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The potential of constructed wetland as wastewater treatment technology for sustainable small industry of Coffee processing in Indonesia

Erina Rahmadyanti[1], Elizabeth Titiek Winanti[1], Dewie Tri Wijayati Wardoyo[2] and Diah Wulandari[3]

[1]*Departement of Civil Engineering, Faculty of Engineering, Universitas Negeri Surabaya, East Java, Indonesia*
[2]*Departement of Management, Faculty of Economic, Universitas Negeri Surabaya, East Java, Indonesia*
[3]*Departement of Mechanical Engineering, Faculty of Engineering, Universitas Negeri Surabaya, East Java, Indonesia*

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ABSTRACT

The affectivity of constructed wetland as an alternative of environmental friendly technology has been studied in many researches. Although its efficacy mostly depends on waste types processed. This research aimed to determine the efficacy of horizontal sub surface flow constructed wetland to process wastewater of coffee processing in small industry contained high organic content (pectin, protein, and sugar), nutrient, soluble material and low pH. The research was experimental research using horizontal subsurface flow constructed on pilot scale, built of glass box (0.5 m high x 0.5 m wide x 1.5 m long), sealed by high density polyethylene (HDPE), positioned on the soil with slope 0.01 mm-1. The substrate used was 10-20 mm gravel, with depth of 0.35 m and 0.15 m free-edge. The plant used was *Typha latifollia*. HSSFCW was operated on three hydraulic loading rate (HLR) of 3, 6, 12 cm.d-1 and employed for 1 day, 2 days, 7 days, and 10 days. HSSFCW performance was seen by comparing effluent and influent for its COD, BOD, TSS, TN and TP parameters. HSSFCW using *Typha latifollia* for processing wastewater in industry is effectively proved. The result of pollutant removal process indicated that higher removal efficiency showed at low HLR of 3 cm/d and high HRT of 10 days. In this research, HSSFCW using *Typha latifollia* was able to reduce BOD, COD and TSS more than 85%. The removal efficiency of COD was 97.12% on HLR 3 cm/d, 86.81% on HLR 6 cm/d, and 85.49% on HLR 12 cm/d. In BOD, removal efficiency was 97.46% on HLR 3 cm/d, 92.48% on HLR 6 cm/d and 86.81% on HLR 12 cm/d. While removal efficiency of TSS was 98.37% on HLR 3 cm/d, 96.69% on HLR 6 cm/d, and 95.11% on HLR of 12 cm/d. Therefore, for specific nutrient removal efficiency of TN and TP was less than 50%. Those were around 46.17% on HLR 3 cm/d, 35.82% on HLR 6 cm/d, and 31.68% on HLR 12 cm/d for TN and 18.67% in HLR 3 cm d, 12.65% on HLR 6 cm/d, and 6.63% on HLR 12 cm/d for TP. Thus, prior treatment is required to optimize the removal efficiency of TN and TP as well as longer HRT observation rather than in BOD, COD, and TSS. Implementing HSSFCW technology is highly possible for small industry of coffee processing due to its high efficiency, low operational and maintenance cost as well as no expert required for the operation.

Key words *: Horizontal sub surface flow constructed wetland, Wastewater of coffee, Typha latifollia*

Introduction

Coffee is one of important trading commodities produced by majority of tropical area and consumed by most of Europeans and Americans (von Enden *et al.*, 2002) (Figueroa *et al.*, 2016). Indonesia is one of four

***Corresponding author's email :** erinarahmadyanti@unesa.ac.id

biggest countries that produced coffee after Brazil, Vietnam, and Columbia with 9% of world total production (Neumann & Gruppe, 2012). The plentiful coffee variants, middle class growth, and lifestyle development in Indonesian causes the significant increase of coffee processing industries. On one hand, the development of coffee processing industry is very encouraging, but on the other hand, it causes many environmental problems. Coffee processing industry uses large amounts of water at various stages of its processing which impact on the amount of wastewater produced or for every kilogram of coffee beans produces 40-45 litres of wastewater in the production process (Zayas *et al.*, 2007). The wastewater generated contains high organic substances (pectin, protein, and sugar), nutrients, dissolved and low pH (Fia *et al.*, 2013)(von Enden *et al.*, 2002). Majority of coffee processing industry is a small industry with no wastewater treatment plant. Those industries have disposed colorless and acidic wastewater without prior treatment to the nearest water bodies such as rivers or surface water and open land. It makes coffee processing industries becoming one of contributor of water pollution (Woldesenbet *et al.*, 2014).

Water pollution is important issue for development because it refers to human health, limited water resources, and sustainability of alternative water sources. Coffee processing industry wastewater has caused the decreasing of dissolved oxygen content in the water which impact on the biotic environment, as those are lethal for fish and other aquatic animals, and the decreasing of the water function (Yemane Tekle, 2015)(Haddis and Devi, 2008) (Padmapriya *et al.*, 2015). Beside, coffee processing industry wastewater could endanger inhabitants who live near to production areas, such as by having eye and skin irritation as well as stomach and respiratory problems (Woldesenbet *et al.*, 2014).

The impact of coffee processing industry wastewater on the environment and health encourage researchers to continuously examine the development of wastewater treatment technology for industries. Various conventional wastewater treatment methods include Activated Sludge Process (ASP), Rotating Biological Contactor (RBC), Sequence Batch Reactor (SBR), etc. These methods have quite limitations, such as large energy requirements, high cost, extensive land, complex construction and operation, temperature sensitivity, as well as excessive dirt production (Sayadi *et al.*, 2012).

There are several related researches in wastewater treatment of coffee processing industry electrochemistry, such as using electrochemical processes with aluminium electrodes that caused pollutants safely discharged to environment. However additional electrolyte solutions were required to increase the COD (Chemical Oxygen Demand) and nitrogen ammonia removal (Asha & Kumar, 2015). Another research suggested that combining flocculation-coagulation with Advanced Oxidation Processes (AOP) using UV and H_2O_2/O_3 photo-oxidation was able to remove the color and organic material in industry wastewater treatment by 87% (Zayas *et al.*, 2007). In addition, coffee processing industry wastewater can be processed using an anaerobic hybrid reactor up-flow with 19.5 litres volume and 18 hours hydraulic retention time to reduce COD by 61%, Biochemical Oxygen Demand (BOD) by 66%, and Total Suspended Solid (TSS) by 58% with organic loading rate of 9.55 kg/m^3/day (Selvamurugan *et al.*, 2010). Furthermore, using Up-flow Anaerobic Sludge Blanket (UASB) in organic loading COD of 3.6 kg/m^3/day for coffee processing industry wastewater treatment can reduce total COD by 77.2% and soluble COD by 83.4% as well as 61% methane concentration in biogas (Rodriguez *et al.*, 2014). Those various methods require special skills and materials to operate which become an obstacle especially for small industries with limited knowledge, technology and capital (Rahmadyanti and Andre, 2016). Therefore, the development of wastewater treatment technology should be continuously carried out to obtain technology that is easily adopted, efficiently in operation and maintenance, environmentally friendly, and meeting the effluent standards set by the local government (Karaman & Kirnak, 2016).

One of wastewater treatment methods which are cost-effective, easy-to-adopt, relatively small energy intake, and meeting effluent standard is constructed wetland (Ye & Li, 2009)(Korkusuz *et al.*, 2004). Constructed wetlands is an alternative for conventional wastewater treatment system of small communities (Wu *et al.*, 2015). Constructed wetland system consists of physical, chemical, and biological process to adapt with various concentration of organic contents (Sayadi *et al.*, 2012). Besides, using vegetation in the process, causing constructed wetland becomes environmentally friendly.

The performance of constructed wetland depends on the micro-bacterial activities, hydraulic retention time, load, temperature, and vegetation types (Travaini-Lima and Sipaúba-Tavares, 2012). Constructed wetland can be used as main treatment as well as become secondary or tertiary treatment to process either domestic or industrial wastewater which are commonly proceeded by prior treatment.

Implementing constructed wetland was generally for domestic wastewater. Up to present time, implementing constructed wetland for industrial wastewater is still studied due to the various composition of industrial wastewaters which need different treatment (Calheiros *et al.*, 2007). This research is aimed to determine the efficacy of constructed wetland to remove several pollutant parameters in industrial wastewater of coffee processing.

Materials and Methods

Constructed wetland pilot units

Horizontal subsurface flow constructed on pilot scale, made up by glass box (0.5 m high x 0.5 m wide x 1.5 m long), sealed by high density polyethylene (HDPE), positioned on the soil with slope 0,01 mm^{-1}. Media used was 10-20 mm gravel (Vymazal, 2010)(Lee *et al.*, 2009) with depth of 0.35 m and freeedge of 0.15 m. The height of media was constantly maintained in the depth of 0.4 m.

Wastewater sampling and analysis

Industrial wastewater of coffee processing was obtained from Arabica coffee pulping process. Sample was kept in refrigerator in the temperature of 4°C for analysis. Sample was first analyzed before giving the treatment to obtain the parameter of pH (potentiometry method), total nitrogen (semi-micro Kjeldahl method), total phosphorus (spectrofotometry method), COD, BOD, and TSS using standard method. Sample was filtered using filter paper before being analyzed. The following step was to analyze the sample for other parameters according to standard method (APHA/AWWA/WEF, 2012). Table 1 shows the characteristics of wastewater in coffee processing.

Vegetation/plants

Constructed wetland was planted with the shoots of the *Typha latifolia*. This vegetation was selected due to the availability and the success in prior researches. Prior research showed that *Typha latifollia* was able to treat industrial wastewater from tannery industry and food processing industry. Hence, it had positive effect in removing COD, BOD, TSS, TN, NH_4-N, TP, FC (Vymazal, 2011). *Typha latifollia* was planted by hand at a density of 5 plants/m^{-2}. This plant had been firstly acclimated for one month using processed water (PDAM) followed by using wastewater from coffee processing for another month. Plant had been observed every week for 2 months to find the toxicity as chlorosis, necrosis, and malformation (Calheiros *et al.*, 2007).

Operation and maintenance

System was operated at room temperature. During the sampling period, the temperature at the site varied between 24-25°C. In the early operation, pH correction was performed using hydrated lime until it closed to 7. Aside of pH correction, urea and simple superphosphate were also carried out to get the ration of 100:5:1 between BOD, nitrogen, and phosphorous (Fia *et al.*, 2013). Coffee processing wastewater then was flown by gravity to the tub (volume 1 m^3) consisting of *Moringa olifiera* grains. Wastewater was kept for a day in the tub to be treated. After receiving prior treatment, wastewater was collected in another tub (volume 1 m^3) to be added with CaOH before flown to constructed wetland through perforated PVC pipes once a day using hydraulic flow control. HSSCW effluent was taken to be analyzed for its pH (potentiometry method) content, total nitrogen (semi-micro Kjeldahl method), total phosphorus (spectrofotometry method), COD, BOD, and TSS using standard method (according to Folin and Ciocalteu, 1927) (APHA/AWWA/WEF, 2012). Three hydraulics loading rate (HLR) of 3, 6, and 12 $cm.d^{-1}$ were employed at day 1, day 2, day 7, and day 10.

Data collection

HSSFCW was operated in the variation of HLR 3, 6, and 12 $cm.d^{-1}$, for a day, 2 days, 7 days and 10days. Effluent samples were taken in each HLR. Those samples were kept in the temperature of 4°C in refrigerator for analysis. Next, samples were analyzed to obtain pH content, total nitrogen, total phosphorus, COD, BOD, and TSS using standard method. Any sampling and analysis procedure were conducted three times to get the data validity. It was performed to determine the affectivity of HSSFCW to process wastewater treatment of coffee processing industry.

Data analysis

All data obtained were analyzed using one-way

ANOVA test followed by LSD test (á =0.05) and software used to analyzed was SPSS version17.0.

Results

Pre treatment of coffee processing industry wastewater

The characteristics of industrial wastewater of coffee processing seen in Table 1 are brown colored, acid, and high organic content. Prior treatment by flowing wastewater to tub with *Moringa olifiera* grains for 24 hours was to cleanse wastewater color from brown to colorless. This treatment was done because color is important for aquatic creatures to produce food by sun aiding. Sunlight density will reduce if the water color is dark. After prior treatment for color, another treatment was to correct pH content of wastewater of coffee processing which normally acid (4.22 ± 0.25 seen in Table 1).

Table 1. Characteristics of coffee processing raw wastewater

Parameter	Mean ± SD	Discharge standard (Indonesia EPA)
pH	4.22 ± 0.25	6-9
BOD_5	1,729 mg/l ± 411	50
COD	3,887 mg/l ± 334	50
TSS	1,963 mg/l ± 282	30
NH_3	4.83 mg/l ± 1.36	-
PO_4^{3-}	3.32 mg/l ± 0.4	-

Figure 1 shows that in day 1 pH which previously was acid became normal (pH close to 7). Then pH became relatively stable until HSSFCW process. It indicated that HSSFCW condition supported the removal process of organic substances optimally. This research resulted that HLR 3 cm/d was the most efficient for pH removal efficiency compared to HLR 6 cm/d and 12 cm/d. It was due to low HLR the neutralization process run optimally.

Other than pH and color, conditioning constructed wetland was also carried out by temperature control. In this research, average temperature in operating HSSFCW was around 24-25ºC.

Pollutant removal in HSSFCW

Organic substance removal

Organic substance in industrial wastewater of coffee processing was indicated by BOD and COD. In industrial wastewater of coffee processing obtain BOD/COD comparison as 0.4. It means that ratio was in the range of 0.36 to 0.54 meaning that industrial wastewater of coffee processing can be decomposed and processed in biodegradable (Abdelhakeem *et al.,* 2016). This research indicated that the highest removal efficiency was obtained on HRT 10 days. Moreover, Figure 2 also showed COD removal efficiency on HLR 3 cm/d was higher than on HLR 6 cm/d and 12 cm/d. COD removal efficiency in this research was 97.12% on HLR 3 cm/d, 86.81% on HLR 6 cm/d, and 85.49% on HLR 12 cm/d. The HLR increase lowered the BOD removal efficiency. The highest removal efficiency was on HLR 3 cm/d.

Similar to COD, the longer HRT is, the higher removal efficiency is obtained. In this research, the highest removal efficiency was obtained in HRT of 10 days due to longer operation in constructed wetland where contact between microbacteria and wastewater to decompose organic substance is longer. Figure 3 showed that similar to COD removal efficiency, BOD removal efficiency is also high. Research showed that BOD removal efficiency

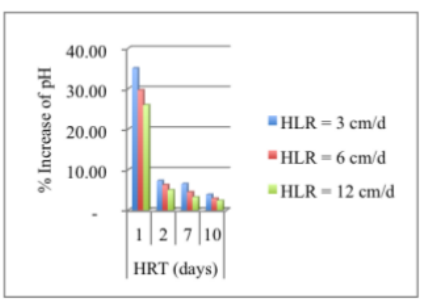

Fig 1. Increase of pH

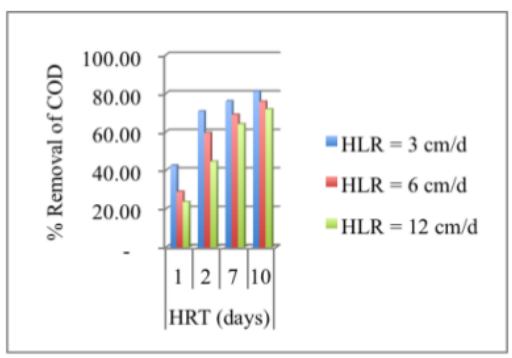

Fig 2. Removal efficiency of COD in HF beds

was 97.46% on HLR 3cm/d, 92.48% on HLR 6 cm/d, and 86.81% on HLR 12 cm/d. Organic substance dissolved in water was slowly decomposed through microbiological process with oxygen in the water.

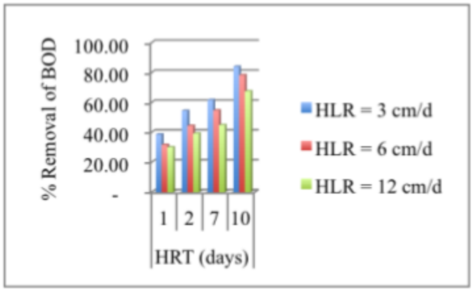

Fig 3. Removal efficiency of BOD in HF beds

TSS Removal

In TSS removal efficiency process, the highest removal efficiency was obtained on HRT 10 days. Similar to BOD and COD removal efficiency, in TSS the longer retention time was, the higher efficiency was obtained. Figure 4 shows that TSS removal efficiency was the highest in day 10 (76.47%) compared to day 1 (40,75%), day 2 (61,05%), and day 7 (69,98%).

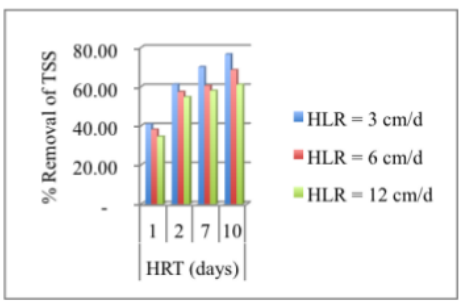

Fig 4. Removal efficiency of TSS in HF beds

Besides, the low HLR made high as TSS removal efficiency 3 cm/d. Respectively, removal efficiency on HLR 3 cm/d, 6 cm/d, and 12 cm/d was 98.37%, 96.69%, and 95.11%. On low HLR, dissolved particle was better sedimented rather than in higher one, because in high HLR, dissolved particle does not have opportunity to sediment, but it will directly flow to effluent.

Nutrient removal

Operating HSSFCW in this research was able to remove high BOD, COD, TSS and pH content. However, it did not occur in other nutrient removal especially on nitrogen and phosphor. This research showed total nitrogen was 46.17% on HLR 3 cm/d, 35.82% on HLR 6 cm/d, and 31.68% on HLR 12 cm/d.

Figure 5 shows that the lowest removal efficiency was on HRT 1 day. It was due to the short time used by bacteria for denitrification process as they were not well-adapted with wetland condition.

The phosphor removal results also show not too high values as well as nitrogen (Figure 6). This research obtained phosphor removal efficiency as 18.67% on HLR 3 cm/d, 12.65% on HLR 6 cm/d, and 6.63% on HLR 12 cm/d.

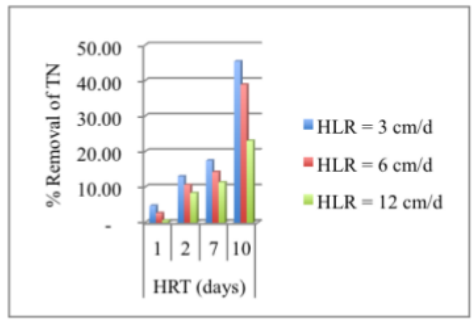

Fig 5. Removal efficiency of TN in HF beds

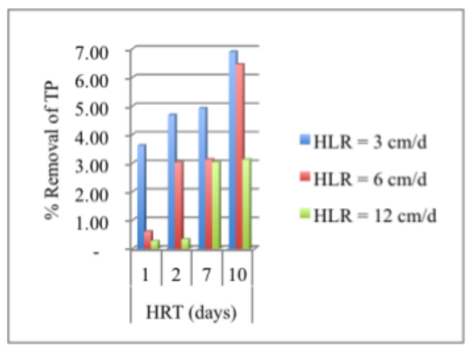

Fig 6. Removal efficiency of TP in HF beds

Discussion

Dark water surface will influence other parameters such as temperature, dissolved oxygen, and BOD (Siddiqui and Waseem, 2012). Colorless water after treating using *Moringa olifiera* grains was expected to support the HSSFCW process optimally. The pH condition could not support the aerobic decomposition process where hinder a methanogenic population, so the efficiency of aerobic process will be decrease (Figueroa *et al.*, 2016). pH optimal for aerobic decomposition process is in the range of 6, 5-8, and 5 (Padmapriya *et al.*, 2015). Therefore, pH correction is needed to obtain the pH content close to 7 to get an ideal condition in supporting constructed wetland process.

pH correction was done by adding CaOH in the colorless water to get pH close to 7. Adding CaOH resulted in pH content around 6-7, and 8. Besides, pH correction also supported nitrification and amonification process in constructed wetlands optimally occurred in pH 6.5-8.5 (Lee *et al.*, 2009) (Travaini-Lima and Sipaúba-Tavares, 2012). Constructed wetland with pH correction and nitrogen and phosphorus addition was efficient in removing COD and BOD as 1.3 times to twice higher than without any prior treatment (Rossmann *et al.*, 2013).

Temperature control conducted was because water temperature highly affects the physiological activities and organism especially due to biochemical reaction. Temperature also affects microbial activities and dissolved oxygen in constructed wetlands (Lee *et al.*, 2009); (Merino-Solís *et al.*, 2015). This condition indicated that constructed wetland in the environment which supports the microbial activities, chemical reaction, and dissolved oxygen optimally. Those processes could influence the removal efficiency of nutrients especially the nitrogen where the optimal process conducted in the temperature around 20-25ºC (Lee *et al.*, 2009).

COD shows the oxygen needs for chemical oxidation process of organic substances. COD score indicates the number of dissolved organic substances which can be oxidized including all unravel material content (Kalshetty *et al.*, 2014). Figure 2 shows that the longer HSSFCW retention time was, the better removal efficiency was performed, because the exposure between wastewater and micro-organism was longer (Wannasri, 2013); (Travaini-Lima and Sipaúba-Tavares, 2012)(Otieno *et al.*, 2017). The result proved that this research was in line with previous researches which stated that pollutant was higher in low hydraulic loading rate (Ye and Li, 2009).

High COD removal efficiency as obtained in this research was mostly caused by sedimentation, filtration, and absorption process. Sedimentation, filtration, and absorption process in activities and metabolism process of microbacteria are main mechanism to lower BOD_5, TSS, TDS, Total N, Total P, and Total C. Furthermore, longer detention time in constructed wetland is important factor in pollutant removal efficiency (Travaini-Lima & Sipaúba-Tavares, 2012). This process is then supported by plant absorption process which contributes to remove organic substance through denitrification and aerobic biodegradation. In constructed wetland system, COD removal was done by microorganism aerobically and anaerobically. COD content in wastewater, media design, operational condition, and substrate type affects to oxygen diffusion and convection. Another factor influencing COD removal is oxygen leakage from roots to rhizosphere. Substance absorption by plant can be ignored compared to biodegradation process (Korkusuz *et al.*, 2004). Explained by another research, organic substance removal did not depend on the existence or inexistence of plant in constructed wetland (Sharma *et al.*, 2014).

Besides COD, organic content is also showed by BOD. BOD is dissolved oxygen needed by microorganism in decomposing organic substance. BOD is used as index in organic pollution in wastewater which is possibly decomposed by bacteria in anaerobic condition (Urgesa, *et al.*, 2017). In conclusion, oxygen need to decompose organic substance is fulfilled. If oxygen need to decompose organic substance is not fulfilled, anaerobic condition will be created (Zayas *et al.*, 2007).

This research showed high removal efficiency of BOD and COD. It indicated that *Typha latifollia* was able to oxygenized bed to support aerobic degradation of organic substance in wastewater. This plant provides substrate for roots, steams, and leaves where microorganism possibly lives through organic molecule fission. Majority (90%) of BOD and COD removal efficiency are conducted by microorganism called "periphyton". The rest (7-10%) are conducted by the plant. Although BOD and COD removal efficiency are good, the final score in effluent is above standard allowed (> 50 mg/L) especially on HLR 3, 6, and 12 cm/d. It is because oxygen released by roots is lower than oxygen needed in aerobic decomposition process. Possible solution to increase HSSFCW performance is by oxygenizing media or extending retention time (Abdelhakeem *et al.*, 2016).

High TSS content in industrial wastewater of coffee processing was mostly reduced through sedimentation process in primary treatment

(Abdelhakeem *et al.*, 2016). This research showed that TSS removal efficiency was not as high as BOD and COD because sedimentation in constructed wetland was less optimal. Therefore, wide area substrates are needed to help sedimentation process. In addition, unoptimized absorption process was due to potential blockage of substrate pores (Haberl *et al.*, 2003); (Vymazal *et al.*, 1998). Absorption ability in this research was caused by continual flow at HSSFCW and *Typha latifollia* which has rooting system that is capable to increase TSS removal efficiency by availability of wider surface. Rooting system is able to reduce the water velocity and strengthen sedimentation and filtration in roots (Abdelhakeem *et al.*, 2016).

Operating HSSFCW in various HLR generated removal efficiency less than 50%. It was similar to previous research (Calheiros *et al.*, 2007); (Vymazal, 2005). Low removal efficiency on nitrogen was due to low capability of HSSFCW to oxidize ammonia because of limited oxygen transfer capacity (Wannasri, 2013). Many researches mentioned that main mechanism in nitrogen process including interaction between microbacteria and nitrogen, sedimentation, chemical absorption, and plant absorption Primary step in nitrogen removal is nitrification followed by denitrification. In constructed wetland, denitrification process has 60-70% roles in total nitrogen removal efficiency, while plant absorption only has 20-30% roles (Lee *et al.*, 2009). Nitrification is a process limited to nitrogen removal at constructed wetland. Denitrification is main mechanism in nitrogen removal at most constructed wetland. The difference in the oxygen needed for nitrification and denitrification become the main hindrance at any wetland process to obtain higher nitrogen removal efficiency (Ye and Li, 2009). Nitrification and denitrification processes occurred on the pH range of 6.5-8 and intensification of ammonia volatilization occurred on pH more than 8.5. This research showed that nitrogen decrease in dry season was due to plant and microbacteria absorptions by releasing nitrogen to atmosphere (Travaini-Lima & Sipaúba-Tavares, 2012).

Phosphorus removal at constructed wetland occurred through absorption, plant absorption, complexity, and precipitation (Vymazal *et al.*, 1998). Phosphorus is kept in sediment accumulation. Phosphorus absorption was main mechanism in any phosphorus removal process in wetlands (Otieno *et al.*, 2017). The less high phosphorus removal efficiency was due to saturation condition caused by continuous flow in HSSFCW. Several researches mentioned that it needed 10 retention days to reduce nutrient in. But the best retention days for wetland was 10-13 days (Merino-Solís *et al.*, 2015). This research also used HRT 10 days, so the removal efficiency obtained was low (< 20%). It was because of using gravel as substrate.

Retention time for phosphorus at constructed wetland depends on wastewater composition, loading rate, type of plant roots, and substrate content used (calcium, aluminium, and iron). If substrate used (gravel, sand, crushed stone, etc.) does not contain high concentration of any element, phosphorus removal efficiency will generally be low (Korkusuz *et al.*, 2004). Therefore, to increase phosphor removal efficiency, it is better to use high concentration substrate such as blast furnace granulated slag (Ca: 34%; Al = 13%; Fe=1%). Gravel used in this research had low absorption capacity. In another research, aside using blast furnace granulated slag, LECA (light weight clay aggregates) or furnace steel slag is possible. Phosphorus removal efficiency level in those substrates is higher than at constructed wetland. It is necessary to observe the absorption and precipitation which are saturated, so it is possible to reduce along with the longer retention time (Vymazal, 2010).

At last, this research was concluded into: 1.) HSSFCW using *Typha latifollia* to treat coffee processing wastewater was effectively proved. The removal efficiency showed higher result on low HLR of 3cm/d and high HRT of 10 days. HSSFCW using *Typha latifollia* in this research was able to reduce BOD, COD, and TSS more than 85%. Thus, removal efficiency of COD was 97.12% on HLR 3 cm/d, 86.81% on HLR 6 cm/d, and 85.49% on HLR 12 cm/d. In BOD, its removal efficiency was 97.46% on HLR 3cm/d, 92.48% on HLR 6 cm/d, and 86.81% on HLR 12 cm/d. While in TSS, its removal efficiency was 98.37% on HLR 3 cm/d, 96.69% on HLR 6 cm/d, and 95.11% on HLR 12 cm/d; 2) However, in TN and TP, those removal efficiency were less than 50%, respectively as 46.17% on HLR 3 cm/d, 35.82% on HLR 6 cm/d, and 31.68% on HLR 12 cm/d, and 18.67% on HLR 3 cm/d, 12.65% on HLR 6 cm/d, and 6.63% on HLR 12 cm/d; 3) Therefore, prior treatment to optimize removal efficiency of TN and TP as well as longer observation period is needed compared to BOD, COD, and TSS and 4). Implementing HSSFCW technology is highly possible in coffee processing small industries due to high efficiency, low operational and maintenance cost, as well as no expert needed in technology operation.

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