Laundry Wastewater Treatment by Hybrid System of Biofilter and Vertical Surface Flow Constructed Wetland with *Equisetum hyemale*

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Abstract

Laundry activity or washing clothes is an activity that almost all people in the world do. Like other human activities, laundry activity also produces waste or filth. But, the waste is often directly disposed of any treatment to the water like rivers or lakes. It finally causes contamination to the nature, one of them is known as eutrophication or nutrition enrichment, then it will harm the growth of aquatic organisms. To overcome the problem, the laundry waste needs to be treated before it is disposed of the nature. Biofilter and Constructed Wetland are low cost systems and easily handled, so this system is suitable to be applied on small or household scale. *Equisetum hyemale* is a decorative plant which has already been used to treat many wastewater, and proves it's effectiveness in reducing the pollutant in wastewater. In this research a hybrid system of Biofilter with additions of activated carbon and Constructed Wetland with *Equisetum hyemale* is used to treat laundry wastewater, with HRT of 4 days we found a decrease of tested parameters, TDS 346.94 mg/L (21.15 %); TSS 11.25 mg/L (88.88 %); BOD 31.86 mg/L (63.68 %); Phosphate 3.41 mg/L (83.28 %); and Detergent 1.10 mg/L (93.1 %).

Keywords: constructed wetland, biofilter, laundry, phosphate, surfactant

Introduction

Washing clothes or laundry is an activity that done by the majority of people in the world. Most people add detergent or soap to remove the dirt from clothes. The main component of detergent is surfactant, a synthetic organic compound that in some types and condition is a peristent compound and hard to degrade. It causes enhancement of organic pollutant in the environment, especially in water bodies, because laundry activities produce a lot of liquid waste. Phosphate and surfactant are the two main pollutant generated from laundry waste. The bad impact of those pollutants has been widely reported such as eutrofication, hindering plant growth and microorganisms, and at certain concentration can cause fish mortality (Rebello *et al.,* 2013; Yuliani *et al.,* 2015).

In order to maintain the balance between industries and the environment, the government has set up a quality standard for all the wastes produced. The quality standard is the maximum amount of the waste parameters, which allowed to be discharged into the environment. Table 1 shows a comparison between the government quality standard and the characteristic of laundry wastewater based on the analysis done by Siahaan and Sudarmadji in 2018. It shows that some parameters of the laundry wastewater produced by some laundry industries has exceeded the maximum limit set by the government. And if this case continuously happens, it could contaminate and harm our environment. Hence, it's important to treat the laundry wastewater before it's discharged into the water bodies.

Biofilter and constructed wetland are example of convenient and inexpensive wastewater treatment. The definition of a biofilter is a waste treatment with the principle of microorganism culture in an inorganic media, the microorganisms will attach and grow on the media and filtering the pollutant (Filiazati *et al*., 2013). River rocks are the commonly used media because it's easy to found and cheap, but nowadays synthetic media made from plastic are also used. In this research granular activated carbon (GAC) is used along with river rocks

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Table 1. Quality standards and characteristics of laundry wastewater

Parameter		Unit	Laundry Wastewater Quality Standards *	Laundry Wastewater Characteristics [1]
Physics	**Temperature**	°C	± 3 °C towards air temperature	-
	TSS	mg/L	100	-
	TDS	mg/L	2000	252
Chemistry	**pH**	-	6.0 – 9.0	6.6
	BOD	mg/L	75	130
	COD	mg/L	150	356.8
	Detergent	mg/L	5	21.945
	Phosphate	mg/L	2 **	7.79

Description :
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**: *Peraturan Menteri Lingkungan Hidup RI Nomor 5 Tahun 2014 Tentang Baku Mutu Air Limbah Bagi Usaha dan /atau Kegiatan Industri Sabun, Deterjen, & Produk-produk Minyak Nabati*
[1] : Laundry wastewater characteristic on Siahaan & Sudarmadji (2018) research
- : no data available

as a biofilter media. GAC is known to have the ability to adsorb phosphate and surfactant (Utomo *et al*., 2018). Constructed wetland (CW) is the nature-inspired wastewater treatment. Generally, CW consist of rocks in the lower part, soil in the middle, and plants in the upper part. Based on the streamline it's divided into a vertical and horizontal flow, and surface flow and sub-surface flow based on where the waste is streamed (above or below the soil surface). In this research vertical surface flow is used, so the wastewater will be streamed above the soil surface and move following the gravity to the bottom of the layer, hopefully enhancing the pollutant removal. A mixture of rocks, soil, and plants causes complex mechanisms in CW that according to Choudhary *et al.* (2011), might help reduce TSS, BOD, COD, nitrogen, phosphate, metals, and pathogen.

Plant types also became the factor that supports the success of wastewaster treatment. The plants need to have endurance towards the extreme environment, and be able to accumulate pollutants. *Equisetum hyemale* or locally known as Scouring-rush horsetail, is a decorative plant belonging to the Equisetaceae family. *E. hyemale* can grow in various places, is easy to care for, and has a good endurance towards external influence (Margowati and Abdullah, 2016), besides it's utilization in treating various kinds of wastes such as households, metals, tannery, and tofu wastes are effectively proven (Danista, 2012; Sutyasmi & Sutanto, 2013; Nugraha & Wardono, 2015; Wardono *et al.*, 2016). The aim of this study is to know the effectiveness of hybrid system biofilter and CW using *E. hyemale* plants in treating laundry waste.

Figure 1. *Equisetum hyemale* plant (photo source : Anonim, 2019)

Materials and Methods

Place and time

The research was conducted in Universitas Kristen Duta Wacana from October 2020 to January 2021. Temperature, TSS, TDS, pH, BOD parameters were measured at the Laboratory of Ecology of DWCU, meanwhile Phosphate and Surfactant parameters were measured at Balai Besar Teknik Kesehatan Lingkungan dan Pengendalian Penyakit Yogyakarta (BBTKLPP).

Materials

Laundry wastewater was obtained from one of the laundry home-bussiness in Yogyakarta. Materials needed in the reactor are plastic drum, 2 aquaria, plastic hoses and the taps to control the water debit, 4 groups of *E. hyemale* plants (consisting of 40 stems plant) with the length ranging between 40-80 cm. Three types of size of rocks used in biofilter and CW, small size (1-2 cm), medium (3-6 cm), large (6-10 cm), and also Granular Activated Carbon (GAC). Soil for the CW and water for the acclimatization were taken from the ricefield in the south area of Yogyakarta. Some equipment for the parameters testing are Petri disc, glass funnel, pH meter, TDS meter, DO kit, dark coloured bottle, Erlenmeyer, pipette, paper filter, ruler, oven, & scale.

Water Quality Measurement

Several common parameters were measured to determine water quality, such as temperature, pH, TDS, TSS, and BOD. Measurement were done in 3 sampling points, i.e. Inlet (untreated laundry waste), the outlet of biofilter, and CW. Biofilter and CW outlet were measured twice a week, while the inlet was once a week during 4 weeks of experiments. Temperature and TDS measurement was conducted using a thermometer and TDS meter, TSS was measured with the gravimetric method, pH value was tested using pH meter and BOD with measures the *Dissolved Oxygen* (DO), value using winkler method.

Phosphate and Detergent Measurement

Phosphate and Surfactant measurement was conducted at BBTKLPP Laboratory with standard APHA 2012, Section 4500 P-D and SNI 06-6989.51-2005.

Plant measurement

Stem length was measured using a

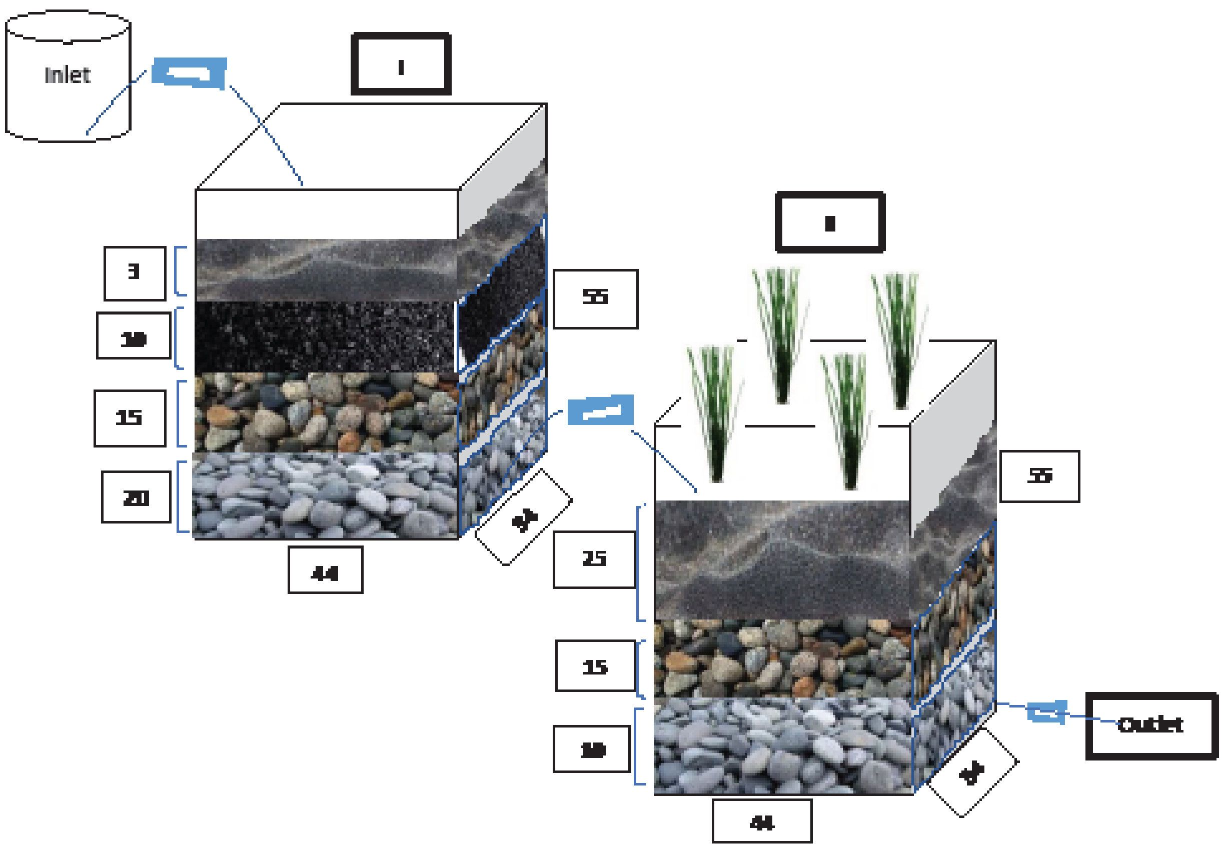

Figure 2. Wastewater plant design, (I) Biofilter, (II) Constructed wetland

ruler, and also a total of the stem before and after the research was measured to find the effect of laundry wastewater on plant growth.

Data Analysis

The data obtained were analyzed using SPSS, with the *One-Way Anova* test to find if the data obtained from each sampling point were significantly different and *Paired sample T-test* to find any significant difference before and after treatment data.

Result

Water Quality and Pollutant Measurement

The data obtained after 4 weeks of observation was averaged and analyzed using the *One-Way Anova* test in SPSS. In physical parameters result shows that the wastewater temperature before and after treatment was in the range of 27-28^oC, which is a safe temperature for living things. As seen in Table 2, suspended solid removal is obtained better than the dissolved solids, with a system precentage efficiency of 88.88%. Mainly removal happens in the biofilter process in both parameters, in which biofilter efficiency removal of TDS is 16.92% and TSS is 78.57%. The data analysis using *One-Way Anova* test showed the TDS and TSS measured in both biofilter and CW outlet is significantly different from the inlet.

Same as the temperature, the average pH value measured in three sampling points is in the range of 7.3 - 7.8 and it's still considered safe for the living organisms in the water. BOD, phosphate, and detergent level was also decreased after 4 weeks of treatment, and the majority of removal also happens in the biofilter treatment with each of them having a removal percentage of more than 50% (Table 3). However, a CW addition to the system also shows a benefit by enhancing the removal percentage in all parameters tested. Data analysis in phosphate and detergent also showing a significant difference between biofilter and CW towards the inlet, with the removal percentage of phosphate is 83.28% and detergent is 93.1%. The data in Tables 2 and 3 show that some parameters such as TDS, BOD, phosphate, and surfactant were exceeds the quality standards before being treated with the systems. After the treatment, almost all the parameters mention before except the phosphate, have met the quality standard.

Plant Measurement

The number and length of the stems shows an increase after the treatment. As showed in the table 4, with the initial amount of 40 stems in each group, the escalation range

Table 2. Water quality measurement and effectivity calculation

Parameters	Inlet	Biofilter	Effectivity (%)	CW	Effectivity (%)	System Effectivity (%)	Quality Standards*
Temperature (^oC)	28.65^b	27.93^{ab}	-	27.67^a	-	-	± 3^oC towards air temperature
TDS (mg/L)	440^b	365.56^a	16.92	346.94^a	5.09	21.15	2000
TSS (mg/L)	101.25^b	26.25^a	78.57	11.25^a	57.14	88.88	100
pH	7.83^a	7.67^a	-	7.32^a	-	-	6.0 – 9.0
BOD (mg/L)	87.73^c	43.39^b	50.54	31.86^a	26.57	63.68	75

Table 3. Pollutant measurement and effectivity calculation

Parameters	Inlet	Biofilter	Effectivity (%)	CW	Effectivity (%)	System Effectivity (%)	Quality Standards*
Phosphate (mg/L)	20.39^b	8.54^a	58.12	3.41^a	60.07	83.28	2**
Detergent (mg/L)	15.95^b	3.18^a	80.06	1.10^a	65.41	93.1	5

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Table 4. Biology parameters measurement

Plant Group	Stems amount			Stems Length (cm)	
	T0	T1	T1-T0	X0	X1
Group 1	40	109	69	67.93[a]	85.25[b]
Group 2	40	129	89	58.45[a]	70.06[a]
Group 3	40	98	58	63.38[a]	78.06[b]
Group 4	40	127	87	57.88[a]	71.6[b]

from 50 - 80 stems, with the highest increase in Group 2. The stems length value in the table 4 is an average of 10 stems, representative of each group. Ten healthy-look stems were measured and given a mark, so they can be measured at the end of the experiment. The result shows a significant difference in stems length before and after the experiment in all of the groups except Group 2.

Discussion

Water Quality

Temperature and pH are two important parameters in assessing water quality. The temperature has the ability to affect chemical reaction, availability of organisms in the water, and thus determining the degradation rate (Herath & Vithanage, 2015). Similar to temperature, pH also affects the diversity of the living organisms in the water, affecting metabolic and degrading activity, altering nutrient and heavy metals solubility which in turn affect nutrient uptake by plants and microorganisms (Vymazal *et al*., 1998). The temperatures measured in this research were normal in the range of 27-28^{o}C (see table 2.), which allow microorganisms and other aquatics organisms (e.g. microalgae, phytoplankton) to live. It is supported by several researches which report that the degradation process still occur in the temperature range between 15-30^{o}C (Stefanakis, 2016; Thalla *et al*., 2019). The pH value measured were also in the normal range, as quotes by Pamungkas (2016), that the ideal pH for the aquatic organisms are mostly in the range 7 – 8.5.

Waters are naturally contain organic and inorganic materials, as the result of rock mineralization, and from died plants or animals. Total Dissolved Solid (TDS), Total Suspended Solid (TSS), and Biochemical Oxygen Demand (BOD) are parameters that represents organic and inorganic salt in the water. TDS represents the soluble material, while TSS represent sthe bigger material or the undissolved material. While BOD, represent the amount of organic matter by calculating the amount of O_2, which is considered used by the microorganisms to degrade the organic material. High value of organic and inorganic salts in wastewater is affected by the amount of phosphate, detergent, and other compounds (Kustiyaningsih & Irawanto, 2020).

Since TDS and BOD are mainly soluble materials, their reduction mechanism mainly depends on microorganisms or plant activity. As mentioned by Choudhary *et al.* (2011), one of the removal mechansims of BOD that happen in constructed wetlands is through biodegradation. Certain microorganisms have the ability to break down certain organic matters, which result in the formations of inorganic salts or ions which make plants or other aquatic organisms easily absorb them. Another possible mechanism is sedimentation-filtration (Choudhary *et al.*, 2011). This mainly happens in the constructed wetland treatment, because of the use of plants and soil. The high density of soil added with the vertical flow, have allowed the water for having a longer time treatment. The easiest way to remove undissolved materials or TSS is through filtration. In this research rock gradation and soil play a major part in TSS removal since both have a high density which caused suspended solid to be trapped.

Pollutant Removal

Phosphorus is the second most important macronutrient needed by plants, after nitrogen. But unfortunatelly, its availability in the soil is very low due to its characteristic that bonds with minerals or metals in the soil and thus, makes it unavailable for the plants (Kalayu, 2019). In soil, phosphorus element exist in the form of insoluble inorganic and organic phosphorus, about 0,05% (Walpola & Yoon, 2012 in Kalayu, 2019), while the rest is present in the form of insoluble phosphate. Phosphate was categorized into 3 types, which are orthophosphate, polyphosphate and organic phosphate. Among those 3, polyphosphate is the type of phosphate that is known to be found in laundry wastewater however, plants can only absorb phosphate in the form of orthophosphate (Herath & Vithanage, 2015). Polyphosphate is basically an inorganic polymer, consisting of phosphate monomers.

The removal of phosphate was found both in the biofilter and CW, which likely happen due to several mechanisms between plant, soil, and microorganisms. Adsorption and degradation are two possible mechanisms that happen in the biofilter and CW processes. The adsorption took place due to the use of GAC, and its ability has been proved by some research (Majid *et al.,* 2017; Utomo *et al*., 2018). In the constructed wetland, soils that naturally contains minerals and metals are fixating the orthophosphates which causes precipitacion of phosphate in the soil layer. The transformation of insoluble to soluble phosphate was performed by microorganisms, which exist in both biofilter (biofilm) and constructed wetland (soils and rhizosphere of *E. hyemale*) (Thomas *et al*., 2017). According to Kalayu (2019), there are 3 possible ways for microorganisms to transform insoluble phosphate to soluble one, which is through lowering soil pH, chelation, and mineralization.

The Same mechanisms also happen in surfactant removal. GAC is also known to be able to adsorb surfactant compounds (Utami, 2013; El-Gawad, 2014; Utomo *et al*., 2018), and the microorganisms also also degrade surfactant compounds, and use its carbon element for metabolism activity. It explains the effectivity of removal of surfactant in the biofilter process, which reaches up to 80% and the final removal effectivity up to 90%. There are several types of surfactant, which differs by their constituent elements, which have different characteristics, and thus have different degradation mechanism that will affect the final results. Sodium Lauryl Ether Sulfate (SLES) and Sodium Alkylbenzene Sulfonate are two possible types of surfactants that exist in the laundry wastewater used in this research. This information was obtained from the detergent packaging used by the laundry owner. There are several possible degradation ways for this two types of surfactants. For SLES, the first degradation will generate intermediate compounds, which later, depending on the microorganisms might undergo the second degradation and generate CO_2 and H_2O (Paulo *et al*., 2017). In Sodium Alkylbenzene Sulfonate, the common degradation pathway was the breakdown of the main chain with β-oxidase enzyme and continued with the tricarboxylic acid cycle (Wu *et al.,* 2019).

Plant measurement

The measurement of the plant's length and number were carried out in order to find out the effect of laundry wastewater treatment on the plant. The result showed there was a growth activity of *Equisetum hyemale*, which can be seen in the increase in the number of stems and the length of the stems in all the plant groups. Group 1 and 3 have the highest increase in length, while group 2 and 4 have the highest increase in number after the treatment. These different growth phenomena can be explained by the metabolism activity of the plants. Metabolisms activity can be done with the availability of nutrition and the external factors which support the growth of the plants (e.g. pH, temperature, humidity, sun exposure, etc.). Plants are an important factor in the constructed wetland system. Some research has proved the effect of plants in CW in the reduction of surfactants. It plays role in providing a place for microorganisms, that are essential in the degradation process. It is also function to retard the water flow, thus the time contact between the wastewater and the wetland system is longer and allow a better degradation or treatment process (Thomas *et al*., 2017).

Conclusion

Based on the research done, the hybrid system of the biofilter and constructed wetland shows a promising treatment for laundry wastewater. The system was able to significantly reduce all the parameters measured. Phosphate and surfactant, which is the main pollutant in laundry wastewater was reduced by up to 80% of both pollutant. The final result of TSS, TDS, and BOD parameters have met up the quality standards set by the goverment. But the final result for phosphate and surfactant still have not met up the government quality standards. Despite that, the final result gave huge differences towards the initial concentration and eventually help to prevent environmental pollution.

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