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Ecological Approach of Campus Wastewater Treatment using Constructed Wetland

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Abstract. This study aimed to determine the potential of constructed wetland for wastewater treatment in campus before safely discharged to water bodies. Parameters analyzed were pH, TSS, COD, BOD, oils and grease, nitrogen and phosphate. There are types of constructed wetlands, yet one used in this study was the horizontal subsurface flow with bed dimension of 1 m length x 0.5 m width x 0.5 m depth, and design flow of 0.0214 m³/d. This area was planted with *Canna Sp.* and used sand with a porosity of 0.42, a hydraulic conductivity of 420 and K₂₀ of 1.84 as the medium. The effluent analysis showed the decreasing in pH from 8.15 to pH of 7.00, while other pollutant parameters decreased as TSS (57-83%), COD (85-87%), BOD (85-88%), oils and grease (85-90%), total nitrogen (91-97%), and total phosphate (97-99 %). Those parameters were able to meet the standards set by government which could be proposed as standard effluents for all universities or colleges to maintain own wastewater treatment.

1. Introduction

The scarcity and quality degradation of clean water in the current time becomes serious problems which are most countries faced world-widely. These situations need a serious concern in order to lessen the water crisis threatening future water supply. One of activities that produces wastewater without any treatment before disposing to water body is campus wastewater, and almost all universities in Indonesia directly discard their wastewater without any treatment contributing in surface water pollution [1]. A holistic system focused on ecological approaches is appropriate than an expensive end-of-pipe system.

One of the wastewater treatments that are possibly to be applied is constructed wetland. Constructed wetland is a man-made filter system constructed from plants, mixed soil as media, and a set of microbes helping to remove pollutants in wastewater. This system is designed as it is in natural, yet it is environmentally controlled in order to gain many benefits [2,3,1]. There are two types of constructed wetlands namely, free surface flow and sub-surface flow. Free surface flow requires larger areas than sub-surface flow, but it has lower costs, while sub-surface flow depends on the wastewater discharge in media.

In urban areas sub surface flow is more suitable to be used because of the availability of areas [1]. There are two hydraulic flow systems in sub surface flow constructed wetland, horizontal flow type and vertical flow type. In horizontal flow system, the water laterally flows beneath the surface through the gravel bed, while in vertical flow system, the water downwardly flows through the increased



particle size layers. The vertical flow system is an efficient, and small-scale wastewater alternative treatment (approximately 30 people) [2,3].

The successes of constructed wetland in wastewater treatment were previously studied. Constructed wetland is able to treat both domestic and industrial wastewater. One of the industrial wastewater treated using constructed wetland was tannery wastewater. Using *Typha latifolia* and *Phragmites australis* in horizontal sub-surface constructed wetland with hydraulic loading rate 6 cm d^{-1} was able to decrease the COD from 2093 mgL^{-1} to 821 mgL^{-1} , BOD 5 from 898 mgL^{-1} to 453 mgL^{-1} , TSS from 79 mgL^{-1} to 24 mgL^{-1} , TN from 126 mgL^{-1} to 95 mgL^{-1} , although TP increased from 0.25 mgL^{-1} to 0.27 mgL^{-1} [4]. Aside treating industrial wastewater, using vertical sub-surface with Indian local vegetation, Napier Bajra Hybrid grass, constructed wetland was able to result in removal efficiency of muddiness as 99%, TSS as 93%, BOD as 94%, COD as 82%, Nitrate as 88%, Phosphates as 63%, and TN as 60% [5]. Based on the researches, type of vegetation, climate, and type of wastewater are factors determining removal efficiency.

Removal efficiency of both wastewater and both type of constructed wetland became a foothold to conduct research using constructed wetland to treat wastewater taken from university in order to preserve the environment. This research could be a foothold for university to treat own wastewater. Horizontal sub-surface flow constructed wetland was selected because wastewater is produced by more than 30 people. This research aimed to analyze the effectiveness of horizontal sub-surface flow constructed wetland (HSSFCW) as an ecological approach to treat wastewater generated by campus activities.

2. Methods

2.1 Sampling technique and characteristics of raw grey water

Wastewater used is grey water taken from canteen in campus Unesa Ketintang Surabaya. Sampling was done manually using a 500 mL sterile glass bottle stored in cooler and it was sent the laboratory for analysis. The sample was analyzed using standard method [6]. The affectivity of treatment in improving water quality can be observed from the Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), nutrients as well as faecal bacteria decreasing [7]. However, this research also conducted observations in pH, Total Suspended Solid (TSS), as well as oils and grease. pH was analyzed using ion-selective electrode, whether COD and BOD were analyzed using potassium dichromate-boiling and incubation method. TSS was analyzed using filter method. Total nitrogen and total phosphate were analyzed using distillation of nesslerization method and molybdenum blue method. Oils and fats were analyzed using gravimetric method. Those analysis results are shown in Table 1. The result in Table 1 was above the standard of quality of grey water allowed to be disposed into water body according to Governor Regulation [8].

Table 1. Characteristic of campus wastewater (grey water) used in the research (n=20)

| Parameter | Common level in wastewater (Mean \pm SD) | Coefficient of variance (%) | P value | Effluent Standard |
|-----------------|---|-----------------------------|---------|-------------------|
| pH | 8.15 ± 0.28 | 2.7 | <0.01 | 6-9 |
| BOD | $220 \pm 0.15 \text{ mgL}^{-1}$ | 71.8 | <0.01 | 50 |
| COD | $356 \pm 0.24 \text{ mgL}^{-1}$ | 63.6 | <0.01 | 50 |
| TSS | $84 \pm 0.22 \text{ mgL}^{-1}$ | 74.4 | <0.01 | 30 |
| Oils and grease | $42 \pm 0.18 \text{ mgL}^{-1}$ | 53.1 | <0.01 | 10 |
| Total Nitrogen | $281.84 \pm 0.05 \text{ mgL}^{-1}$ | 92.2 | <0.01 | - |
| Total phosphate | $21.95 \pm 0.21 \text{ mgL}^{-1}$ | 55.4 | <0.01 | - |

2.2 Experimental design of constructed wetland

The HSSFCW reactor was designed based on flow rate and organic loading rate calculation [9] using glass material with dimensions of 50 cm (width) x 50 cm (depth) x 100 cm (length). The reactor was divided into 3 parts and the baffle was placed to produce a zigzag stream. The wastewater was flown into the HSSFCW through an inlet associated with the feeding tank with an intermittent feeding mechanism of $0.0214 \text{ m}^3\text{d}^{-1}$. Wastewater flew horizontally through the bed media filter and accumulated on the outlet, and observed on day 1, day 3 and day 5.

2.2.1 *Filter bed.* The medium used was sand with porosity of 0.42, hydraulic conductivity of 420, and K_{20} of 1.84 [9]. The flow directed from inlet to outlet was horizontal through a medium with 5 cm length of gravel, 70 cm length of sieving sand no 20, and 15 cm length of sieving sand no. 60.

2.2.2 *Vegetation and acclimatization.* Selecting plants is very important in designing constructed wetland because those affect oxygen levels in water and soil or in media used, and help providing the surface area below water surface required for bacterial colonization [10, 5]. However, in this study *Canna sp.* was used in constructed wetland design. *Canna sp.* used was 3-4 weeks old with a height of 60-70 cm and had 0.3 m root depth. The plants were from the same seed and cultured on compost and chaff media. Later, those moved to media constructed wetland for acclimatization. This process needed 2 months where plants had been watered with clean water for 1 month and another month those had been flown with wastewater in order to make the plants adapt the media prepared for the research.

2.3 Data analysis

All statistical data were analyzed using SPSS 17.0. The significant differences were analyzed using one-way ANOVA followed by LSD test ($\alpha = 0,05$).

3. Results and discussion

3.1 pH removal

Result showed the pH decreasing from 8.15 to 6.6 ± 0.28 ($P < 0.01$) on retention day 1, increased to 7.0 ± 0.47 ($P < 0.01$) on day 3, but decreased into 6.8 ± 0.35 ($P < 0.01$) on day 5 with the temperature range 27-28°C as it showed in Table 2. pH in constructed wetland correlated with calcium content in the water ($\text{pH } 7 = 20 \text{ mg Ca L}^{-1}$). pH was managed to be stable as a sudden pH changes gave impact to biota in the constructed wetland. A decrease in pH at retention day 1 showed the domination of anaerobic condition, although it gradually increases the following days. In addition to pH, temperatures also play a role in chemical and biological processes especially in BOD decomposition, nitrification and denitrification. Warm environmental conditions and wastewater characteristics affect the degradation of organic materials and nutrient removal [11]. Although there was pH decreasing in this research, but it remained in the range of 6.5-7.5 and with average temperature between 25°C-35°C which is very suitable for high microbial activity [12, 13] as well as for growing the plant [4]. Variations in pH was possibly caused by the weather differences during sampling (sunny or cloudy), thus preventing the sunlight reached wastewater as it passed HSSFCW.

Table 2. The analysis result of HSSFW effluent in pH

| Influent (raw grey water) | Time retention of HSSFCW effluent | | | Effluent standard |
|------------------------------|-----------------------------------|-------|-----------------|----------------------|
| | Day 1 | Day 3 | Day 5 | |
| 8.15 ± 0.28 | 6.60 ± 0.21 | 6-9 | 6.80 ± 0.35 | 6-9 |

3.2 Organics removal

As seen in Table 3, BOD decreased from 220 mg/l to $28 \pm 0.44 \text{ mgL}^{-1}$ ($P < 0.01$) on day 1; $31 \pm 0.38 \text{ mgL}^{-1}$ ($P < 0.01$) on day 3; and $26 \pm 0.17 \text{ mgL}^{-1}$ ($P < 0.01$) on day 5. The result showed $87.27 \pm 0.35\%$ (1 day time retention), $85.91 \pm 0.2\%$ (3 days' time retention), and $88.18 \pm 0.16\%$ (5 days' time retention). High BOD removal was also showed in the previous researches, such as *Phragmites mauritianus* resulting on 96% removal efficiency [14]; *Eichhorniacrassipes* resulting 81% removal efficiency [15]; and along with [16,17,4] who argued that constructed wetland with horizontal flows had high BOD and COD removal efficiency as well as TSS, yet it had low nutrient (nitrogen and phosphor) removal efficiency. In this research, BOD removal efficiency that decreased in day 3 of time retention was possibly due to the non-optimal of biologic process such as decomposing process of organics caused by weather or the unfinished adapting process of the plants in new media of constructed wetland, proved by the increasing removal percentage on day 5 of time retention.

Table 3. The analysis result of HSSFCW effluent in BOD

| Influent (raw grey water) | Time retention of HSSFCW effluent | | | Effluent standard |
|---------------------------------|-----------------------------------|--------------------------------|--------------------------------|-----------------------|
| | Day 1 | Day 3 | Day 5 | |
| $220 \pm 0.15 \text{ mgL}^{-1}$ | $28 \pm 0.44 \text{ mgL}^{-1}$ | $31 \pm 0.38 \text{ mgL}^{-1}$ | $26 \pm 0.17 \text{ mgL}^{-1}$ | 30 mgL^{-1} |
| | $87.27 \pm 0.35\%$ | $85.91 \pm 0.2\%$ | $88.18 \pm 0.16\%$ | |

In Table 4, COD content decreased from $356 \pm 0.24 \text{ mgL}^{-1}$ ($P < 0.01$) to $46 \pm 0.36 \text{ mgL}^{-1}$ ($P < 0.01$) on day 1; $50 \pm 0.19 \text{ mgL}^{-1}$ ($P < 0.01$) on day 3; and $44 \pm 0.22 \text{ mgL}^{-1}$ ($P < 0.01$) on day 5. Thus, COD removal efficiency was $87.08 \pm 0.3\%$ on day 1, $85.96 \pm 0.2\%$ on day 3, and $87.64 \pm 0.2\%$ on day 5. The high rates of removal efficiency ranging from 85 to 87% was possibly be due to: 1) long retention time; 2) substrate which accumulated large amount of bacteria; and 3) organic biodegradation [18].

In COD removal process, bacteria were a key role [19,20,21] and were not the vegetation [22]. The bacterial main role was to perform microbiological degradation when the matrix layer was attached to the plant roots [23]. This mechanism occurred due to the oxygen produced by photosynthesis in the leaves and transferred to the root to grow the bacteria which function is to decipher the organic content [24].

Table 4. The analysis result of HSSFCW effluent in COD

| Influent (raw grey water) | Time retention of HSSFCW effluent | | | Effluent standard |
|---------------------------------|-----------------------------------|--------------------------------|--------------------------------|-----------------------|
| | Day 1 | Day 3 | Day 5 | |
| $356 \pm 0.24 \text{ mgL}^{-1}$ | $46 \pm 0.36 \text{ mgL}^{-1}$ | $50 \pm 0.19 \text{ mgL}^{-1}$ | $44 \pm 0.22 \text{ mgL}^{-1}$ | 50 mgL^{-1} |
| | $87.08 \pm 0.3\%$ | $85.96 \pm 0.2\%$ | $87.64 \pm 0.2\%$ | |

3.3 TSS removal

The total suspended solid was all the particles dissolved in the wastewater. The result showed that the campus wastewater has high turbidity level (exceeds the quality standard set by the East Java provincial government) due to the residual food mixed with wastewater considering the samples taken from canteen wastewater. At the influent, TSS content was $84 \pm 0.22 \text{ mgL}^{-1}$ ($P < 0.01$), after treated it became $14 \pm 0.15 \text{ mgL}^{-1}$ ($P < 0.01$) on the day 1, $20 \pm 0.32 \text{ mgL}^{-1}$ ($P < 0.01$) on the day 3, and $36 \pm 0.28 \text{ mgL}^{-1}$ ($P < 0.01$) on the day 5 (Table 5).

The result of HSSFCW treatment showed that the decrease of TSS removal efficiency $83.33 \pm 0.2\%$ (day 1), $76.19 \pm 0.3\%$ (day 3), and $57.14 \pm 0.2\%$ (day 5) as shown in Table 5. It was possibly due to high TSS content. Thus, the amount of solute particles decreased the sunlight entering the water, lowered the ability of photosynthesis of plant, swallowed the water depth, raised the heat absorbed by water, lowered dissolved oxygen content, and triggered the disease and parasite growth, as well as elevated the ammonia toxicity [25,26].

The high removal efficiency on day 1 showed that particles in wastewater were easily sediment by gravity or physical screening processes [27,28,29,17]. In HSSFCW system, the flow occurred uniformly and consistently so it was possibly to continuously drain the wastewater into the system which reduces the disturbance of the particles to sediment without being disturbed by other sedimentation attached to the constructed wetland media [30].

Table 5. The analysis result of HSSFW effluent in TSS

| Influent (raw grey water) | Time retention of HSSFCW effluent | | | Effluent Standard |
|------------------------------|-----------------------------------|--------------------------------|--------------------------------|----------------------|
| | Day 1 | Day 3 | Day 5 | |
| 84 ± 0,22 mgL ⁻¹ | 14 ± 0.15 mgL ⁻¹ | 20 ± 0.32 mgL ⁻¹ | 36 ± 0.28 mgL ⁻¹ | 50 mgL ⁻¹ |
| | 83 ± 0.2% | 76 ± 0.3% | 57 ± 0.2% | |

3.4 Nutrient removal

The two nutrients observed in this research were phosphate and nitrogen. Phosphate content before HSSFCW treatment was 21.95 ± 0.21 mgL⁻¹(P<0.01), after treatment it decreased into 0.125 ± 0.39 mgL⁻¹(P<0.01) on day 1, 0.18 ± 0.35 mgL⁻¹(P<0.01) on day 3, and 0.53 ± 0.37 mgL⁻¹(P<0.01) on day 5. In phosphate removal process, the removal efficiency was 99.43 ± 0.3% on day 1, 99.18 ± 0.25% on day 3, and 97.59 ± 0.32% on day 5 (Table 6).

The rate of phosphate removal efficiency in this research was higher than in other previous studies. Several previous studies suggested that the absorption of phosphate in wastewater using a pumice media in constructed wetland be able to produce 39% decrease removal [31]. Besides, it was reported that in wastewater with low P concentration, the removal efficiency could reach 70% using coarse sand coated with aluminium hydroxide [32]. This difference was probably caused by several things such as pH supporting plant growth and microbial activity, so those could optimize the phosphate removal.

In this research, the decrease of efficiency on day 3 and 5 day was likely due to the HSSCW saturation conditions which slowly inhibited the decomposition of organic material containing phosphorus by decomposing bacteria. Up today 5, the phosphorous concentration was 0.53 mg/l which acceptable considering the quality standard [8]. This condition required observation with longer retention time or it was given pre-treatment before treating wastewater in HSSFCW to obtain best results. As described in the previous researches, hydraulic loading and retention time were very significant in determining the rate of sedimentation and nutrient removal in constructed wetland, the contact time between nutrient load and wetland sediment and vegetation [33, 34].

Table 6. The analysis result of HSSFW effluent in phosphate

| Influent (raw grey water) | Time retention of HSSFCW effluent | | | Effluent standard |
|-------------------------------|-----------------------------------|----------------------------------|----------------------------------|----------------------|
| | Day 1 | Day 3 | Day 5 | |
| 21.95 ± 0.21mgL ⁻¹ | 0.125 ± 0.39 mgL ⁻¹ | 0.18 ± 0.35 mgL ⁻¹ | 0.53 ± 0.37 mgL ⁻¹ | - mgL ⁻¹ |
| | 99.43 ± 0.3% | 99.18 ± 0.25% | 97.59 ± 0.32% | |

Nitrogen nutrient removal in Table 7, the influent nitrogen content was 281.84 mgL⁻¹(P<0.01) before HSSFCW, yet it decreased into 12.95 mgL⁻¹(P<0.01) on day; 1, 5.94mgL⁻¹(P<0.01) on day 3; but increased into 21.15 mgL⁻¹(P<0.01) on day 5. It showed that the removal efficiency of nitrogen was 91 to 95% after being treated in HSSFCW system with *Canna sp.* The high percentage of nitrogen removal more than 90% indicated the decomposition of pollutants contained in wastewater, the perfect amino-organic nitrogen, and the adequate nitrification process in the system. When the wastewater entering the HSSCW system triggered the conversion of Ammonium in wastewater to nitrates by

Nitrosomonas bacteria [35, 36] nitrates was subsequently absorbed by *Canna sp* and underwent process of converting to nitrogen (nitric oxide, nitrous oxide and dinitrogen) by chemo-autotrophic bacteria [31,37,11]. Hoggins became a habitat for microorganisms that effectively help removing nitrogen from contaminated water for their physiological needs.

In addition, the capacity of constructed wetland plants in absorbing nutrients varied depending on the type of plant, the quality of the waste water, the oxygen-carrying plants which related to root growth [38]. Nitrogen removal in constructed wetland relied on the nitrification-denitrification, plant-adsorption, and ammonia-nitrogen volatilization processes occurring throughout the constructed wetland process [39]. On day 5, the decrease in the nitrogen removal efficiency from $97.54 \pm 0.15\%$ to $91.25 \pm 0.05\%$ was likely due to the sand movement from the media to the pebble indicating where the sand had larger surface area to support microorganisms and needed longer retention time for biological processes such as denitrification and nitrification [40]. Additionally, the decrease in nitrogen removal efficiency was likely due to oxygen deprivation in HSSFCW filter media as a result of waterlogged conditions [38].

Table 7. The analysis result of HSSFCW effluent in nitrogen

| Influent (raw grey water) | Time retention of HSSFCW effluent | | | Effluent standard |
|------------------------------------|-----------------------------------|----------------------------------|-----------------------------------|----------------------|
| | Day 1 | Day 3 | Day 5 | |
| $281.84 \pm 0.05 \text{ mgL}^{-1}$ | $12.95 \pm 0.11 \text{ mgL}^{-1}$ | $5.94 \pm 0.23 \text{ mgL}^{-1}$ | $21.15 \pm 0.14 \text{ mgL}^{-1}$ | - mgL^{-1} |
| | $94.65 \pm 0.05\%$ | $97.54 \pm 0.15\%$ | $91.25 \pm 0.05\%$ | |

3.5 Oils and grease removal

The result showed that HSSFCW successfully decreased the oils and grease content from 42 mgL^{-1} ($P < 0.01$) to 4 mgL^{-1} ($P < 0.01$) in the retention day 3 and 5. The removal efficiency was $85.71 \pm 0.2\%$ on the day 1 and gradually increases on the day 3 and 5 as $90.48 \pm 0.3\%$. This removal ability was due to oils and grease trapped in plant roots (*Canna sp.*). The rice field vegetation had a capacity as an oxygen carrier and a water conduction root associated with the root system development [39].

Table 8. The analysis result of HSSFCW effluent in oils and grease

| Influent (raw grey water) | Time retention of HSSFCW effluent | | | Effluent standard |
|--------------------------------|-----------------------------------|-------------------------------|-------------------------------|-----------------------|
| | Day 1 | Day 3 | Day 5 | |
| $42 \pm 0.18 \text{ mgL}^{-1}$ | $6 \pm 0.25 \text{ mgL}^{-1}$ | $4 \pm 0.46 \text{ mgL}^{-1}$ | $4 \pm 0.37 \text{ mgL}^{-1}$ | 10 mgL^{-1} |
| | $85.71 \pm 0.2\%$ | $90.48 \pm 0.3\%$ | $90.48 \pm 0.3\%$ | |

4. Conclusion

HSSFCW using *Canna sp.* was proved to be very effective in treating campus wastewater. The results of the effluent analysis showed decrease in pH from 8.15 to normal pH of 7.00 as well as decrease in other pollutants such as TSS (57-83%), COD (85-87%), BOD (85-88%), oils and grease (85-90%), total nitrogen (91-97%), and total phosphate (97-99%). Although the removal efficiency of parameters is high, there are two parameters that are still higher than standard of domestic wastewater required by Governor Regulation No. 72 of 2013, namely nitrogen and phosphate. For TSS, the removal efficiency was decreased on day 5 due to the possibility of high TSS content of the raw. Therefore, for the best efficiency, there should be conducted pre-treatment of all pollutants contained in wastewater before processed in HSSFCW or combined with other processing types.

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