Nitrogen removal on recycling water process of wastewater treatment plant effluent using subsurface horizontal wetland with continuous feed

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Abstract. Recycling water is a generic term for water reclamation and reuse to solve the scarcity of water. Constructed wetlands have been recognized as providing many benefits for wastewater treatment including water supply and control by recycling water. This research aims to find the best condition to significantly remove nitrogen using constructed wetland for recycling water of Bojongsoang Waste Water Treatment Plan (WWTP) effluent. Using media of soil, sand, gravel, and vegetation (Typha latifolia and Scirpus grossus) with an aeration system, BOD and COD parameters have been remarkably reduced. On the contrary, the removal efficiency for nitrogen is only between 50–60%. Modifications were then conducted by three step of treatment, i.e., Step I is to remove BOD/COD using Typha latifolia with an aeration system, Step II is to decrease nitrogen using Scirpus grossus with/without aeration, and Step III is to complete the nitrogen removal with denitrification process by Glycine max without aeration. Results of the research show that the nitrogen removal has been successfully increased to a high efficiency between 80–99%. The combination of aeration system and vegetation greatly affects the nitrogen removal. The vegetation acts as the organic nitrogen consumer (plant uptake) for amino acids, nitrate, and ammonium as nutrition, as well as the oxygen supplier to the roots so that aerobic microsites are formed for ammonification microorganisms.

Keywords: constructed wetland, nitrogen removal, recycling water, WWTP

1. Introduction
The high human activity from both domestic and commercial sectors such as industries has resulted in the scarcity of clean water due to water pollution. Wastewater treatment is equipped with wastewater recycling technologies based on the account that the treated water can be recovered for non-potable use with a quality of up to grade 3 [6]. One of the WWTP effluents that can be utilized for recycling technology is the treated water coming from Bojongsoang WWTP which collects the domestic wastewater of eastern and central southern Bandung with the capacity of 596,556 people for the total Bandung’s citizen of 2,390,120 people, according to PDAM Tirta Wening.

An alternative to treat the wastewater effluent efficiently and economically is needed to attain a better quality of water that can be used sustainably, and wetland can be a promising option. The wetland will be applied to solve the problems of domestic wastewater because it is a low-cost
installation that requires neither sophisticated technology nor specifically skilled operator to manage it [1]. The use of plant and microbial presence certainly has a crucial role in the degradation of N and P compounds [14] explained that compared with the arable crops, wetland plants could obtain a decent removal efficiency Huett et al. because of the presence of nitrifying bacteria on the root surface [14]. P. Kemp and George also described in their research that the N removal process would be better if it is carried out in two stages of treatment [5]. There is a good correlation between N and P removal in constructed wetland reactors [10]. Combining the legume plant Glycine max (soybean) reportedly affects the number of bacteria forming a mutualistic symbiosis with soybean roots to enhance nitrogen fixation [8].

From the previous study, the obtained nitrogen removal efficiency was still low at 50–60% [9]. Therefore, this research will be conducted on wetland modification by using the optimum conditions from prior studies regarding the volume ratio and optimum surface area, the addition of aeration, as well as by combining a legume vegetation (Glycine max) for nitrogen removal optimization.

2. Research Method

2.1. Research preparation

Experiments were performed using wastewater effluent of Bojongsoang WWTP from maturation ponds. Reactors were made from resin and poly-ethylene structure which was divided into three zones, i.e., inlet, treatment, and outlet area. The inlet and outlet zone contain gravel with a similar diameter of 2 cm, while the treatment zone contain soil, sand, gravel, and vegetation. The reactor’s slope is 0.1%. The wetland aeration system uses aluminum pipes to keep the oxygen supply. There were three kinds of vegetation used in this research, i.e. Typha latifolia, Scirpus grossus, and Glycine max. The reactor volume may vary for each stage: \( V_1 = (0.7 \times 0.5 \times 0.4) \) m³; \( V_2 = (0.4 \times 0.3 \times 0.3) \) m³; and \( V_3 = (0.35 \times 0.32 \times 0.30) \) m³.

2.2. Research variations

The research was carried out using several variations concerning vegetation types and the aeration system. The nitrogen removal was measured with and without aeration using different kinds of vegetation in each sequence. The first sequence, the water from Reactor 1 (T. latifolia) was delivered to Reactor 2 that contains S.grossus, followed by the aeration system, then conveyed to the last reactor that has S.grossus. The second sequence, the water from Reactor 1 was delivered to Reactor 3 that contains S.grossus, followed by the aeration system, then brought to the last reactor that has G.max. The third sequence, the effluent from Reactor 1 was delivered to Reactor 4 that contains S.Grossus, this time without aeration process, then carried to the last reactor that has G.max.

All the sequences have different treatment so that the optimum condition for nitrogen and phosphate removal can be deduced from the comparison. Besides, there were also three variations of N/P ratio as well(N/P = 10, 20, 30) to gain more accurate results and the correlation between the removal of N and P can be identified. The concentration of nitrogen was raised by adding the chemical of NH₄Cl, whereas the phosphate concentration was increased by augmenting the chemical of KH₂PO₄.

From observing the 1st and 2nd Sequence, has the G.max increased the nitrogen removal efficiency? While from the 2nd and 3rd Sequence, has the aeration contributed to increasing the nitrogen removal efficiency?

2.3. Sampling and analytical methods

The key parameters to measure the water quality consist of physical and chemical parameters. Sampleings were conducted daily to analyze the pH and temperature using pH-meter, as well as COD by micro COD. In steady state (when the degradation of carbon had reached a fairly constant point), the analyses of BOD, total solids, ammonium, nitrite, nitrate, and total ammonium (Total Kjeldahl Nitrogen) were conducted using Winkler titration, gravimetric method, spectrophotometer, and distillation.
3. Results and Discussion

The effluent of Bojongsoang WWTP has met the quality standard for the 4th grade stream standards of the water quality classification used in Indonesia. For the 2nd grade standard, there are several parameters that still exceed the threshold for recycled water, i.e., BOD, COD, and nitrite. The typical treatment process of a constructed wetland is as follows: (1) Wastewater is added at the inlet, (2) It flows through the subsurface, (3) It then makes contact with the root system of the plants as the aerobic and anaerobic zones have developed in the growing media, and (4) As the wastewater flows toward the outlet, biochemical reactions remove or transform some of the chemical contents [2].

Nitrogen is a compound that has a natural variation in the degree of oxidation. This oxidation rate ranges from +5 to -3, composed of organic and inorganic nitrogen compounds. Nitrogen removal rates correlate with initial concentrations of nitrogen. Inorganic nitrogen and phosphate compounds are necessary for plant growth and are potential to maximize the amount of nutrient removed from wastewater effluents using macrophytes [3]. There are five main principals of the nitrogen transformation: (1) ammonification/mineralization, (2) nitrification, (3) denitrification, (4) nitrogen fixation, and (5) nitrogen assimilation.

![Figure 1. Nitrogen removal of the 1st Sequence.](image)

The inlet concentrations of NTK parameter is 8.4–31.92 mg/L-N, whereas of ammonium is 1.85–9.76 mg/L-NH₄⁺. Thus, the concentration of N-organic can be calculated of about 6.09–22.16 mg/L-N (see Figure 1). Most of the nitrogen compounds in water are organic. Those organic nitrogens will transform into ammonia biologically by ammonification process, which is the first step of nitrogen mineralization and called as ammonia volatilization.

The transformation of ammonia into ammonium is affected by pH and temperature condition as well as the availability of dissolved oxygen in the water. The reactor without the second aeration delivered a better removal of organic nitrogen compared with other sequences at 0.6–1.1 fraction of distance (see Figure 1-3). Microorganisms only take the nitrogen if they need it for their growth, they will otherwise take carbon as the main nutrition [11] so that the nitrogen removal occurs slowly.
In this step, the vegetation plays the role as the organic nitrogen consumer (plant uptake) for amino acids, nitrate, and ammonium as nutrition, also as the oxygen supplier to the roots so that aerobic microsites are formed for ammonification microorganisms. The best organic removal condition is found in the sequence using the variation of *T. latifolia*, *S. grossus*, and *G. max*.

At the pH and average temperature of 7 and 25°C, respectively, ammonia will be ionized into ammonium of about 99.4% [4], while at pH of 8, about 95% of the total ammonia nitrogen will be ionized into ammonium [12]. Figure 1–3 show that the ammonium removal was better with the efficiency of 99% when the variation of *T. latifolia*, *S. grossus*, and *G. max* was used. On the other hand, the ammonia removal occurred well at the 2nd and 3rd Sequences as the effect of aeration. The decreasing ammonium is due to the oxidation process involving autotroph microbes to yield nitrite and nitrate afterward, and this process is called nitrification. The nitrification process occurred well in the aerobic condition, involving nitrification microorganisms namely *Nitrosomonas* and *Nitrobacter*. At each degradation process, the nitrification needs oxygen as the terminal electron acceptor. Figure 1–3 depict the nitrification process as a function of distance as well as the effect of vegetation variation and aeration.

The aeration system highly affects the nitrification process because oxygen is the terminal acceptor electrons involving autotroph microorganisms. However, autotroph groups cannot keep up with the heterotrophs in using oxygen so that autotrophs will be active when the carbon concentration in water is very low. Therefore, an extended aeration is needed to allow a thorough nitrification process to occur. The final step is denitrification, which is by increasing the electron toward nitrite and nitrate, gas phase products will be formed due to the reaction, e.g., nitrogen (N₂), nitrous oxide (N₂O), or nitric oxide (NO). Denitrification will occur when there is no free oxygen or known as an anoxic condition like in Reactor 5 (*S. grossus*), Reactor 6 (*G. max*), and Reactor 7 (*G. max*). The microorganisms involved are *Bacillus*, *Enterobacter*, *Micrococcus*, *Pseudomonas*, and *Spirilium* [4].
The total nitrogen removal was measured by Total Kjeldahl Nitrogen (NTK) which is the sum of total ammonium and organic nitrogen. The inlet concentration of NTK is 8.4–31.92 mg/L. Figure 1–3 shows that the decreasing of the total nitrogen concentration occurred in the constructed wetland is an effect of the variation of vegetation and aeration system. Reactor 6 (Glycine max) gave the best results than others. There is nevertheless no significant effect of the aeration system on the total nitrogen level because nitrogens are present in many forms and have different responses to the oxygen consumption in water.

4. Conclusion
Concerning the removal efficiency and energy consumption, the third sequence (T.latifolia + aeration, S.grossus, G.max) delivered the best performance compared with others. The contaminant concentration in the effluent after the treatment comprised ammonium ranging between 0.002–0.4 mg/LN\textsubscript{4}+–N, nitrite of 0.0001–0.0009 mg/L NO\textsubscript{2}–N, nitrate of 0.08–1.89 mg/L NO\textsubscript{3}–N; NTK (Total Nitrogen Kjeldahl) ranging between 1.06–1.26 mg/L-N; N-Organic of 1.05–1.25 mg/L-N; Total Phosphate in the range of 0.01–0.08 mg/L-P; COD of 6–17 mg/L; and BOD of 1–4 mg/L. According to PP 82/2001, those parameters have met the quality standard for the 2\textsuperscript{nd} grade that can be used as recycled water.

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