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APPLICATION OF CONSTRUCTED WETLANDS TO REMOVE NITROGENOUS AND PHOSPHOROUS COMPOUNDS FROM LEACHATE RUN-OFF LIQUID

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ABSTRAK

Air lindi adalah salah satu pencemar pada lingkungan. Karakteristik umum dari air lindi diantaranya adalah konsentrasi yang tinggi dari senyawa nitrogen (N) dan fosfor (P). Untuk mengurangi kadar dari pencemar yang terkandung dalam air lindi diperlukan suatu pengolahan. Rawa Buatan adalah salah satu alternatif teknologi pengolahan yang dapat digunakan. Skala pilot dari sistem Rawa Buatan Aliran Vertikal Menanjak digunakan pada penelitian ini untuk mengolah run–off air lindi. Tanaman yang digunakan adalah Canna, Hydrilla, *dan* Nymphaea *yang ditanam secara berurutan pada 3 buah kolam pengolahan. Penelitian ini bertujuan: (1) mengevaluasi kemampuan sistem Rawa Buatan Aliran Vertikal Menanjak dalam mengurangi kandungan senyawa N dan P serta (2) memahami peranan dari tanaman dalam mengurangi senyawa N dan P. Evaluasi dari nilai efisiensi pengurangan (RE) menunjukkan bahwa sistem dapat mengurangi kandungan senyawa N dan P dengan sangat baik (pada umumnya RE>80%). Analisis regresi menunjukkan adanya korelasi yang kuat dan signifikan antara berat basah canna dan* Nymphaea *dengan pengurangan N dan P dalam sistem. Korelasi yang kuat ini mempunyai arti bahwa ukuran tanaman harus diperhitungkan dalam kaitannya dengan pemeliharaan efektivitas rawa buatan dalam mengurangi senyawa N dan P..*

Kata kunci: rawa buatan;air lindi; nitrogen; fosfor.

ABSTRACT

Leachate liquid is one of the hazardous pollutants in the environment. Some general characteristics of leachate liquid are the high concentration of nitrogenous (N) and phosphorous (P) compounds. To reduce the amount of pollutant in leachate liquid, treatment is needed. Constructed Wetlands (CW) is one alternative treatment technology that can be applied. A pilot plant scale Vertical Up-Flow Constructed Wetland (VUFCW) system is used in this study to treat leachate run-off liquid. Plants that used in this system were Canna, Hydrilla*, and* Nymphaea. *These plants are planted in a series CW-Beds, consist of three beds. This research aimed to: (1) evaluate VUFCW System capability in removing N and P compounds, and (2) understand the role of plants in removing N and P. Evaluation of Removal Efficiency (RE) value shows that the VUFCW System can remove N and P compounds very well (generally RE > 80 %). Regression analysis shows that, there are strong and significant correlation between wet weight of* Canna *and* Nymphaea *and the TN and TP removal in the system. This strong correlation means that the size of plants has to be considered in order to keep the CW system effectiveness in removing N and P.*

Key words: constructed wetlands; leachate; nitrogen; phosphorous

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INTRODUCTION

Leachate is a liquid waste produced from leaching process which involving sub-surface water percolation through permeable materials. Leachate liquid is generally produced in high volume on dumping sites (Nemerow & Dasgupta, 1991). Some general characteristics of leachate liquid are the high concentration of nitrogen and phosphorous substances. A research that conducted by Diana (1992) in Bantar Gebang Dumping Site (Bekasi District – West Java) shows that leachate liquid from this dumping site had NH_3-N, NO_2-N, and NO_3-N concentration range from 60.47 - 209.91 mg/L, 0.0160 – 0.3374 mg/L, and 16.99 – 31.88 mg/L, respectively. Meanwhile, Tchobanaglous *et al.* (1977) stated that PO_4-P and TP concentration in leachate liquid typically ranged from 1 – 50 mg/L and 1 – 70 mg/L.

To control leachate liquid pollution, the dumping site area must be lined by impermeable liner (geo-textile or clay), and produced leachate liquid channeled to a treatment installation. Constructed Wetland (CW) is one alternative technology that can be applied to treat leachate liquid. This technology is an applicable technology because it doesn't need high and complex technology for its installation and operation. This benefit makes CW technology suitable to be applied in developing countries like Indonesia. The application of constructed wetlands to treat leachate liquid has been conducted in few countries, like Slovenia and UK (Bulc, *et al.,* 1997; Enviros Consulting, 2005).

Pollutants removal in constructed wetland is a natural processes that involve plants, sediment (soil, sand, and/or gravel), microorganisms, and sunlight as a source of energy (Yang & Wu, 2000). This research was carried out to evaluate the capability of a pilot scale of Vertical Up Flow Constructed Wetland (VUFCW) System in removing nitrogenous and phosphorus compounds in leachate run-off liquid. Leachate run-off liquid used was from Rawa Kucing Dumping Site (Tangerang District – Banten). Rawa Kucing Dumping Site is an open dumping and un-liner dumping site which receiving trashes from municipal and market around Tangerang District amounted ± 1330 m^3 per day.

Plants used in this research were *Canna*, *Hydrilla*, and *Nymphaea*. These plants planted in a series of constructed wetlands beds (CW-Beds) consists of three beds. Sediments used in this research were gravel and sand. Beside CW-Beds as a primary treatment, sedimentation bed and filtration bed (filled by charcoal) were used as a preliminary treatment; and as polisher – clarifier bed was used. Constructed wetland construction with plants selection like this has been used to treat wastewater from tapioca industry and the result of N and P removal was excellent (Awalina & Meutia, 2005). The objectives of this research are to evaluate VUFCW System capability in removing N and P compounds, as well as to understand the role of the plants in the removal-proccesses.

METHODS

VUFCW System Construction

VUFCW System consisted of 7 beds which arranged in series order (Figure 1). Container used as CW-Bed was a cylindrical fiber tank with 3 m^2 surface area and 80 cm height. Each CW-Bed was filled by gravel and sand as sediment. The height of sediment in CW-Bed 1 (Tank IV), CW-Bed 2 (Tank V), and CW-Bed 3 (Tank VI) were 45 cm, 30 cm, and 25 cm. The heights of water column in each CW-Bed are 5 cm, 23 cm, and 31 cm. CW-Bed IV was planted by *Canna* with population size of 12 individuals/tank. CW-Bed V was planted by *Hydrilla* with population size of 11 clumps/tank, each clump has 5 shoots. CW-Bed VI was planted by *Nymphaea* with population size of 6 individuals/tank. The total surface area of the whole tank in VUFCW System construction was 10.6 m^2.

Continuous flow leachate influent with average flow rate of 23.4 L/hour was applied in this research, made up the estimated Hydraulic Retention Time (HRT) in the whole VUFCW System of 130,08 hours (~ 6 days). Each HRT period was considered as one system run, so that there were 4 system runs applied during this research.

$$RE = \frac{Load_{influent} - Load_{effluent}}{Load_{influent}} \times 100\%$$

RE = Removal Efficiency (%); $Load_{influent}$ = pollutant load in influent (g/m^2/day); $Load_{effluent}$ = pollutant load in effluent (g/m^2/day)

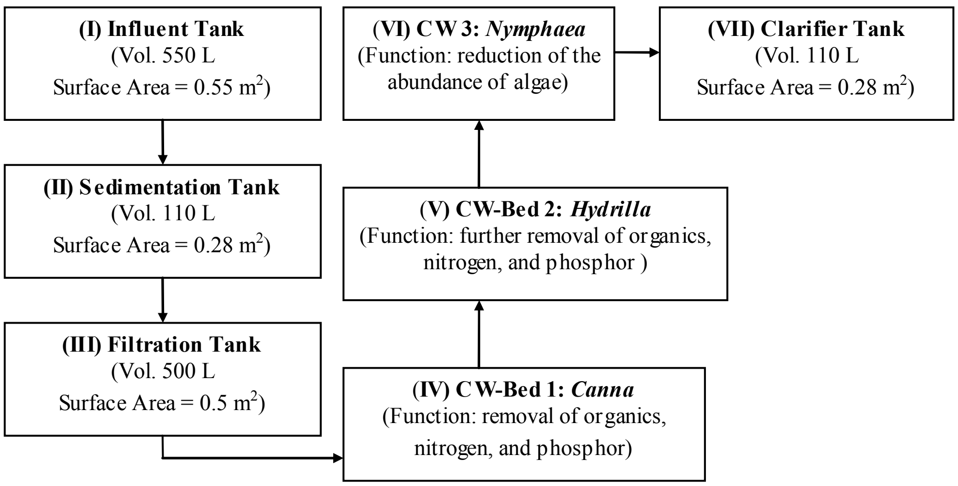

Figure1. Diagram of VUFCW System

Assessment of VUFCW System for Removing Nitrogenous and Phosphorus Compounds

Nitrogenous and phosphorus parameters that analyzed in this research were: NH_3-N, NO_2-N, NO_3-N, TN, PO_4-P, and TP, which were analised–according to the *Standard Methods for the Examination of Water and Wastewater* (1998).

The N-P removal capability of the VUFCW System was assessed by calculating the amount of load reduction(g/m^2/day) and the percentage of Removal Efficiency (RE). Pollutant load that calculated by this formula was the "surface load". Removal efficiency percentage was calculated for each treatment stage and for the system as a whole. Removal efficiency percentage was calculated by this following formula (Greenway & Wooley, 2000):

Role of the Plants on the N-P Removal

One of the plants functions in the CW-Beds is to absorb many kinds of inorganic pollutants, especially the nutrient pollutants like N and P. The capability of the plants to absorb N and P depends on the size and age of the plants. Young plants absorb nutrient in large quantity, as they have a high needs of nutrient to support their rapid growth. This young stage with its rapid growth is called exponential growth period (Kimball, 1998).

Study on the role of the plants on the N-P removal in the system was carried out by means of correlation analysis between the plant wet weight and the N-P removal rate under a hypothesis that the plants N-P removal capacity is deteriorated down with the age. Nitrogenous and phosphorus were represented by the parameters of Total Nitrogen (TN) and Total Phosphorous (TP). These two parameters are considered to represent all the nitrogen and phosphorous compounds occurred in the water, including the inorganic N and P that available for absorption by plant (NH_3, NO_3, PO_4) and others form of N and P that potentially change to NH_3, NO_3, PO_4. The regression-correlation analysis was performed using Minitab 11 Software. This regression-correlation analysis was only carried out on *Canna* (CW-Bed 1) and *Nymphaea* (CW-Bed 2), as there was a difficulty to determine the *Hydrilla*s growth rate due to its rapid budding.

Plants that analyzed in this research are *Canna* (CW-Bed 1) and *Nymphaea* (CW-Bed 2). Analysis is not done for *Hydrilla* because the time series calculation of *Hydrilla* growth is difficult to be done (since the rapid growth of *Hydrilla* buds). The plants wet weight was estimated by scaling 2 x 2 cm^2 leave samples and than extrapolated to the total surface area of leaves in CW-Bed. Four *Canna* individuals are taken as sample (from population of 12), and 3 *Nymphaea* individuals are taken as sample (from population of 6).

RESULT AND DISCUSSION

N-P Removal Capacity of the VUFCW System

This research shows that VUFCW System has excellent capability in removing N and P compounds (Table 1).

The N-P removal processes was mainly occurred after leachate entering CW-Beds (Tank IV, V, and VI). Pre-treatment stage which consisted of sedimentation process in Tank II and filtration and adsorption processes in Tank III was observed to remove the load of NH_3-N, NO_2-N, NO_3-N, PO_4-P, and TP in average of 18.13 %, 45.09 %, 38.10 %, 23.83 %, 16.08 %, and 41.29 %, respectively. Mean while application of *Canna* in Tank IV and *Hydrilla* in Tank V induced the cumulative N-P removal eficiency up to > 75 %. At the same time, growth of *Nymphaea* in Tank VI and additoin of clarifier tank (Tank VII) afterward resulted in much more N-P removal. Thus entirely the VUFCW System removed N and P load > 80 % (Figure 2 – 3).

The above phenomenon shows the important role of plants in removing N and P load. Nitrogen removal in CW-Beds involves some processes, they are: adsorption and filtration by sediment and plant's root system, mineralization, ammonification, de-nitrification, nitrification, volatilization, and absorption of inorganic nitrogen by plants and microorganism (Reddy & D'Angelo, 1997). In these processes the plants have functions not only to absorp the inorganic nitrogen, but also to supply oxygen for aerobic bacteria and providing attachment place for many kinds of bacteria. Oxygen that produced by plants is utilized by many kinds of bacteria in mineralization and nitrification processes.

There are several processes involved in CW-Beds phosphorus removal, namely: adsorption and filtration by sediment and plant's root system, sedimentation, polyphosphate hydrolysis, and ortho-phosphate (PO_4) absorption by plants and microorganisms (Reddy & D'Angelo, 1997). Oxygen needed in polyphosphate hydrolysis process is also supplied by plants.

By the high nitrogen and phosphorus load RE (> 80 %), VUFCW System in this research is able to produce an effluent with concentration of NH_3-N, NO_2-N, NO_3-N, TN, PO_4-P, and TP in the average values of 0.70 /L, 0.13 mg/L, 1.30 /L, 5.38 g/L, 0.04 mg/L, and 0,12 mg/L. At the same time, the pH, conductivity, DO, turbidity, and temperature values of the effluent are 7.61, 0.41 mS/cm, 3.68 mg/L, 10 NTU, and 31.6 ^oC.

Table 1. VUFCW System capability in removing N and P load

Parameter	Concentration (mg/L)		Load ($g/m^2/day$)		Removal	
	Influent	Effluent	Influent	Efluent	($g/m^2/day$)	(%)
NH_3-N	3.60 – 15.43 (11.07)	0.14 – 1.16 (0.70)	0.20 – 0.86 (0.61)	0.01 – 0.07 (0.04)	0.19 – 0.81 (0.58)	89.46 – 96.09 (93.88)
NO_2-N	0.04 – 0.72 (0.28)	0.01 – 0.45 (0.13)	0.002 – 0.04 (0.01)	0.002 – 0.03 (0.01)	0.00 – 0.015 (0.008)	0.20 – 91.68 (54.32)
NO_3-N	2.44 – 13.87 (6.16)	0.73 – 2.08 (1.30)	0.14 – 0.78 (0.34)	0.04 – 0.12 (0.07)	0.09 – 0.69 (0.27)	47.50 – 89.42 (70.63)
Total N	18.95 – 58.78 (34.64)	2.77 – 12.34 (5.38)	1.06 – 3.28 (1.93)	0.16 – 0.69 (0.30)	0.90 – 2.59 (1.63)	79.00 – 90.51 (85.82)
PO_4-P	0.46 – 0.97 (0.65)	0.01 – 0.08 (0.04)	0.02 – 0.05 (0.04)	0.001 – 0.004 (0.002)	0.02 – 0.05 (0.03)	91.25 – 97.82 (94.04)
Total P	0.77 – 1.90 (1.32)	0.08 – 0.17 (0.11)	0.04 – 0.11 (0.07)	0.005 – 0.01 (0.007)	0.04 – 0.10 (0.07)	87.39 – 93.73 (88.05)

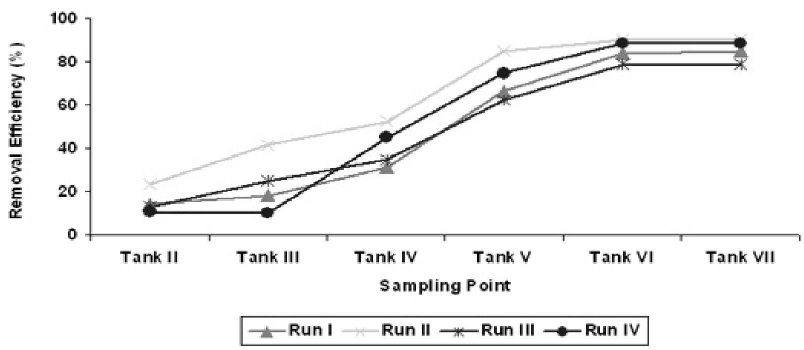

Figure 2. Cumulative RE percentage for TN parameter

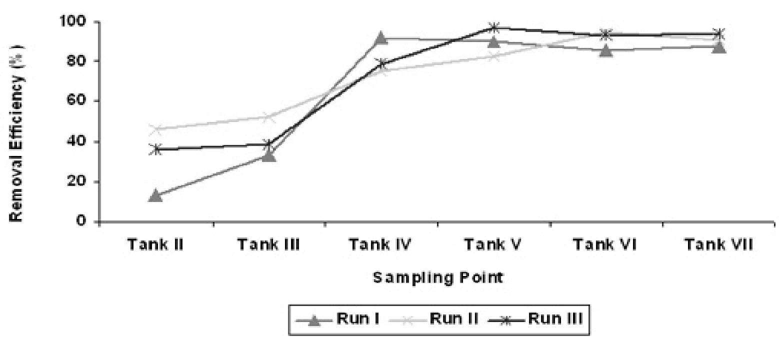

Figure 3. Cumulative RE percentage for TP parameter

Role of the Plants on the N-P Removal

Figure 4 and 5 show that the TN and TP removal in the VUFCW System had strong and significant correlation with the wet weight of *Canna*. *R-square* and *P-value* for regression between the TN removal and the wet weight of *Canna* were 99.8 % and 0.0656. *R-square* and *P-value* for regression between the TP removal and the wet weight of *Canna* were 88.5 % and 0.0717. This regression analysis shows the large influence of plants size on TN and TP removal. The role of nitrogen and phosphorous as the essential nutrient for plant growth has made this two elements absorb in large quantity by plants. The capability of plants to absorb N and P is primarily high before reaching mature stage, and decreasing afterthen. In the very late stage, the old plants will die and decay. This decaying process will release N and P back to the environment. Since that, information on the optimal stage of plant in absorbing N and P is importance to make constructed wetlands works effectively as wastewater treatment installation.

Canna shows good Total Nitrogen (TN) removal performance until wet weight of *Canna* reach the size of 300 g/m^2. Up to that size, *Canna* is capable to receive maximal TN load of 8.23 g/m^2/day and reducing it maximally 72.95 % (Figure 4). Meanwhile, the high phosphorous removal was observed until wet weight of *Canna* reach the size of 150 g/m^2, in which the system was capable to receive maximum TP load of 0.53 g/m2/day and reducing it up to 88.29 % (Figure 5).

There was also a strong correlation observed between TN and TP removal and wet weight of *Nymphaea* plants, even thought it was not as strong as that in Canna. *R-square* and *P-value* for regression between TN removal and wet weight of *Nymphaea* were 73 % and 0.12. At the same time, *R-square* and *P-value* for regression between TP removal and wet weight of *Nymphaea* were 87.9 % and 0.28 (Figure 6 and 7).

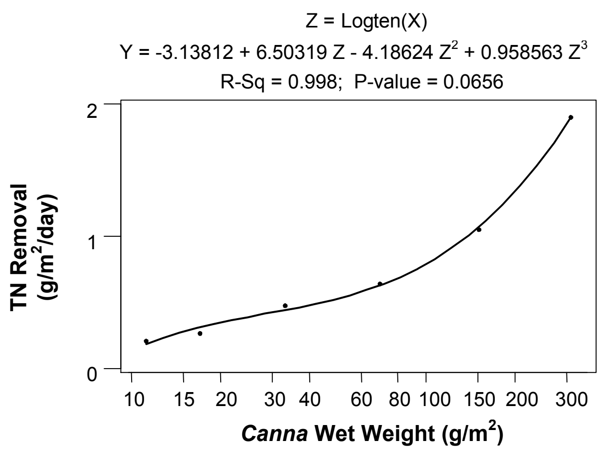

Figure 4. Regression between *Canna* WW and TN Removal

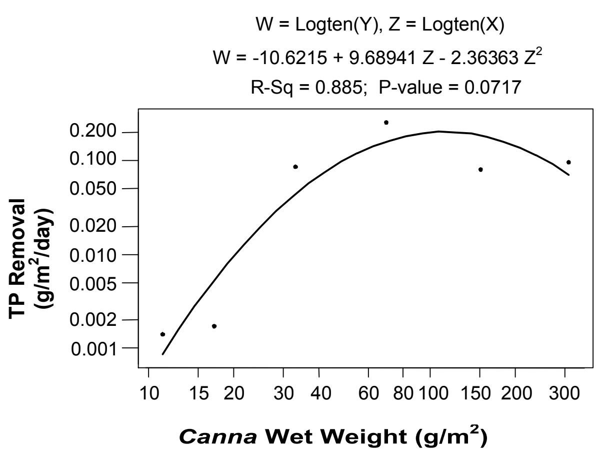

Figure 5. Regression between *Canna* WW and TP Removal

Nymphaea shows good TN removal performance until reaching wet weight of 35 g/m^2, in which the system was capable to receive TN load up to 4.1761 g/m^2/day and reducing it up to 53.26 % (Figure 6). In case of TP parameter, *Nymphaea* shows good load removal performance until reaching wet weight of 40 g/m^2. Up to that size, *Nymphaea* is capable to receive TP load up to 0.06 g/m^2/day and reducing it up to 68.09 % (Figure 7).

This information about the optimal size of *Canna* and *Nymphaea* in removing TN and TP load can be used as a reference to determine the schedule of plants regeneration in the CW-Beds.

CONCLUSION

VUFCW System in this research has excellent capability in removing N and P compounds. This VUFCW System is able to remove the load of N and P parameters with RE percentage in average > 80 %. Regression analysis between TN and TP removal with the plant's wet weight shows that plants size in CW-Bed has large influence on the TN and TP removal. The high capability of plants in absorbing N and P is largely obtained before plants reach the mature stage. *Canna* shows good TN removal performance until its wet weight reaches the size of 300 g/m^2, and for the

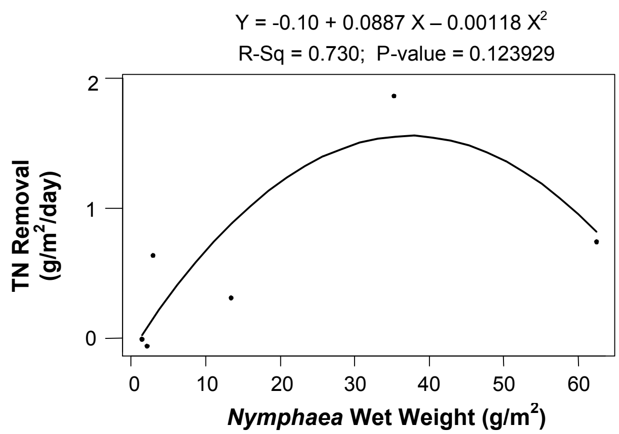

Figure 6. Regression between *Nymphaea* WW and TN Removal

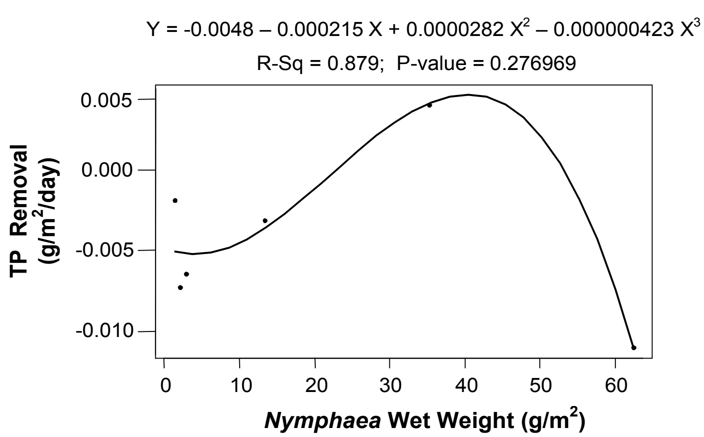

Figure 7. Regression between *Nymphaea* WW and TP Removal

TP removal performance until reaching the size of 150 g/m^2. At the same time, good performance of TN and TP removal by *Nymphaea* was achieved before the plant reached the wet weight size of 35 g/m^2 and 40 g/m^2, respectively.

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