



The Performance of Improved Pulp and Paper Wastewater Treatment Plant

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ABSTRACT

Paper mill producing several type papers has a wastewater treatment plant with an aerated lagoon system to remove their pollutants. But the removal efficiency of this system is still low so that the effluent is still not complying with the Indonesian of effluent quality standards yet. It needs pre-treatment plant before aerated lagoon. In an effort to improve the performance of wastewater treatment plant, study of wastewater characteristics, wastewater treatment, the establishment of treatment systems and equipment design have been carried out. After construction of pre-treatment plant, the field trial of wastewater treatment plant using wastewater originated from several type of paper produced was conducted. Result of laboratory-scale experiment showed that the paper mill needs a wastewater treatment with physical-chemical system before aerated lagoon treatment. Field trial of wastewater treatment showed that the removal of suspended solids (TSS) of 97%, COD of 88%, BOD₅ of 85%, and a pH of 6.2 to 7.7 could be obtained using 5 - 10 % NaOH solution at doses of 50-240 mg/L and 0.1% cationic polyelectrolyte (PE) solution as flocculants at dose of 1.0 to 1.5 mg/L. Application of physical-chemical treatment plant can lighten the load on an aerated lagoon treatment. Effluent quality of aerated lagoon discharged into environment has met the Indonesian of effluent quality standard.

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INTRODUCTION

The paper mill is known as one of industries consuming lots of fresh water. Therefore, paper mill discharges a large amount of wastewater containing fine particle of fibres and additives as one of the major sources of aquatic pollution [1-3]. The wastewater of paper mill contains high concentration of pollutant, in terms of Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD) and Total Suspended Solids (TSS) which is harmful to receiving waters affecting to flora and fauna of aquatic system [2-6]. To prevent environmental pollution, some countries has established more stringent of the wastewater discharge criteria. Therefore, the effective wastewater treatments are needed to full fill it [7].

Paper mill with the production capacity of around 100 tons per day producing several types of papers discharge the wastewater in maximum of 150 m³ per hour. Their waste water characteristics contain high concentration of TSS, COD, BOD₅ and pH which is fluctuated. This paper mill has already an aerated lagoon to treat their wastewater. But the effluent quality discharged into the receiver water body by this treatment system is still not meet with the Indonesian effluent quality standard yet. In an effort to comply with the requirements of the Indonesian effluent standard quality, this paper mill endeavoured to improve the quality of effluent discharged with the performance improvement of their

wastewater treatment plant [8-9]. Upgrading of their wastewater treatment system was performed by additional of equalization basin to collect their wastewater characteristic and primary treatment which is consisted of coagulation, flocculation and sedimentation basin units. These additional units are to reduce the pollutant concentration before it is further treated in the existing treatment of aerated lagoon. Additional of equalization basin is very important to homogenize wastewater for both flow and characteristics [10-12]. A relative constant of flow and characteristics will ease in adjusting dosage of coagulant and flocculants in the coagulation and flocculation processes, respectively. The proper addition of coagulant and flocculants dosages assists in agglomeration of colloidal particles into small particles (fine flocks) in coagulation process and to be larger and heavier of clump (flocks) in flocculation process [13-15]. Then, the solids and the treated wastewater are separated by precipitation process in sedimentation basin.

The objective of this paper is to improve the performance of wastewater treatment plant of a paper mill by addition of equalization, coagulation, flocculation and sedimentation units in order, the effluent quality comply with the Indonesian effluent quality standard. Design and the results of additional wastewater treatment units, and the effluent quality are described in this paper.

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MATERIAL AND METHOD

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

Jar test experiment

A jar test experiment was performed with the conventional jar apparatus with six paddles using 1,000 mL wastewater samples. Coagulation process was done by rapid mixing with 150 revolutions per minute (rpm) speed for two minutes, after addition of varying doses of 50 - 240 mg/L of 10 % NaOH solution. Then flocculation process was carried out with 40 rpm speed for 30 minutes, after the addition of 0.1% cationic polyelectrolyte (PE) solution as flocculants at varying dose of 1.0 to 1.5 mg/L. After that, sedimentation process was carried out for 60 minutes to allow flocks settled in the bottom of beaker glass. Treated wastewater was separated from the sludge by decantation.

Determination of treatment system and equipment dimension

The design of a wastewater treatment system and equipment dimension that is appropriate to improve the performance of the existing of waste water treatment plant (WWTP) is based on maximum flow 150 m³/day. Secondary data from some literatures to calculate the size of the equipment dimension was also used.

Equalization basin dimension was determined based on design criteria reported by Ouano [11] and Wilson [16] that equalization tank should be sufficient to hold at least two hours of the detention time at the peak wastewater flow [8, 16]. Detention time can be calculated by equation 1 as stated as following [4, 8].

$$t_d = V/Q \quad (1)$$

Coagulation or rapid mixing basin dimension was determined based on design criteria of detention time values in the range of 30 – 120 second (s) and mean velocity gradient (G) values in the range of 250 – 1,500 per second (s⁻¹). Power required for rapid mixing is calculated by equations 2 and 3 stated as following [4, 8].

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

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

Flocculation basin was determined based on design criteria of detention time values in the range of 10 – 30 minutes and mean velocity gradient (G) values in the range of 20 – 80 s⁻¹ [4, 10]. Sedimentation basin (primary clarifier) determined is based on design criteria of primary settling having detention time values in the range of 1.5 – 4 hours with the overflow rate (OFR) of 20 – 60 m³/m².day [4, 11].

Trial operation of wastewater treatment plant and effluent quality monitoring

Trial operation of wastewater treatment was carried out after equalization, coagulation, flocculation, and sedimentation basins were constructed completely. Trial operation of

wastewater treatment was conducted based on jar test experiment results. The effluent quality of wastewater treatment was monitored for several months.

Analytical methods

The wastewater discharged from paper mill, effluent from sedimentation basin (primary clarifier), and effluent from aerated lagoon were taken and characterized for pH, COD, BOD₅, and TSS as per the American public Health Association (APHA) standard methods.

RESULTS AND DISCUSSION

Sources and characteristics of wastewater

The main source of wastewater of this paper mill is mostly comes from the excess white water coming out of the fibre recovery unit and a small portion comes from water used to wash equipment and floors. Table 1 shows that the pH of wastewater is a rather acidic and high TSS and COD concentrations. The acidic wastewater caused by aluminium sulphate (Al₂SO₄.18H₂O) residues used as chemicals additive in papermaking process which is carried out into wastewater. This residual aluminium sulphate is very useful as a coagulating agent in the coagulation process. Coagulation process can work well if the pH of wastewater is in the range of 5.5 to 8.0 [4, 7]. Therefore, the addition of alkaline chemicals such as caustic soda (NaOH) solution into wastewater is needed to raise the pH. This high TSS and COD concentrations in wastewater was came from celluloses and chemicals such as fillers used in the paper making process. It seems that most of the organic and inorganic substances in suspension were easily precipitated. Looking at the characteristics of wastewater, physics-chemical treatment such as coagulation, flocculation and sedimentation is necessary to reduce TSS concentration. This condition has influenced the treatment removal of aerated lagoon.

Effluent characteristics and their removal of aerated lagoon

Before upgrading of WWTP as shown in Figure 1, the wastewater come out of the paper production process is directly passed through into the aerated lagoon. In this case the aerated pond has functioned as reservoir, decomposing of organic pollutants substances and sludge sedimentation. Therefore, the main function of the aerated lagoon is to decompose organic pollutants substances which are not properly working caused by high TSS content as stated in Table 1. High TSS, COD, and BOD₅ contents of paper mill wastewater are very influential in treatment and removal of pollutants in aerated lagoon. Effluent concentration and removal of TSS, COD, and BOD₅ parameters resulted in from aerated lagoon which is shown in Table 1. Aerated lagoon could only remove TSS in the amount of 33-66% with the TSS concentration of 220– 1,300 mg/L. COD and BOD₅ removals are still low in amount of 20% each with their concentration of 762 – 2,344 mg/L and 330 – 1,144 mg/L, respectively. These effluent concentrations are still not complies with Indonesian effluent quality standard yet. To reduce their pollutant concentration, it requires the equalization basin to homogenize wastewater for both flow and concentration in primary treatment (coagulation, flocculation and sedimentation basins) units [10-12].

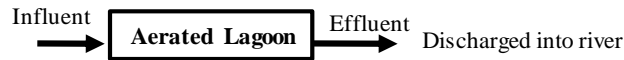


Figure 1. Flow diagram of wastewater treatment plant (WWTP) of paper mill before improvement

TABLE 1. Influent and effluent characteristics of aerated lagoon and their removal comparing with Indonesian effluent quality standard

Parameter	Aerated lagoon		Removal (%)	Indonesian effluent quality standard
	Influent	Effluent		
pH	4.08 – 6.30	6.40 – 6.75	-	6 – 9
TSS (mg/L)	650 – 1,950	220 – 1,300	33 – 66	100
COD (mg/L)	952 – 2,928	762 – 2,344	20	200
BOD ₅ (mg/L)	415 – 1,430	330 – 1,144	20	100

Determination of treatment system unit

a) Equalization basin

Detention time selection of equalization basin refers to design criteria reported by Ouano [11] and Wilson [16] that equalization tank should be sufficient to hold at least two hours of the detention time at the peak wastewater flow rate [11, 16]. In this design, it was set at four hours with the purpose to accommodate if this paper mill will increase the paper production. At maximum flow rate (Q) of 150 m³ per hour, volume of equalization basin is calculated by Equation 1 has total volume of 600 m³. The water depth was set at 3 m with the free board of 1 m so that the total depth of this equalization basin is 4 m. Length and width of equalization basin was set equal, so that the calculation result of length and width of equalization basin is 14.14 m each. To avoid precipitation of solids and to aerate wastewater, equalization basin is equipped with a surface aerator to stir wastewater and to get homogeneous characteristics before further treatment.

b) Coagulation/Rapid mixing basin

Rapid mixing basin was set for a residence time of 120 second and the velocity gradient (G) of 1,000 per second (s⁻¹) [8]. At maximum flow rate of 150 m³ per hour, volume of rapid mixing basin calculated by Equation 1 has the volume of 5 m³. Water depth was selected of 1.85 m so that this rapid mixing basin has the diameter (D_T) of 3.43 m. This rapid mixing basin was provided by 4 baffle mounted vertically at tank wall with the width of 0.3 m to avoid mass swirling of the liquid causing the decreasing the effectiveness of mixing [4, 8]. Using Equation 2 and data of rapid mixing volume (V), velocity gradient (G), and dynamic viscosity (μ) of wastewater at 30°C of 0.000798 Ns/m² [4, 8], motor power required (P) to rotate agitator in rapid mixing basin can be obtained of 3,390 watts or 5.32 horse power (hp). Using Equation 3 and data of power required (P), impeller constant (k) for turbine six flat blades of 6.30 [4, 8], revolution speed of agitator (N) of 1.67 revolution per second and density (ρ) of wastewater at 30°C of 995.7 kg/m³ [8], the impeller diameter (D_i) of rapid mixing can be obtained of 0.67 m. This impeller has central disk diameter of 0.5 m provided with the impeller blade length of 0.17 m and impeller blade width of 0.13 m. This impeller was mounted in the height of 0.67 m

from bottom [4, 8]. Sketch of turbine six flat blades impeller is shown in Figure 2.

c) Flocculation basin

Well design for flocculation basin, the Gt values, the multiplying of the velocity gradient (G) to detention time (t), should be from 10⁴ to 10⁵ [4, 8]. In this case to get strong flocks, flocculation basin was set for a detention time of 20 minutes (1,200 seconds) and high velocity gradient of 80 s⁻¹ so that the Gt values is in the amount of 96,000 [4, 10, 14]. Based on equation 1, detention time of 20 minutes and maximum flow rate (Q) of 150 m³ per hour, volume of the flocculation basin can be obtained of 50 m³. Water depth (H) and width of flocculation basin were set of 3 m each; the length of flocculation basin can be obtained of 5.6 m. Flocculation basin is equipped with vertical paddle-wheel agitator with slow rotation to get heavy flock which ease precipitate. Sketch of vertical paddle-wheel agitator is shown in Figure 3.

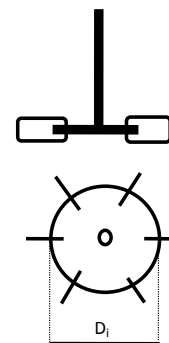


Figure 2. Sketch of turbine six flat blades impeller

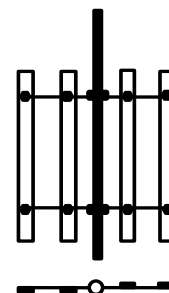


Figure 3. Sketch of vertical paddle-wheel agitator

d) Sedimentation basin (clarifier)

Sedimentation basin (clarifier) is design based on the overflow rate (OFR) of 20 – 60 m³/m².day [4, 13]. At maximum flow rate (Q) of 150 m³ per hour and the selected overflow rate of 24 m³/m² day, the surface area (A) of sedimentation basin (primary clarifier) can be calculated by Equation 4 stated as follows:

$$A = Q / OFR \tag{4}$$

By this equation the surface area (A) of sedimentation basin (primary clarifier) is 6.25 m². The diameter of clarifier can be calculated by equation 5 as the following.

$$A = \left(\frac{\pi}{4}\right) / D^2 \tag{5}$$

By this equation the diameter of clarifier is 8 m. This sedimentation basin is equipped with rake rotating slowly once to encourage solids settle in the bottom of the sedimentation basin.

Jar test experiment

Jar test experiment result indicates that the addition of 5 - 10% NaOH solution with doses of 50 - 240 mg/L into wastewater can increase pH of wastewater and the coagulation of colloids has begun to form small particles (fine flocks). The occurrence of the coagulation of suspended solid might be caused by the residual aluminum sulfate contained in

wastewater with sufficient quantities and it serves as a coagulant agent. In the coagulation process of wastewater of some types of paper making, it generally does not require additional of aluminum sulfate to coagulate their suspended solid as shown in Table 2. Then, to magnify fine flock into larger flock, the addition of 0.1% polyelectrolyte solution (PE) of cationic flocculants with a dose of 1.0 to 1.5 ppm in flocculation process. This process can produce flocks which are large and easy to settle.

Clear effluent is obtained after settling process. This 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 matter in the effluent. Thus, the total suspended solid will reduce in the effluent and the sedimentation rate of organic matter will also increase [3, 17]. Effluent quality and removal percentage of each parameter of jar test experiment result is shown in Table 2. This table shows that use of 5 - 10 % NaOH solution at dose of 50 – 240 ppm and 0.1% PE solution can raise the effluent pH of 6.2 – 7.7. In addition, the concentration of TSS, COD and BOD₅ also decrease upto in the range of 42 - 52 mg/L, 142 – 319 mg/L, and 68 – 163 mg/L, respectively. The removal efficiencies of 92 – 98%, 77 – 88%, and 76 – 85% can be obtained for TSS, COD and BOD₅ parameters, respectively.

TABLE 2. Effluent quality and removal percentage of jar test experiment

Paper type	NaOH solution (mg/L)			Influent					Effluent			Removal (%)		
	5% 10%		0.1%PE solution (mg/L)	pH	TSS (mg/L)	COD (mg/L)	BOD ₅ (mg/L)	pH	TSS (mg/L)	COD (mg/L)	BOD ₅ (mg/L)	TSS	COD	BOD ₅
	5%	10%												
A	200	-	1.0	5.4	1,435	1,928	925	7.7	42	229	135	97	88	85
B	-	70	1.0	5.3	1,515	952	428	6.8	47	142	68	97	85	84
C	-	240	1.5	4.6	1,768	1,054	464	7.4	45	240	113	97	77	76
D	50	-	1.0	6.3	1,950	1,080	518	7.7	42	252	126	98	77	76
E	50	-	1.0	4.5	660	1,762	863	6.2	52	319	163	92	82	81

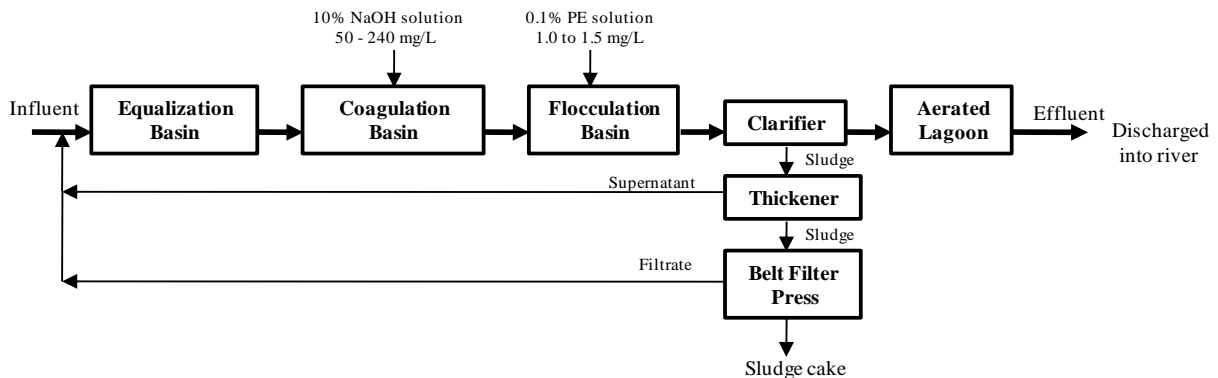


Figure 4. Flow diagram of improved wastewater treatment plant of paper mill

Effluent quality and performance of wastewater treatment plant (WWTP)

Dose of NaOH and PE solution from jar test experiment result was applied during trial operation of WWTP. The effluent quality of WWTP was monitored for several months as shown Figures 5 to 8. Figure 5 indicates the pH of sedimentation basin (clarifier) effluent of 6.02 – 8.72 is higher than that of influent pH of 4.08 – 6.54. pH of aerated lagoon effluent which is discharged into receiver water body of 6.12 – 6.97 has complied with Indonesian effluent quality standard of 6 – 9. Physico-chemical wastewater treatment applied has resulted in high removal of TSS, COD and BOD₅ parameters. TSS removal upto 97% and TSS concentration of 28 – 60 mg/L reached to clarifier effluent. While effluent of aerated lagoon has TSS concentration (35 – 91 mg/L); a little bit higher than that of clarifier effluent due to lack of proper operation of the aerated lagoon. However, it has met with Indonesian effluent quality standard of 100 mg/L (Figure 6). Thus, total removal for TSS parameter is in the amount of 95 – 98%. Effluent clarifier contain COD concentration of 172 – 132 mg/L with the removal efficiency of 87 – 88%. While COD concentration contained in the aerated lagoon effluent discharged into environment is in the range of 125 – 222 mg/L. It generally has met with Indonesian effluent quality standard of 100 mg/L as shown in Figure 7. Total removal for COD parameter is in the amount of 88 – 91%. In this case, aerated lagoon only remove COD parameter in the amount of 1 – 3%.

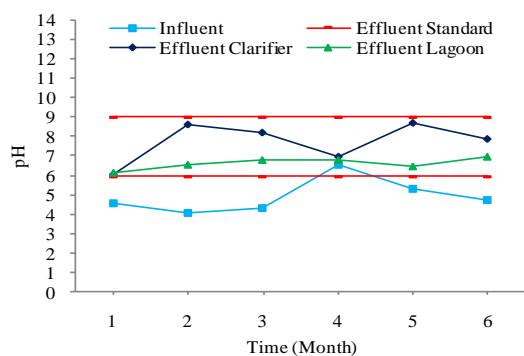


Figure 5. pH of influent and effluent

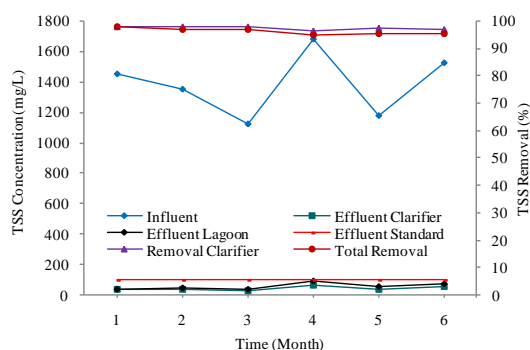


Figure 6. Concentration and removal of TSS

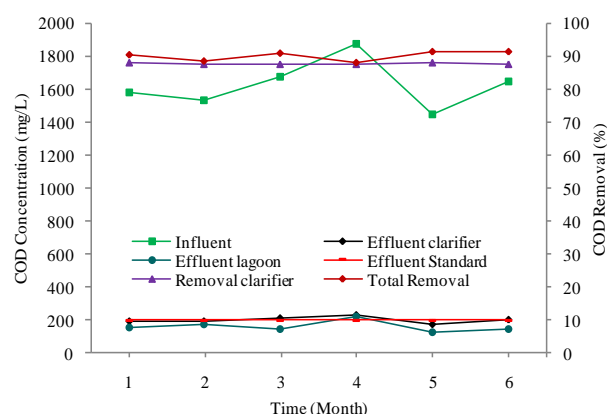


Figure 7. Concentration and removal of COD

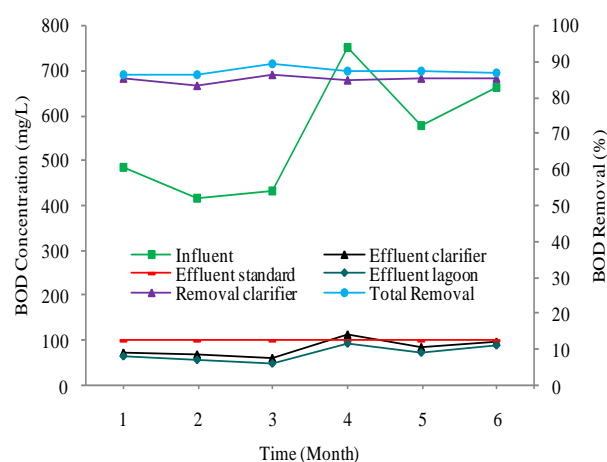


Figure 8. Concentration and removal of BOD₅

The BOD₅ concentration of clarifier effluent is 59 – 115 mg/L; the removal efficiency is 83 – 86%. Whereas, the aerated lagoon effluent contain BOD₅ concentration of 47 – 94 mg/L. It has complied with the Indonesian effluent quality standard of 100 mg/L as shown in Figure 8. Total removal for BOD₅ parameter is in the amount of 86 – 89%. In this case, aerated lagoon only remove BOD₅ parameter in the amount of 3%.

CONCLUSIONS

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

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Persian Abstract

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چکیده

کارخانه چوب و کاغذ چندین نوع کاغذ تولید می نماید که تصفیه فاضلاب با استفاده از سیستم لجن فعال و هوادهی برای حذف آلاینده های خود بهرمنداست. اما راندمان حذف این سیستم همچنان پائین است به طوری که پساب هنوز هم با استانداردهای کیفیت مطلوب طبق شاخص آندونزیایی از استانداردهای کیفیت پساب مطابقت ندارد. این کارخانه قبل از تصفیه و قبل از استفاده از سیستم لجن فعال به هوادهی نیاز دارد. تلاش برای بهبود عملکرد تصفیه خانه فاضلاب، مطالعه ویژگی های فاضلاب، تصفیه فاضلاب، ایجاد سیستم های تصفیه و طراحی تجهیزات صورت گرفته است. پس از ساخت و میبها نمودن سیستم نمونه پساب، بصورت آزمایشی در تصفیه خانه فاضلاب و با استفاده از انواع فاضلاب از کارخانه کاغذ تهیه گردید. نتیجه آزمایش آزمایشگاهی نشان داد که کارخانه کاغذ نیاز به تصفیه فاضلاب با سیستم فیزیکی شیمیایی قبل از تصفیه با سیستم لجن فعال با هوادهی دارد. نتایج آزمایش تصفیه فاضلاب نشان داد که حذف مواد جامد معلق 97 (TSS)٪، COD 88 ٪، BOD5 85 ٪ و pH 6.2 تا 7/7 با استفاده از محلول 5 تا 10٪ NaOH در دوزهای 50-240 میلی گرم در لیتر و 1/1٪ محلول پلی اتیلن الکترولیتی کاتیونی (PE) به عنوان فلوکلانانت در دوز 10 تا 15 میلی گرم بر لیتر نائل گردید. استفاده از واحد تصفیه فیزیکی و شیمیایی می تواند بار آلی فاضلاب را در تصفیه لجن فعال با هوادهی را آسان سازد. کیفیت مطلوب پساب های لجن هوادهی می تواند به محیط زیست منتقل می شود، که مطابق با استانداردهای کیفیت آندونزیایی خواهد بود.