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IMPROVING THE EFFLUENT QUALITY OF PAPER MILL TO SUPPORT A SUSTAINABLE ENVIRONMENT

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ABSTRACT

The paper mill producing specialty paper has a wastewater treatment plant with an aeration pond system to remove their pollutants. However, the removal efficiency of this system is still low so that the effluent is still not meeting the Indonesian of effluent quality standards yet. The pretreatment plant before aeration pond is needed. In an effort to support a sustainable environment, a study of wastewater characteristics, flow measurements, laboratory scale experiment of wastewater treatment, and the establishment of treatment systems and equipment design have been carried out. After construction of pretreatment plant, the field trial of waste water treatment plant using wastewater coming from various types of paper produced has also been done. Result of laboratory-scale investigation shows that the paper mill needs a wastewater treatment with physical-chemical system before the treatment in the pond aeration. Field trial of wastewater treatment shows that the reduction of suspended solids (TSS) of 97%, COD of 88%, BOD_5 of 85%, and a pH of 6.2 to 7.7 could be obtained by using 5 - 10 % NaOH solution with doses of 50-240 ppm and 0.1% cationic polyelectrolyte (PE) solution as flocculants at a dose of 1.0 to 1.5 ppm. The addition of physical-chemical treatment plant can lighten the load on an aeration pond treatment. Effluent quality of aeration pond discharged into environment has met the Indonesian effluent quality standards. In this case this paper mill supports a sustainable environment.

*Keywords***:** Aeration pond; Effluent; Paper mill; Physical-chemical treatment

1. INTRODUCTION

The paper mill is considered to be one of the major units in terms of fresh water usage and therefore discharges a large amount of wastewater. In paper mill, fine particle of fibers and additives can be lost and escape with the processed water of various operations and finally flowing out as mill effluent as one of the major sources of aquatic pollution (Zeritis, 1991; Kumar *et al.*, 2011; Razali *et.al*., 2012; Ali *et al.*, 2013). The effluent of the paper mill contains high concentration of pollutant, in terms of Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD) and Total Suspended Solids (TSS) (Kumar *et al.*, 2011; Ali *et al.*, 2013). These pollutants of paper mill effluent are harmful to the receiving waters which will affect the flora and fauna of the aquatic system (Razali *et al.*, 2012; Ali *et al.*, 2013; Tripathi *et al.*, 2013). To prevent the environmental pollution, more stringent of the wastewaters discharge criteria has been established in some countries. Therefore, the effective wastewater treatments are needed (Tzoupanos, 2008).

Paper mill with the production capacity of around 100 tons per day producing several types of fine paper discharges the wastewater in maximum of 150 m^3 per day. Their wastewater characteristics contain high concentration of TSS, COD, BOD_5 and pH, and

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it is fluctuated. This paper mill already has an aeration pond to treat their wastewater. Unfortunately, the effluent quality discharged into the receiving water body by this treatment system is still not meeting with the Indonesian effluent quality standard yet.

In an effort to comply with the requirements of the quality effluent standard to support a sustainable environment and it is further to a sustainable socioeconomic system, this paper mill endeavored to improve their effluent discharged by upgrading their wastewater treatment system (Dally, 1990; Morelli, 2005). The upgrading of their wastewater treatment system has been done by the additional of pretreatment (equalization basin) and primary treatment (coagulation, flocculation and sedimentation basins) units especially to reduce the pollutant concentration before it is further treated in the existing treatment of aeration pond. Additional of equalization basin is very important to homogenize wastewater for both flow and characteristics (Wilson, 1981; Metcalf, 1991; Goel *et al.*, 2005). A relative constant of flow and characteristics will ease in adjusting the dose of coagulant in coagulation and flocculants in flocculation processes. Suitable addition of coagulation and flocculation dose serves in agglomeration of colloidal particles into small particles (fine flocs) in coagulation process and to be larger and heavier of clump (flocs) in flocculation process (Turkman, 1991; Nash *et al.*, 2004; Awaleh, 2014). Afterwards, the solids and the treated wastewater are separated by precipitation process in the sedimentation basin.

The purpose of this paper is to present the performance improvement of wastewater treatment plant of a paper mill with the addition of equalization, coagulation, flocculation and sedimentation units so that the effluent quality meets the Indonesian effluent quality standard. The design and the results of the additional wastewater treatment units and the effluent quality are described in this paper.

2. EXPERIMENTAL

2.1. Materials

Wastewater was taken from paper mill producing several types of fine paper. The characteristics of the wastewater are presented in Table 1. 10% of NaOH solution and 0.1% of cationic polyelectrolyte (PE) solution as flocculants were used to increase the wastewater pH and to agglomerate the fine flocs in flocculation experiment, respectively. All chemicals used in this study were technical reagent grade.

Table 1 The characteristics of the wastewater of paper mill

No.	Parameter	Unit	Concentration
1.	pH	-	4.08 – 6.30
2.	TSS	mg/l	650 – 1,950
3.	COD	mg/l	952 – 2,928
4.	BOD_5	mg/l	415 – 1,430

2.2. Methodology/Experimental

a) Jar test

A jar test was performed with the conventional jar apparatus with six paddles using 1,000 ml of wastewater samples. Coagulation phase was done by the rapid mixing using 150 rpm speed for two minutes after addition of 10 % of NaOH solution in the concentration range of 50 - 240 ppm. . The flocculation phase was then carried out using centrifugation at 20 rpm speed for 30 minutes after the addition of 0.1% cationic polyelectrolyte (PE) solution as a flocculant at varying dose of 1.0 to 1.5 ppm. After that, the sedimentation phase was carried out for 60 minutes to allow the flocs to settle and the treated wastewater was then separated from the sludge.

b) Determination of the treatment system and the dimension of the equipment

The design of a wastewater treatment system and equipment's dimension that are appropriate to improve the performance of the existing WWTP is based on the maximum flow of 150 m^3/day and the characteristics of wastewater as shown in Table 1. Secondary data from some literatures was also used to calculate the size of the equipment's dimension.

Equalization basin dimension was determined based on the design criteria reported by Paulson i.e. an equalization tank should be sufficient to hold at least two hours of the hourly peak wastewater flow (Ouano, 1983; Metcalf, 1991). Coagulation or rapid mixing basin dimension was determined based on the design criteria of detention time values in the range of 30 – 120 second and the mean velocity gradient (G) values in the range of 250 – 1,500 s^{-1}. The required power for rapid mixing is calculated by equation 1 and equation 2 given below (Metcalf, 1991).

$$P = G^2 V \mu \quad (1)$$

Where,

P = power requirement (Watt)
G = mean velocity gradient (s^{-1})
V = rapid mixing volume (m^3)
μ = dynamic viscosity (N.s/m^2)

$$P = k \rho N^3 D^5 \quad (2)$$

Where,

P = power requirement (Watt)
k = impeller constant
ρ = mass density of fluid (kg/m^3)
N = revolution per second (rev/s)
D = diameter of impeller (m)

The fflocculation basin was determined based on the design criteria of detention time values in the range of 10 – 30 minutes and the mean velocity gradient (G) values in the range of 20 – 80 s^{-1} (Metcalf, 1991). The sedimentation/clarifier basin was determined based on the design criteria of primary settling followed by the secondary treatment having detention time values in the range of 1.5 – 4 hours and the overflow rate of 20 – 60 m^3/m^2.day (Metcalf, 1991).

c) Trial operation of wastewater treatment and effluent quality monitoring

Trial operation of wastewater treatment was carried out after equalization, coagulation, flocculation, and sedimentation basins were completely constructed. Trial operation of wastewater treatment was conducted based on the jar test results. The effluent quality of wastewater treatment was monitored for several months.

2.3. Analytical Methods

The wastewater discharged from paper mill, the effluent from primary treatment, and the effluent from the aeration pond were taken and characterized for pH, COD, BOD_5, and TSS values according to the American Public Health Association (APHA) standard methods.

3. RESULTS AND DISCUSSION

3.1. Sources and characteristics of wastewater

The main source of wastewater in this paper industry comes mostly from the excess white water coming out of the fiber recovery unit and a small portion comes from water used to wash the equipments and floors. The pH of wastewater is low enough, possibly due to the residual Aluminum sulphate ($Al_2SO_4.18H_2O$), a chemical additive used in papermaking. This residual Aluminum sulphate may be useful as a coagulating agent in the coagulation process. Coagulation process can proceed well in the pH of 5.5 to 8.0 (Metcalf, 1991; Tzoupanos, 2008). Therefore, the addition of alkaline chemicals into the wastewater is needed to raise the pH value. The high content of TSS and COD in the wastewater is caused by the cellulose and chemicals such as fillers used in the paper making process. It seems that most of the organic and inorganic substances occur in the suspension. Thus, they will be easy to precipitate. Considering the characteristics of wastewater, physics-chemical treatment (coagulation, flocculation and sedimentation), it is necessary to reduce TSS concentration of the wastewater.

The discharged wastewater of paper mill as shown in Table 1 is slightly acidic and has high concentration of TSS, COD, and BOD_5.. This condition will highly affect the treatment in the aeration pond. Table 2 indicates that the effluent aeration pond still contained a high concentration of TSS, COD, and BOD_5. It does not meet the Indonesian effluent quality standard yet.

Table 2 Effluent characteristics of the aeration pond

No.	Parameter	Unit	Effluent of aeration pond	Indonesian effluent quality standard
1.	pH	-	6.40 – 6.75	6 – 9
2.	TSS	mg/l	220 – 1,300	100
3.	COD	mg/l	762 – 2,344	200
4.	BOD_5	mg/l	330 – 1,144	100

To reduce their pollutant concentration in the wastewater, the homogenization the flow and concentration of the wastewater in the equalization basin and primary treatments (coagulation, flocculation and sedimentation basins) units are needed (Wilson, 1981; Metcalf, 1991; Goel *et al.*, 2005).

3.2. Determination of the treatment system unit

a) Equalization basin

The detention time in the equalization tank was set for four hours. The selection of this equalization tank detention time is based on thedesign criteria reported by Paulson (Ouano, 1983). At the peak flow rate of 150 m^3 per hour and the selected depth of 3 m, this equalization basin has the volume of 600 m^3 with the length and width of 14.14 m each. This equalization basin is equipped with an aerator to stir the wastewater in order to homogenize it(Goel *et al.*, 2005).

b) Coagulation/Rapid mixing basin

The rapid mixing basin was set for a residence time of 120 second and the velocity gradient (G) of 1,000 s^{-1} (Metcalf, 1991). At the peak flow rate of 150 m^3 per hour and the selected depth of 1.85 m, this rapid mixing basin has the volume of 5 m^3 with the length and width of 1.64 m each. Based on the data of rapid mixing volume (V), velocity gradient (G), wastewater viscosity (μ = 0.00131 Ns/m^2) and equation 1, the motor power required (P) for the rapid mixing is 3,210 watts or 3 horse power (hp). Using data of the required power (P), impeller constant (k= 6.30) for six turbine type stirrer blades, revolution per second (N = 100 rpm/60), density of wastewater (ρ = 1,000 kg/m^3) and equation 2, the diameter of the impeller of 0.64 m for the rapid mixing can be obtained (Metcalf, 1991; Nasr *et al.*, 2004).

c) Flocculation basin

A well design for flocculation basin, the Gt values, the multiplying of the velocity gradient (G) to detention time (t), should be in the range of 10^4 to 10^5 (Metcalf, 1991). In this case, to get the strong flocs, the flocculation basin was set for a detention time of 20 minutes (1,200 second) and high velocity gradient of 80 s^{-1} so that the Gt values of 96,000 is obtained (Metcalf, 1991; Nasr *et al.*, 2004). At the peak flow rate of 150 m^3 per hour and the selected depth of 3 m, this flocculation basin has the volume of 50 m^3 with the length of 16.7 m and the width of 3 m. The flocculation basin is equipped with paddle type agitator with slow rotation speed (14 rpm).

d) Clarifier

The clarifier is designed based on the overflow rate of 20 – 60 m^3/m^2.day (Metcalf, 1991; Nasr *et al.*, 2004). At the peak flow rate of 150 m^3 per hour and the selected overflow rate of 24 m^3/m^2 day, the sedimentation has the diameter of 8 m. This sedimentation is equipped with a rake which revolves slowly once in a time to raise the solid settled in the bottom of the sedimentation basin.

3.3. Jar test experiment

The jar test result indicates that the addition of 5 - 10% of NaOH solution with the doses in the range of 50 - 240 mg/l in the wastewater, can increase the pH of wastewater. In addition, the coagulation of colloids to form small particles (fine flocs) has occurred. The occurrence of the coagulation of suspended solid might be caused by the residual aluminum sulphate contained in wastewater. This residual aluminium sulphate presented in a sufficient concentration and served as a coagulant agent. In the coagulation process of wastewater of some types of fine paper making industry, the addition of aluminum sulphate to coagulate their suspended solid as shown in Table 3 is not needed. To magnify the fine floc into the larger flocs, 0.1% of polyelectrolyte solution (PE) as a cationic flocculants with a dose of 1.0 to 1.5 ppm was added in the flocculation process. This process can produce floc which is large and easy to settle. Clear effluent is obtained after the settling process. The addition of NaOH and PE to fine paper mill wastewater formed insoluble materials in the form of aluminum hydroxide. They, in turn, facilitate the precipitation of colloids and increase the sedimentation rate of other particulate matters present in the effluent. Thus, the total suspended solid in the effluent will reduce and the sedimentation rate of organic matter will increase (Razali *et al.*, 2012; Loloei *et al.*, 2016). The effluent quality and the removal percentage of each parameter of jar test result are shown in Table 3. This table shows that the use of 5 - 10 % of NaOH solution at dose of 50 – 240 ppm and 0.1% of PE solution can raise the effluent pH of 6.2 – 7.7. In addition, the concentration of TSS, COD and BOD_5 also decrease in the range of up to 42 - 52 mg/l, 142 – 319 mg/l, and 68 – 163 mg/l, respectively. The removal efficiencies of TSS, COD, and BOD_5 were 92 – 98%, 77 – 88%, and 76 – 85% respectively.

Table 3 Effluent quality and removal percentage of jar test result

No	Fine paper type	NaOH solution		0.1% PE solution	Influent (mg/l)				Effluent (mg/l)				Removal (%)		
		5%	10%		pH	TSS	COD	BOD_5	pH	TSS	COD	BOD_5	TSS	COD	BOD_5
1	A	-	240 ppm	1.5 ppm	4.6	1,768	1,054	464	7.4	45	240	113	97	77	76
2	B		70 ppm	1.0 ppm	5.3	1,515	952	428	6.8	47	142	68	97	85	84
3	C	200 ppm	-	1.0 ppm	5.4	1,435	1,928	925	7.7	42	229	135	97	88	85
4	D	50 ppm	-	1.0 ppm	4.5	660	1,762	863	6.2	52	319	163	92	82	81
5	E	50 ppm	-	1.0 ppm	6.3	1,950	1,080	518	7.7	42	252	126	98	77	76
6	F	50 ppm	-	1.0 ppm	4.8	650	1,232	567	6.6	49	251	126	92	80	78

3.4. Effluent quality and the performance of wastewater treatment

The dose of NaOH and PE solution of jar test result was applied during the trial operation of the wastewater treatment. The effluent quality of wastewater treatment was monitored for several months as shown in the following Figures. Figure 1 indicates that the pH of the sedimentation basin (clarifier) effluent was in the range of 6.02 – 8.72. This is higher than that of influent pH, which was in the range of 4.08 – 6.54. The pH of the aeration pond effluent that was discharged into receiver water body was in the range of 6.12 – 6.97. This already met the Indonesian effluent quality standard, which is in the range of 6 – 9.

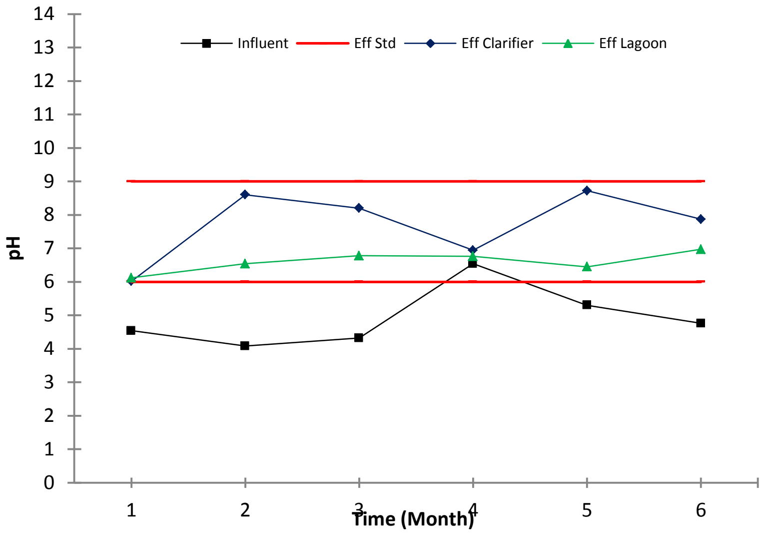

Figure 1 pH of the influent and effluent

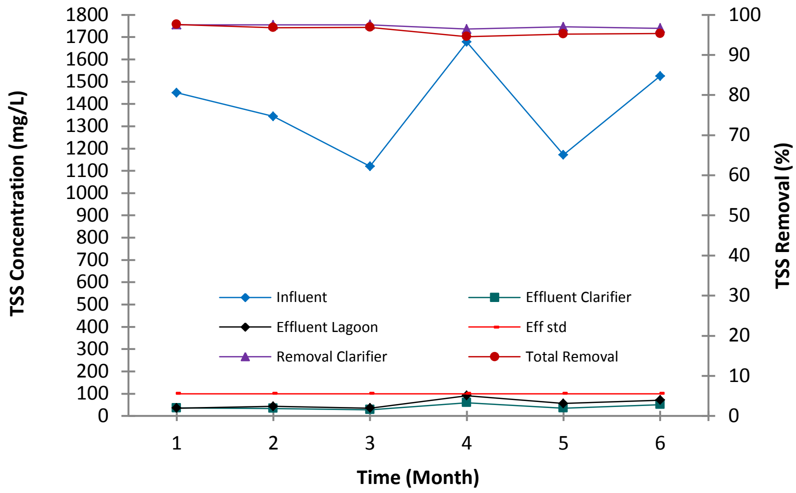

Figure 2 Concentration and removal of TSS

The applied physico-chemical treatment for the wastewater resulted in a high removal of TSS, COD and BOD_5 parameters. TSS removal reached 97% and TSS concentration of the clarifier effluent was 28 – 60 mg/l. The effluent of the aeration pond has TSS concentration of 35 – 91 mg/l. This value is higher than that of the clarifier effluent. This is possibly due to the lack of the proper operation in the aeration pond. However, this value has met the Indonesian effluent quality standard, which is100 mg/l (Figure 2). Thus, the total removal for TSS parameter is in the amount of 95 – 98%.

The COD concentration of effluent in the clarifier was in the range of 172 – 132 mg/l with the removal efficiency of 87 – 88%. The COD concentration contained in the aeration pond effluent discharged into the environment is in the range of 125 – 222 mg/l. It generally has met the Indonesian effluent quality standard of 100 mg/l as shown in Figure 3. The total removal for COD parameter is in the amount of 88 – 91%. In this case, the aeration pond only reduced the COD concentration in the amount of 1 – 3%.

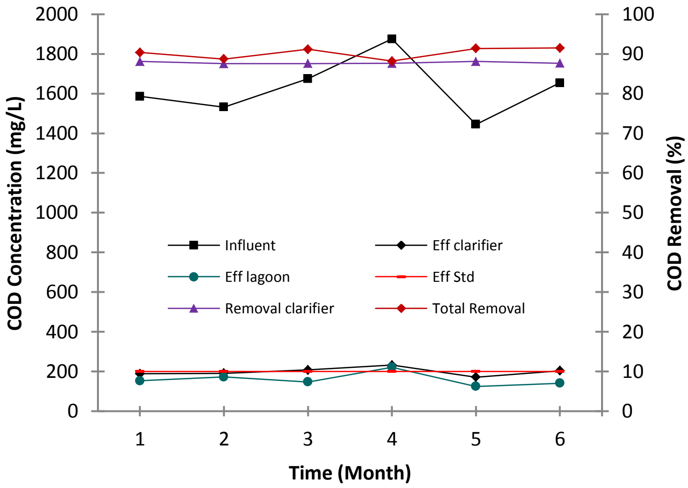

Figure 3 Concentration and removal of COD

The BOD_5 concentration of the effluent clarifier is 59 – 115 mg/l with the removal efficiency of 83 – 86% while the aeration pond effluent contained BOD_5 concentration of 47 – 94 mg/l. It has met the Indonesian effluent quality standard of 100 mg/l as shown in Figure 3. The total removal for BOD_5 parameter is in the amount of 86 – 89%. In this case, the aeration pondreduced the BOD_5 concentration in the amount of 3%.

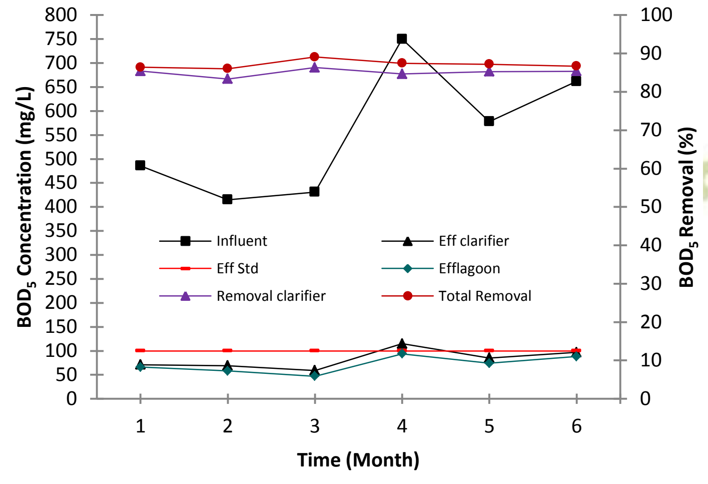

Figure 4 Concentration and removal of BOD_5

4. CONCLUSION

The addition of the equalization basin to homogenize the wastewater for both flow and concentration, and primary treatment (coagulation, flocculation and sedimentation basins) could improve the performance of the wastewater treatment plant of paper mill. The effluent quality of the paper mill which was discharged into environment has met the Indonesian effluent quality standard. This paper mill has supported and maintained a sustainable environment.

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