides unit and MLF without plant is shown in Figure 6. On the first week, the effluent concentration in each unit, for both COD and BOD parameters, was almost the same. However, the difference was significant after that period. Treatment efficiency on SCW-MLF vertical flow with Vetiveria Zizanioides increased linearly with the plant growth. The higher the growth of the plant as well as its leaves and roots, the higher the plant’s ability to absorb organic materials. Furthermore, the deeper and spread out the roots were, the more the microorganism around the roots. Therefore, it increases the removal efficiency of SCW-MLF vertical flow with Vetiveria zizanioides. Hence, SCW-MLF is affected by medium, the roots of Vetiveria zizanioides as well as the microorganism living in both media, while the MLF unit is affected only by the medium and microorganism living in it. This phenomenon explains why microorganism capacity in MLF unit was less effective compared to SCW-MLF with Vetiveria Zizanioides unit. The result was similar to the analysis of Darajeh et al. (2014) on oil palm. According to the research, Vetiveria zizanioides removed COD on a low concentration of Palm Oil Mill Effluent (POME) by 94% and 39% at high concentration [18]. Also, Vetiveria zizanioides removed BOD by 90% at a minimum concentration of POME and 60% at maximum concentration, while control set (without plant) only removed 15% of BOD.

The removal efficiency of TP in SCW-MLF vertical flow with Vetiveria Zizanioides was between 45.71 and 76.54% but was between 0.56 and 41.08% in the MLF unit without the plant. Also, the removal efficiency of TKN in the unit with Vetiveria zizanioides was from 10.37 to 77.13% but was between 2.56 and 33.33% in MLF unit without the plant. Figures 8 and 9 show the comparison between TP and TKN parameters in the outlets of aeration tank, SCW-MLF vertical flow with Vetiveria Zizanioides and MLF without the plant. According to Vymazal (2010) and Abou-elela et al., (2013), results with vertical flow SCW record high removal efficiency of TP, TN and NH4-N [19][20].

The removal of TKN in SCW-MLF unit was possible due to ammonification followed by nitrification, assimilation and fixation processes. However, only ammonification and nitrification processes occurred in the MLF unit, considering the fact that assimilation process only happens with the plant. Therefore, the removal efficiency in SCW-MLF is higher compared with MLF. The plant uses biomass from microorganism metabolism to form N, P, CO2, H2O and pure organic compound which provide nutrient for its growth.
and reproduction and the surplus biomass is cultivated in the roots. More so, aerobic microorganisms use the remaining carbon, phosphate and nitrogen to form new cells and convert some into energy. Oxygen function as an electron acceptor during oxidation of organic material and the reaction stops in the absence of oxygen. An essential role for plants is to reduce contaminants, organic matter, nitrogen and phosphorus [21]. This result is similar with research by conducted by Hoang et al., [2011] with Sesbania sesban and Konnerup et al., [2008] with Canna and Heliconia [22, 23]. There are four benefits of the plant: (i) serves as filter for suspended solid material, (ii) growth medium for microorganism, (iii) its roots supply oxygen into the medium and (iv) maintains the substrate (Tchobanologlous, 1987, Brix, 1993) [14]. The indications of growth and reproduction of Vetiveria Zizanioides in this study were the height and growth of new shoots, respectively. The average plant height after acclimatization (during planting) was 60.5 cm. This was measured for 30 days during the research period. In addition, Vetiveria zizanioides remove odor and vector usually present in the waste or stagnant water such as mosquito, flies, etc. Furthermore, the presence of the plant in canteen wastewater treatment unit gives a beautiful landscape view. Area constant in each unit were calculated and compared with that of Moshiri (1993) as shown in Table 1.

### Table 1. Area Contants at SCW-MLF and MLF

<table>
<thead>
<tr>
<th>No.</th>
<th>Parameter</th>
<th>K of SCW-MLF (m/day)</th>
<th>K of MLF (m/day)</th>
<th>K of Moshiri (m/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>COD</td>
<td>0.568 – 0.887</td>
<td>0.1229 – 0.284</td>
<td>0.055 – 0.16</td>
</tr>
<tr>
<td>2.</td>
<td>BOD</td>
<td>0.55 – 0.78</td>
<td>0.09 – 0.320</td>
<td>0.18</td>
</tr>
<tr>
<td>3.</td>
<td>TKN</td>
<td>0.35 – 0.98</td>
<td>0.09</td>
<td>0.027 – 0.55</td>
</tr>
<tr>
<td>4.</td>
<td>TP</td>
<td>0.08 – 0.79</td>
<td>0.09 – 0.20</td>
<td>0.027 – 0.033</td>
</tr>
</tbody>
</table>

Two-sided t-tests were also used to identify any significant differences between the two units with different parameters with and without plants and pollutant removal efficiencies with p<0.05. The findings showed a significant difference between the means of the two units, as the t calculation was more than t table as shown in Table 2.

### Table 2. T-Test Results

<table>
<thead>
<tr>
<th>No.</th>
<th>Parameter</th>
<th>T calculation</th>
<th>T Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>COD</td>
<td>6.166</td>
<td>1.729</td>
</tr>
<tr>
<td>2.</td>
<td>BOD</td>
<td>5.172</td>
<td>1.729</td>
</tr>
<tr>
<td>3.</td>
<td>TKN</td>
<td>2.417</td>
<td>2.015</td>
</tr>
<tr>
<td>4.</td>
<td>TP</td>
<td>2.358</td>
<td>2.015</td>
</tr>
<tr>
<td>5.</td>
<td>Oil and Grease</td>
<td>2.471</td>
<td>2.015</td>
</tr>
</tbody>
</table>

### 4. CONCLUSION

The unit comprising of SCW-MLF vertical flow with Vetiveria Zizanioides effectively reduced the concentrations of COD, BOD, TP, TKN in canteen wastewater compared with the MLF unit. The medium in multilayer, the roots of Vetiveria zizanioides and microorganism living in both medium all play a vital role in enhancing the efficiency of SCW-MLF, while only two factors, the medium and microorganism living in it determine the efficiency of MLF. In conclusion, SCW-MLF can be used as an alternative canteen wastewater treatment which has low cost in terms of operations and resulting in a beautiful landscape view. Aside these, no odor or insects were detected with the use of SCW-MLF.

### 5. ACKNOWLEDGEMENT

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### 6. REFERENCES


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