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Full Scale Application of Integrated Upflow Anaerobic Filter (UAF) - Constructed Wetland (CWs) in Small Scale Batik Industry Wastewater Treatment

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ABSTRACT

This research was aimed to evaluate the implementation of integrated Upflow Anaerobic Filter (UAF)-Constructed Wetlands (CWs) in real condition of wastewater treatment plant in batik small scale industry. The full-scale reactor consisted of equalization chamber with Hydraulic Retention Time (HRT) of 2 days; Upflow Anaerobic Filter (UAF) with HRT of 6 days, and Horizontal Subsurface Constructed Wetlands (HSSCWs) with HRT of 1.5 days. The UAF - CWs integrated technology was used to treat batik wastewater with Chemical Oxygen Demand (COD) inlet of 1339 – 2034 mg/L and pH of 9.0 – 9.4. This study showed that single UAF technology alone was able to reduced COD 56 – 78%, while the integration UAF–CWs technology improved the performance to 85% and reduced the pH into 7.5 – 7.8.

1. INTRODUCTION

Batik small scale industry discharges specific wastewater that contains paraffin, dyes (synthetic and natural dye), starch, and caustic soda. It makes the wastewater characteristic with a high load of COD and pH. The major pollutants of wastewater come from dyeing and paraffin removal process (Yuliasni et al., 2017). Recently, the commonly applied technology in small scale industry is coagulation-flocculation (Acquabella, 2006; Mehta, 2012; Rodrigues, Madeira, & Boaventura, 2012). However, the trouble of coagulation-flocculation process are their inability to meet the effluent standard requirement as well as still generates a high amount of toxic sludge. There are other alternative technologies in batik wastewater treatment at laboratory scale such as decolorization white root fungi (Subarno, 2007), membrane nanofiltration (Rashidi, Sulaiman, & Hashim, 2012), photocatalytic for decolorization and demineralization (Wan Mohd Khalik et al., 2015), and phytoremediation (Setiyono & Gustaman, 2017). However, due to still having many drawbacks such as durability, feasibility and effectiveness, those technologies are not quite familiar for full-scale application on treating high strength batik wastewater.

Many studies reported that one of the reasons for high concentration of COD batik or textile wastewater is of high amount azo dyes concentration that inhibits removal of COD biologically. Azo dyes are relatively non-biodegradable compounds but the double-azo linkage can be easily cut under anaerobic condition, transformed into

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toxic aromatic amine. Toxic aromatic amine compounds are completely demineralized under aerobic condition. Demineralized aromatic amines are proven to be environmentally friendly. The combination of biological technology which involves anaerobic and aerobic organisms as catalysts for the oxidation-reduction reaction of azo dyes degradation can be an alternative to a more sustainable way of wastewater treatment technology. Therefore the development of this technology has gone rapidly (Beydilli & Pavlostathis, 2005; Himanshu, 2011; Van Der Zee & Villaverde, 2005) (Figure 1).

The combination of anaerobic-aerobic technology for biologically removing azo dyes in the form of unbiodegradable COD is an integrated technology Upflow Anaerobic Reactor (UAR)-Activated Sludge (AS). Integration technology of UAR-AS has been tried in the laboratory scale to treat batik wastewater without chemical pretreatment and could remove COD in wastewater up to 74.98 – 91.66% % (Yuliasni et al., 2017). Thus, the idea of this study is to combine the Upflow Anaerobic Filter (UAF) - Wetland in a full-scale application and to evaluate its use. Upflow Anaerobic Filter (UAF) is an anaerobic reactor that contains baffle and filter technology to create physical (depositional) and biological mechanism. Water-resistant compartments contain several layers of submerged media, become settlement surface area for bacteria. Wastewater flow in anaerobic filter reactors is from the bottom up (up-flow), aiming to make contact between wastewater and biomass in the filter to increase anaerobic degradation (Morel and Diener 2006). For Aerobic, the utilization of Horizontal Subsurface wetland system (Wetland) can not only oxidize azo dyes but also other organic pollutants such as COD, Ammonia and phosphorous (Geovana et al., 2016).

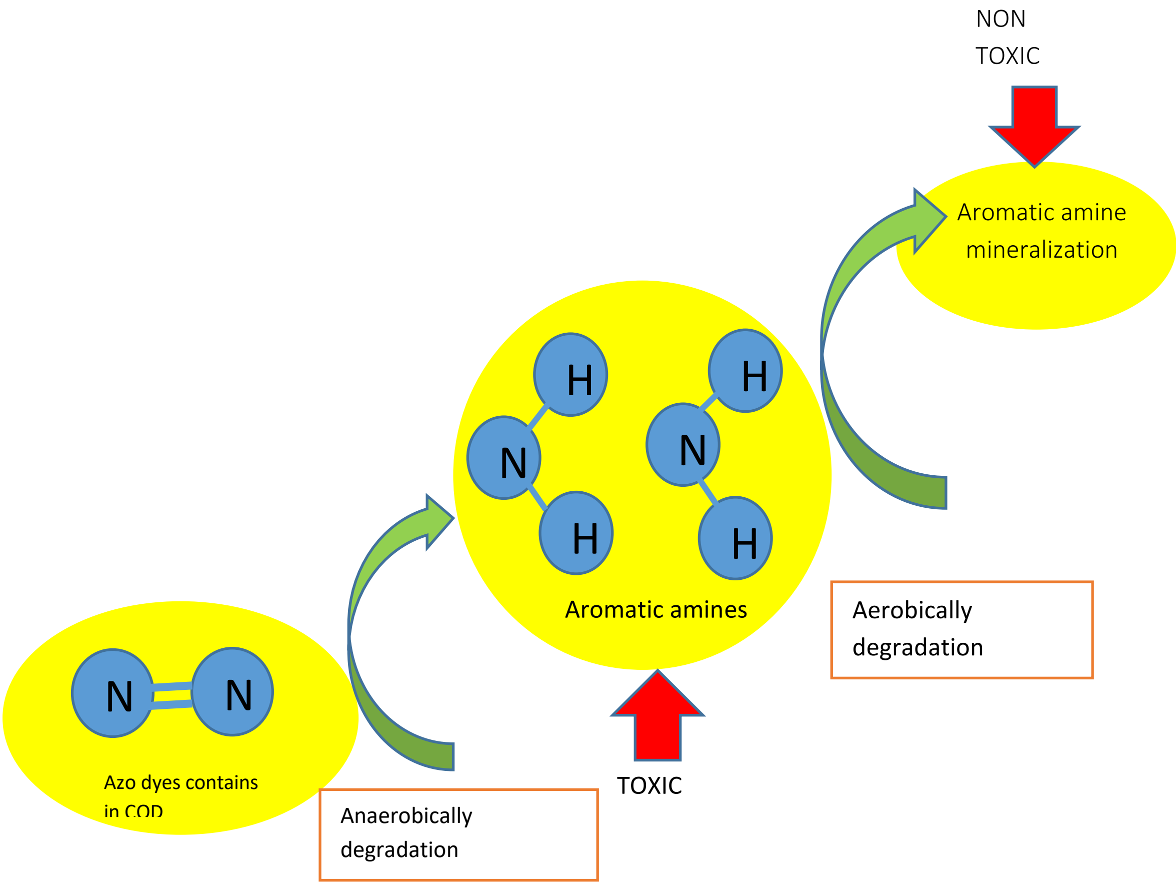


Figure 1. An illustration of biologically azo dyes removal that contained in COD

Constructed wetland is a complex system that includes natural treatment, sedimentation, filtration, gas transfer, adsorption, chemical and biological processing activities, due to microorganism activity in soil and plant activities. Soil, rock, or gravel media provide a surface for attaching microorganisms, contribute to macrophytic growth, and also as a filtration media and contaminant absorber (Alireza Valipour & Ahn, 2016). Rhizomes and roots will provide substrate for bacteria that attach and aerated the root area, and absorb Nitrogen (N), Phosphorus (P) pollutants taken through the root epidermis and vascular, and then transported up to the stems and leaves (A Valipour, Azizi, Raman, Jamshidi, & Hamnabard, 2014). Horizontal Subsurface Constructed Wetland (HSSCWs) was used in this study because of its robust construction and low operational cost (Leady, 1997). Heliconia, Typha, Papyrus were used as plant in this study because of their effectiveness to remove pollutant, their compatibility to the tropical weather and their aesthetical look (Sandoval, Zamora-Castro, Vidal-Álvarez, & Marín-Muñiz, 2019; Vymazal, 2013).

This study aims to evaluate the performance and effectiveness of COD and pH reduction in the application of the combined Upflow Anaerobic Filter (UAF) technology followed by Constructed Wetlands (CWs) using *Heliconia sp, Typha latifolia,* and *Cyperus papyrus* plants in real conditions in the wastewater treatment plant at a small batik industry.

2. MATERIAL AND METHODS

2.1 Material

Batik wastewater, with characteristic written in Table 1, was used. Upflow Anaerobic Filter (UAF) was made of concrete bricks. The liquid capacity was 24 m^3. Overall volume was divided into 6 equal compartments. Honeycomb filters made of plastics were attached inside of the compartment no.2 to compartment no.5, while compartment no.1 and no.6 were only chambers with no filter in it. All compartments were filled with microorganisms seed (sludge). Microorganisms seed was derived from anaerobic mix cultures from the tofu industry. The addition of the initial seed was 30% of total volume of the UAF reactor. Sugar, Starch and micronutrient were used to ensure the development of anaerobic mix cultures in the UAF (see Figure 2 (A) chamber B1 to B6).

Constructed Wetlands (CWs) model was referred to Horizontal Subsurface Constructed Wetlands (HSSCWs) model. Typha *(Typha Latifolia)*, Papirus *(Cyperus papirus)*, dan Heliconia *(Heliconia sp)* were used. CWs was also made of concrete bricks. Gravels with gradual size in diameters were filled in it. Gavels volume occupied 65% of the total volume of CWs. (See Figure 2 (A), chamber C1 and C2).

Batik wastewater inlets were collected in two periods, first period was collected when the industry generated high strength wastewater (referred as Sampling 1 in Table 1), the second period was collected when industry generated low strength wastewater (referred as Sampling 2 in Table 1).

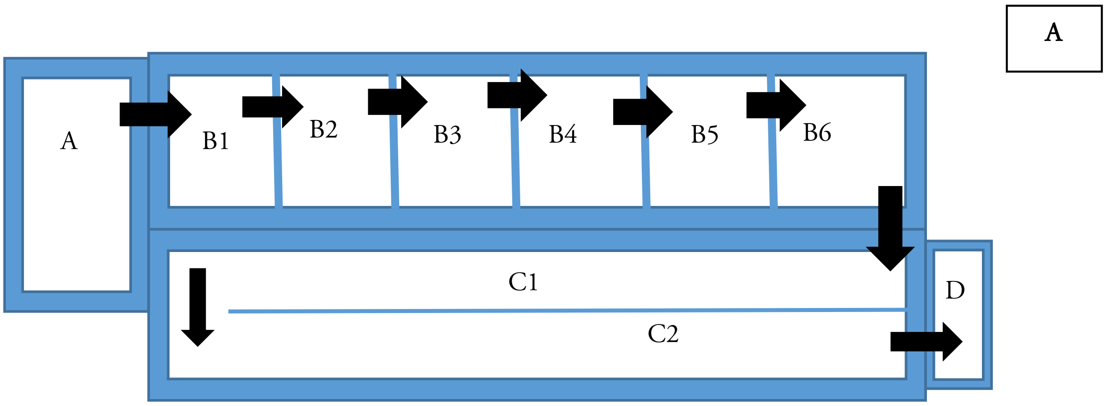
Tabel 1. Batik Wastewater Characteristics

No	Parameter	Unit	Sampling 1	Sampling 2
1	Temperature	°C	29,0	29,0
2	TSS	mg/L	2461	815,0
3	BOD_5	mg/L	1105	762,5
4	COD	mg/L	7858	4466
5	Phenol	mg/L	0,058	0,022
6	Crom	mg/L	<0,010	<0,010
7	Amonia	mg/L	1.725	1,125
8	Sulfide (S^{2-})	mg/L	5,030	3,520
9	Fat and Grease	mg/L	2,50	1,40
10	MBAS	mg/L	0,383	0,185
11	pH	-	9,1	8,5

2.3 Methods

2.3.1. Reactor construction

The full scale reactor consisted of equalization chamber (Dimension = : 4.0 m; W: 2.0 m; H: 1.0 m, designed HRT: 2 days), UAF (Dimension: L: 7.5 m (6 compartements total) x W: 1.0 m; H: 3.85, HRT 6 days), HSSCW compartement 1 dimension L:7.10m; W: 1.00 m: H: 1.00); HSSCW compartement 2 dimension L: 8.25 m; W: 0.8 m: H: 1.00 m). The reactor scheme is shown in Figure 2.



Legend:
A : Equalization chamber (with baffle separator for wax)
B1 to B6 : UAF with 6 compartments (B1 is referred to UAF no.1, and so on)
C1 and C2 : CWs with 2 compartments
D : Effluent chamber

B

Figure 2. Scheme diagram (A) and real image (B) of full-scale integrated UAF-CW technology

2.3.2 Operational condition

There were 3 stages have been done, namely seeding, acclimatization and continue application. Seeding was done by adding anaerobic mix cultured seed derived from tofu WWTP to occupy 30% of total UAF volume, while 70% was occupied by water. Starch, sugar and micronutrient were added and then UAF was left for 7 days. During that time, pH, and gas formation were monitored. Afterwards, the acclimatization stage was done by adding batik wastewater with gradual concentration 30%, 50%, 70%, 85%, and 100%. In theacclimatization stage, pH, COD inlet and outlet were monitored. Lastly, for continue application, 100% of wastewater was added continuously. Complete textile wastewater standard parameters were analyzed (i.e: BOD, COD, pH, temperature, ammonia, sulfide, total chrom, color and oil and grease).

2.3.3 Evaluation of wastewater treatment plant performance

Evaluation conducted by observing the performance of the system consisting of equalization unit, anaerobic units, and wetland in COD degradation and pH condition. After each unit works optimally, the performance of all existing units were observed. The calculation performance of the technology using equation:

$$\{(Ci - Ce)/Ci\}*100\%$$

Ci : influent/inlet concentration
Ce : effluent/outlet concentration

2.3.4 Analysis

Complete textile wastewater standard parameters were analyzed using the methodology described in Standard Methods (SM) for the Examination of Water and Waste Water (APHA) and SNI (Standar Nasional Indonesia) : COD (APHA 23nd, 5220 D), BOD_5 (APHA 22nd, 5210 B), TSS (APHA 22nd, 2540 A.D), oil and grease (APHA 22nd, 5520 A,C), Cr total (APHA 22nd, 3111 B), phenol (APHA 22nd 5330 B, C, D), ammonia (APHA 22nd 4500 NH_3), sulfide (APHA 22nd, 4500 S^{2-}) temperature (SNI 06-6989.23-2005) and pH (SNI 06-6989.11.2004).

3. RESULT AND DISCUSSION

Batik wastewater is mainly containing of wax and azo dyes that would completely biodegradable using the combination of anaerobic-aerobic technology (Yuliasni et al., 2017). Thus, in this study, the integrated technology that consists of Upflow Anaerobic Filter (UAF) - Constructed wetland (CWs) was used. In UAF chamber, most biological organic, either biodegradable or recalcitrant, would be anaerobically reduced. Double-bond azo would be cut into aromatic amines single bond, then mineralized by aerobic microorganisms that plenty occurred in CWs (Beydilli & Pavlostathis, 2005; Van Der Zee & Villaverde, 2005; Yemashov a & Kalyuzhnyi, 2006).

As also shown in Figure 2, raw wastewater was collected in the equalization chamber with retention time (HRT) of 1 day. In the equalization chamber, the soluble organic (soluble COD) and insoluble organic (wax) were separated using a baffle. Insoluble organic such as wax was collected in another chamber and soluble organic wastewater was pumped from the equalization chamber into UAF chamber. UAF was consisted of pipe that planted vertically inside of the chamber and was used upflow model as in (Chowdhury, Viraraghavan, & Srinivasan, 2010) to allow liquid equally distributed inside the chambers. UAF was consisted of 6 compartments with filters, to allow a plug flow flowrate and to achieve a long solid retention time (SRT) (Drtil, Bod, & Herdov, 2002).

3.1 The performance of Upflow Anaerobic Filter

Due to the utilization of anaerobic microorganisms and the high strength COD concentration of influent wastewater (COD: 1000 - 2300 mg/L) and also high pH (pH > 9), to boost and maintain the growth of microorganism, three stages were done namely: seeding, acclimatization and continuous application.

3.2 Seeding

In this research seeding process is carried out by adding anaerobic microbes of 1200 kg (to reach 30% of the building height) each compartment in the UAF unit. The UAF unit consists of 6 compartments with each volume 4 m^3. Microorganisms were added with 300 mg/L sugar nutrient and clean water until the reactor was full and observed the emergence of gas bubbles as a visual indicator of the formation of hydrogen or methane gas resulted from the anaerobic bacteria metabolic process.

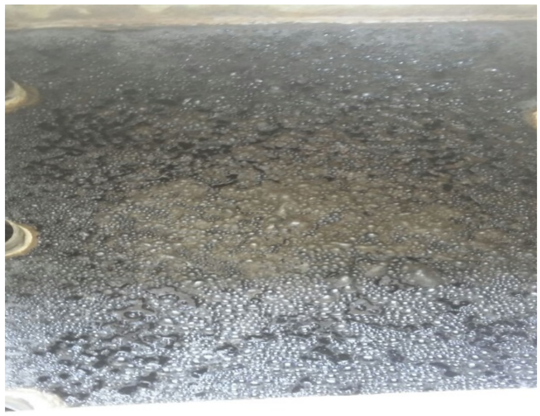


Figure 3. Microbial visual activity observation

3.3 Acclimatization

The acclimatization process was carried out by feeding wastewater at a certain concentration which is gradually increased to each compartment in batch system. The concentration of wastewater fed to UAF unit starts from concentration of 30% (wastewater: clean water ratio = 30:70); 50%; 70%; 85% and 100%. Because of the variation of the wastewater inlet, the gradual increase of COD concentration was not achieved. The COD inlet increased gradually at 30% to 75%, but because of the change of the production process of batik wastewater, at 85% and 100%, the inlet COD were lower than usual value. For each concentration, the wastewater was allowed to stand for 6 days for microbial adaptation to the concentration of wastewater. As an additional carbon source, sugar and starch of 125 mg/L were added. To evaluate the results of the acclimatization process, dissolved COD and pH parameters were observed. Sampling for dissolved COD and pH was carried out only in compartment 1, assuming the compartment 1 condition was representative of the other 5 compartments. The results of the acclimatization process are presented in Figure 4.

As shown in Figure 4, the COD inlet (day 0) initially was around 375 mg/L. There was no significant decrease in COD in the variation at 30% and 50% concentration of wastewater. This condition was probably due to microbes in initial stages of acclimatization were not fully active yet. When wastewater concentrations were increased at 70% and 85% (COD 623.7 and 395 mg/L), COD degradation reached on 58.8% and 45.7%, respectively, indicate that microbes were already active and degrade pollutants. However, when wastewater concentration increased at 100%, with COD value of only about 275.5 mg/L, the efficiency of COD reduction decreased only 15%, with visual observations that there was reducing of active microbes. To ensure that microbes did not collapse, MLSS analysis was performed in UAF reactor with a result of 448 mg/L.

3.4 Continous UAF operation

The next stage was the continuous UAF reactor operation carried out by feeding wastewater from equalization tank 1.5 m^3 for 2 hours per day (Q = 12 L/min). Nutrient of sugar and starch 125 mg/L respectively were also added to help lower the pH due to the ability of sugar and starch to anaerobically produce VFA that slightly acidic (Feijoo, Soto, Mndez, & Lema, 1995). Observation was carried out every day for 17 days, with observed parameters were COD and pH. All samples were analyzed once. pH was also observed because ph inlet is too high and high pH was regarded as inhibition factor for the growth of both anaerobic and aerobic microorganisms (Jung, Lee, Shin, & Chung, 2000). The result of observation can be seen in Figure 5.

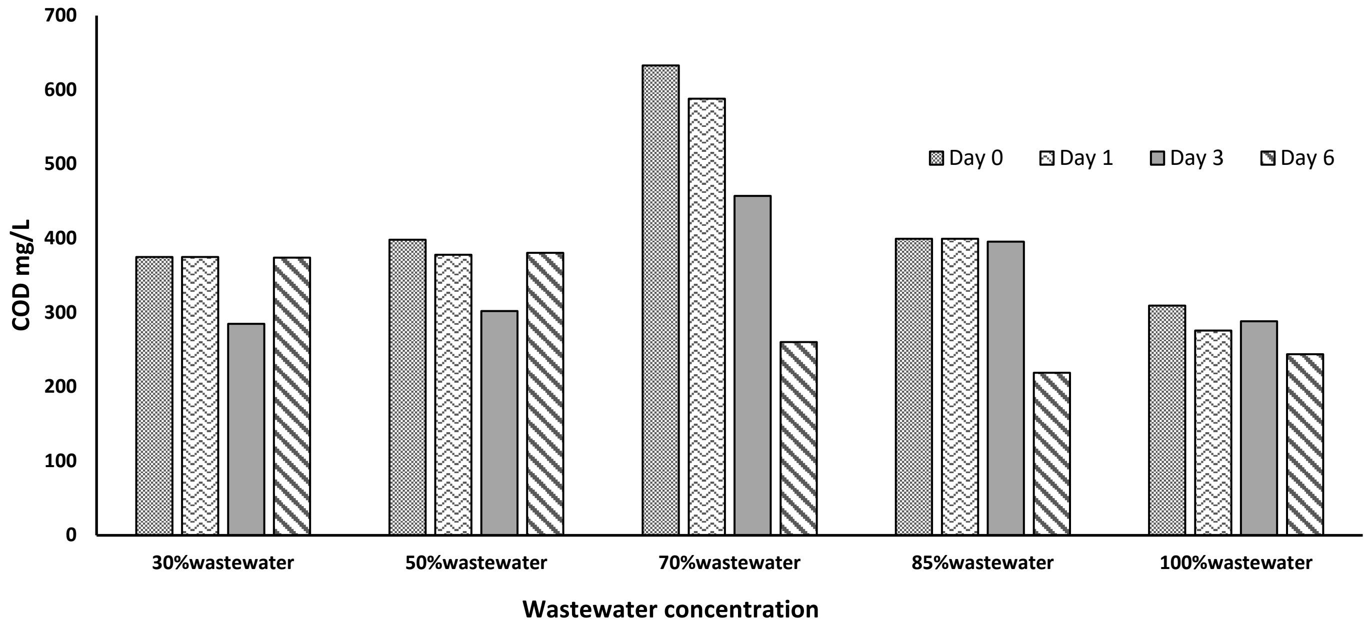


Figure 4. COD degradation profile in the acclimatization process

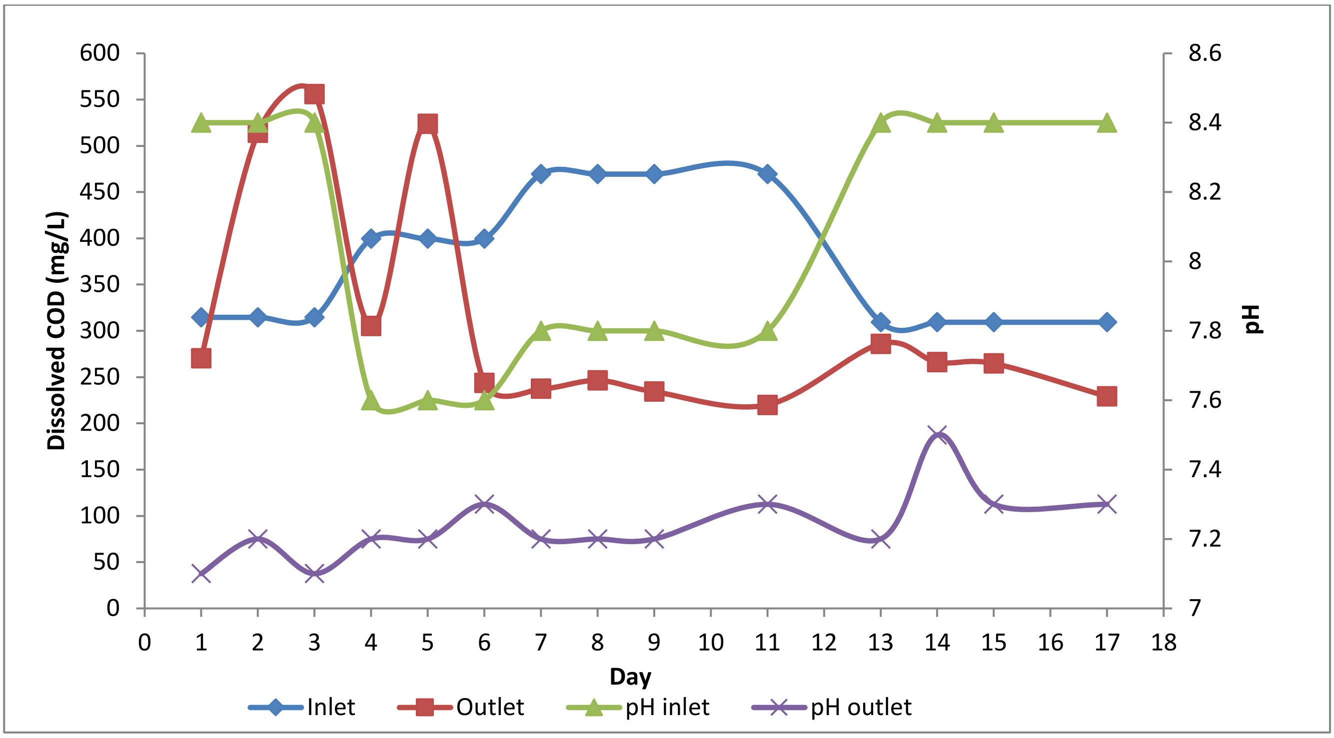


Figure 5. Soluble COD and pH profile in UAF

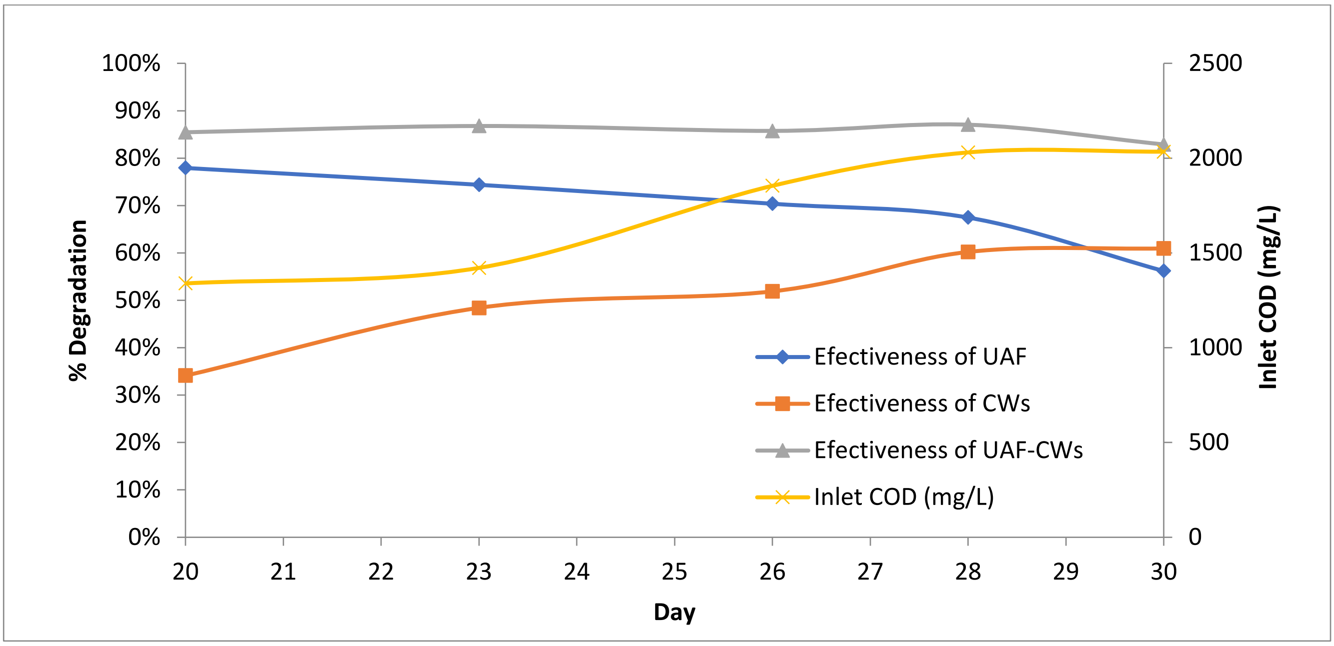


Figure 6. Effectiveness in UAF, Costructed Wetlands (CWs) dan UAF-CWs

Figure 4 shows that COD inlet ranges from 300 - 469 mg/L. COD outlet fluctuate in the first 6 days, even COD outlet tends to be higher than COD inlet. However after day 6 to day 17, COD outlet tends to be stable in the range of 220 - 280 mg / L. pH inlet tends to fluctuate in the range of 7.6 - 8.4, but pH outlet tends to be stable in the range of 7.1 - 7.5. This phenomena proved that the system could lower the pH. Furthermore, decreased pH can also be an indication of degradation process in UAF, which in VFA's were present as a reduction/ degradation products of complex organics pollutant, in this case, COD that contains in azo dyes.

3.5 The performance of integrated UAF – CW technology

Performance of UAF unit and wetland observed starting from day 20. The observation was conducted in 10 days continuous operation reactor, and the observed parameters were COD and pH with periodically sampling period. The observations are presented in Figure 6.

In the observation performance of combined UAF-CW, inlet COD values range from 1339 to 2034 mg/L. Average percentage COD reduction in the UAF system is 69.26% while in CWs system is 51.1%. pH inlet is high, ranging from 9.0 - 9.4, outlet pH from UAF system is between 7.4 - 8.1 and from the CWs system is between 7.5-7.8. Although the effectiveness in UAF reactor tends to decrease, the effectiveness in wetland unit tends to increase, so that effectiveness in the combined UAF-wetland tends to be stable at around 85%. Figure 7 is presented to observe the visual effect of the degradation of COD in the system in line with data in Figure 6. The intensity of the color and turbidity were gradually decreased, from inlet to the wetland outlet, which also an indication of azo dyes degradation/ removal (measured as COD).

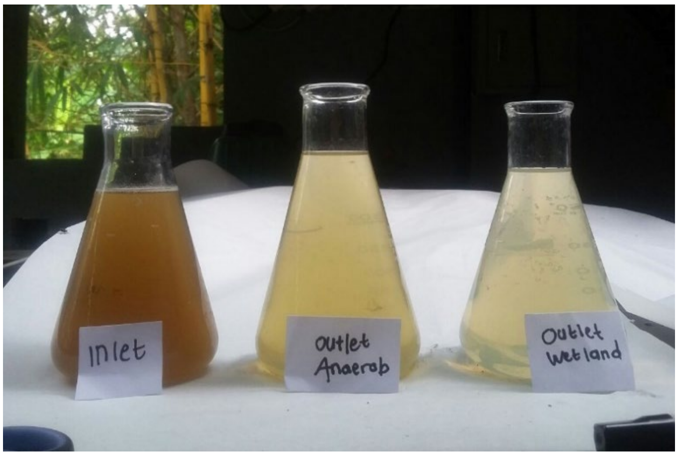


Figure 7. Visual of wastewater from inlet, UAF, and wetland

4. CONCLUSION

Complex unbiodegradable organics pollutant contains in batik wastewater could be biologically degraded by the combination of the technology UAF and CWs (HSSCW). UAF technology can anaerobically degrade organic pollutant, and at the same time lowering the pH. CWs can aerobically complete the biological degradation. The combination technology can be an alternative for full-scale application for treating batik wastewater.

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