



Chemical Treatment in Industrial Wastewater of Polyester Synthetic Fiber Made from Recycled Polyethylene Terephthalate Bottles: Minimize Environmental Impacts

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ABSTRACT

The polyester synthetic fiber (PSF) industry has recycled polyethylene terephthalate (PET) bottle into raw material and converted them into economically valuable textile materials. This study was aimed to provide an overview of wastewater treatment from PSF industry in minimizing its impact on the environment. The study of wastewater treatment from PSF industry has been carried out in chemical-physical treatments. The Jar Test experiment has been conducted with coagulant and flocculant addition into 1000 mL of wastewater inside a 1 L beaker glass. Wastewater was treated with 3 coagulants and flocculant doses varied in the range of poly aluminum chloride (PAC) 175-225 mg/L and PE 0.25 mg/L. The results showed that the dose utilization of 200 mg/L of 5% PAC coagulant solution and 0.25 mg/L dose of 0.02% poly electrolyte (PE) flocculant solution could produce a treated wastewater that has complied with the effluent quality standards. The application of this optimum dose can reduce wastewater pollutants substances of PSF industry which can minimize its impact on the environment.

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INTRODUCTION¹

The world's population consumes one million plastic bottles in every minute. Large amounts of polyethylene terephthalate (PET) plastic bottle waste are disposed on the landfills every year. It has been reported that the annual world production rate of PET plastic were 41.56 and 73.36 million tons in 2014 and 2020, respectively [1]. Plastic bottles are considered non-biodegradable waste because of their long decomposition time. Even if the amount of converted PET plastic bottles waste is less than 10%, the initiative of the textile industry to convert it into polyester fabrics nonetheless will help to protect our planet and future [2, 3].

After cleaning and treatment processes, the recycled PET plastic bottle waste may become new materials with economic value. At the recycling plant, Polyethylene Terephthalate (PET) bottle waste will be processed into dacron, strapping band, and geotextile materials. One of

the recycled material results from PET bottle is polyester synthetic fiber (PSF) which has a resembling shape of synthetic cotton. This material will be marketed in three forms, namely solid fiber, hollow conjugate (HC), or hollow conjugate silicon (HCS) [4-6].

The PSF production process may consist of several stages including the washing process of the recycled PET plastic bottle to remove glue, paper labels, dirt and contained product. Washing process was carried out at an ambient temperature of 90°C for 12 minutes. Detergent and NaOH were usually utilized as washing solution to remove dirt, oil and protein. Clean PET plastic bottles are then chopped into small flakes and dried. The drying process of PET bottle flakes was conducted to reduce moisture content into a maximum of 2%. Dye, brightening optical and titanium dioxide were added in this process, to make PET bottle flakes visibly look brighter and cleaner. The dry PET flakes were then spun. The spinning process begun with transferring the PET

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bottle flakes from the fill hopper to the screw extruder. In the screw extruder, PET bottle flakes were heated, melted and pressed through a spinnerete which will produce plastic fiber filaments. The plastic fiber filaments were sprayed with water to prevent sticking to each other and then cut with a blade [2, 5-8].

PSF industry is usually equipped with production support facilities, such as boilers and oil heaters to support the heat washing process, the spinning process, and the wastewater treatment plant [5]. In the plastic recycling process, wastewater containing high concentrations of COD was produced which must be treated first before being discharged into the environment. Wastewater effluent discharged into the environment/water body must follow the effluent quality standard requirements for textile industry wastewater based on the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number P.16/2019.

Wastewater treatment of PSF industry may be conducted through chemical treatment by a coagulation-flocculation process. The coagulation process is a process of destabilizing particles using coagulants to form small agglomerates. Flocculation is a process in which particles formed as a consequence of destabilization to form a larger agglomerate. The coagulation-flocculation process is one of the best options for treating industrial wastewater. The coagulants are including aluminum sulfate, ferric chloride, lime, iron sulfate, and polyaluminum chloride (PAC). The coagulation-flocculation process is considered as one of the methods of industrial wastewater treatment which is efficient in reducing the concentration of COD, TSS and color. The main advantage of chemical treatment process is that most of COD and TSS contents are reduced thus the secondary treatment will be more cost-effective [9-11]. The PAC polymer coagulant has a better ability to reduce wastewater pollutants, especially color parameter than the Aluminum Sulfate ($Al_2(SO_4)_3$) coagulant because of its polymer form with long and branched chain thus may capture more colloid particles [12, 13]. In addition, it is also more beneficial for the industry not only due to its cost minimization for reducing color and COD, but also for minimizing the environmental impact [11, 12, 14, 15].

Wastewater which causes surface water coloration is aesthetically undesirable and causes disruption of the aquatic biosphere due to sunlight penetration decrement and dissolved oxygen depletion. In addition, colored compounds also may contribute to the failure of biological wastewater treatment processes. Biological processing was generally less capable in reducing color, but the much more capable to reduce in BOD and COD. Therefore, the wastewater effluent from activated sludge, a biological treatment process, may still contain high color and COD content [11, 15]. In addition, biological treatment/activated sludge, may take high energy consumption, generates large amounts of sludge

production, and raises operational problems including color, foaming, and bulking in secondary clarifiers [9, 10, 12, 13].

Chemical wastewater treatment is usually operated using a sequential treatment combination of a coagulation process using a coagulant followed by a flocculation process using a flocculant. The main function of flocculants, which consist of very high mass polyelectrolytes and usually cationic charges, is to collect small flocks into large flocks [12, 16]. The wastewater chemical treatment process might serve as either single process of primary chemical treatment or as a pre-treatment stage before biological treatment [17]. The coagulation process using lime at a dose of 1400 mg/L could reduce the turbidity of wastewater by 94%, a decrease in COD by 86%, a decrease in TSS by 93%, a decrease in TDS by 78% and a decrease in color by 91.6% [18]. Wastewater treatment for washing recycling PET bottles with coagulation-flocculation treatment using 4 mg/L of $FeCl_3$ (4%) coagulant solution as much as and 0.8 mg/L of Polyelectrolyte (PE) (0.2%) flocculant solution, may reduce COD by 58.28% [19, 20].

The study of chemical treatment for the wastewater of PSF industry is presented in this paper. The effect of coagulant and flocculant dose combinations on the quality of treated wastewater is also described. This study aims to provide an overview of wastewater treatment for PSF industry which raw material was PET plastic waste in minimizing the impact on the environment.

MATERIAL AND METHODS

The wastewater used in the experiment was wastewater from the PSF industry which is using recycled PET bottles as raw materials. The plant located in West Java Province, Indonesia, with wastewater discharge was <100 m³/day. The chemicals used were 10% PAC solution as a coagulant and 0.02% cationic poly electrolyte (PE) solution as a flocculant.

The Jar Test experiment used 1000 mL of the target wastewater, which was put into a 1 L beaker glass with coagulants and flocculants addition. Wastewater was treated with 3 variety of coagulant and flocculant doses which are P1: 175 mg/L PAC and 0.25 mg/L PE; P2: 200 mg/L PAC and 0.25 mg/L PE; and P3: 225 mg/L PAC and 0.25 mg/L PE. The process of coagulation of wastewater was carried out with a stirring rotation of 100 rpm for 2 minutes and the flocculation process was carried out with a stirring rotation of 40 rpm for 15 minutes. After the flocculation process was complete, the stirring process was stopped and the resulting mixture of wastewater was left for about 2 hours for the sedimentation process, separating the treated wastewater and the sludge.

The quality of wastewater before and after being chemical treatment was analyzed by methods for the

parameters of BOD₅ (iodometric-titrimetric), COD (sealed digestion and spectrometric), TSS (filtration-gravimetric), Phenol (colorimetric), Chromium (Atomic Absorption Spectrometry), NH₃-N (distillation-titrimetric), Sulfide (ion-selective electrode), Oil and Grease (*n*-Hexane extraction), pH (electrometric) and color (spectrophotometric) as per the American Public Health Association (APHA) standard methods [21].

RESULTS AND DISCUSSION

Wastewater quality before treatment

The quality of untreated wastewater that originated from the PSF industry which is using recycled PET plastic bottle is shown in Table 1. This PSF industry does not have an adequate wastewater treatment plant (WWTP) installed yet.

The pH, phenol, chromium, ammonia and sulfide parameters have complied with the quality standards based on Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number P.16/2019 for the textile industry which produces wastewater with a discharge of < 100 m³/day. However, other parameters such as parameters BOD₅, COD, TSS, oil, grease and color are still above the standard requirements. Before being released, PSF industry wastewater contains high levels of pollutants, both organic and inorganic compounds, as indicated by the COD, BOD₅ and TSS parameters, which need to be treated first before being discharged into the environment to avoid negative impact on the environment. The quality of PSF industrial wastewater is slightly lower than that reported by Santos et.al. [22] which was PET bottle washing wastewater which has COD 750-983 mg/L, TSS 732-1136 mg/L and turbidity 280-330 NTU. The turbidity and COD value co-

maintained in wastewater are influenced by the amount of surfactant used. From the results of the characterization, it may be seen that several parameters have not been able to comply the quality standards, namely: BOD₅, COD, TSS, and Color. The next study will discuss the four parameters with the addition of pH because it may affect the effectiveness of the coagulation-flocculation process.

Effect of coagulant and flocculant doses treatment on the quality of treated wastewater

The results of wastewater treatment with chemical treatment with the codes P-1, P-2 and P-3 for parameters of pH, COD, BOD₅, TSS and color can be seen in Figures 1, 2, 3, 4 and 5, respectively. All of the treated wastewater with three doses variations has neutral pH value, which are in the range of 7.1-7.3. All of them are in the range of effluent standard requirements for pH which is 6 - 9 (Figure 1).

The wastewater quality of all three treatment variations (P-1, P-2 and P-3), have complied with effluent quality standard requirements for COD parameters < 150 mg/L (Figure 2). However, wastewater quality with low-

Table 1. Characterization of raw wastewater before treatment

No.	Parameter	Concentration	Effluent Quality Standards (EQS)
1	BOD ₅ , mg/L	264	60
2	COD, mg/L	579	150
3	TSS, mg/L	269	50
4	Phenol, mg/L	0.26	0.5
5	Chromium, mg/L	0.05	1
6	Ammonia (NH ₃ -N), mg/L	5.4	8
7	Sulfide (S ²⁻), mg/L	0.06	0.3
8	Oil and Grease, mg/L	4.4	3
9	pH	6.8	6 - 9
10	Color, Pt-Co	345	200
11	Discharge, m ³ /day	< 100	100

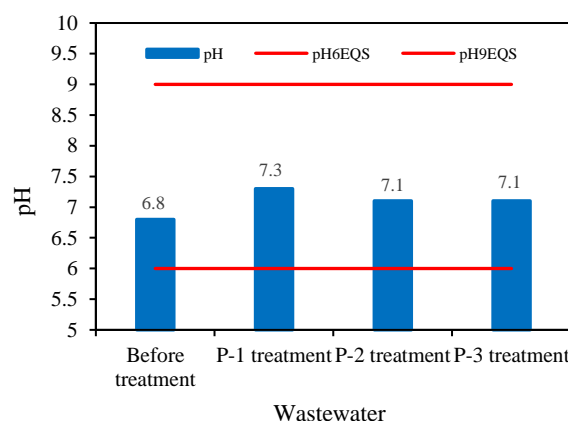


Figure 1. pH of wastewater before and after treatment

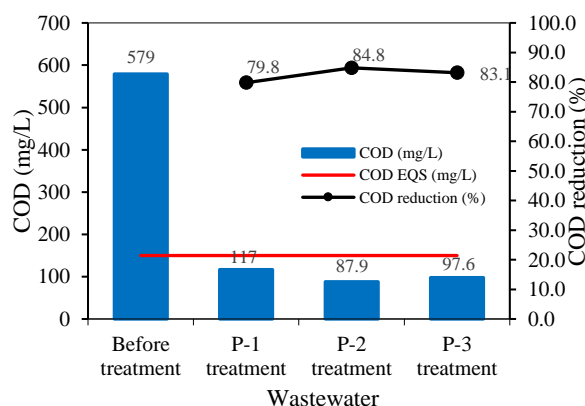


Figure 2. COD wastewater before and after treatment

est COD value of 87.9 mg/L (and highest COD reduction: 84.5%) may be obtained with P-2 treatment, which was using 200 mg/L of 5% Poly Aluminum Chloride (PAC) coagulant solution and 0.25 mg/L of 0.02% Poly Electrolyte (PE) flocculant solution.

All three treatment variations, could reduce BOD₅ parameters by 92.7 - 93.1% from the untreated wastewater, with the remain concentration of BOD₅ parameters for treated wastewater is around 18.2 - 19.3 mg/L, which already below the effluent quality standard for the BOD₅ parameter, which is < 60 mg/L (Figure 3).

The TSS concentration of treated wastewater with P-1, P-2 and P-3 variations was already very low, which is around 5.4-7.5 mg/L, already far below the effluent quality standard for TSS parameters < 50 mg/L (Figure 4). The P-1, P-2 and P-3 treatment variations were able to reduce TSS concentrations by 97.2 - 98.0%.

Wastewater treatment with P-1, P-2 and P-3 treatment variations could reduce color by 84% with a color value of 55 Pt-Co. The color value of treated wastewater is already below the quality standard requirements for color parameters < 200 Pt-Co (Figure 5).

When the color of untreated wastewater was compared to the treated wastewater, the comparison showed a big gap from brown color at the untreated wastewater, and clear color for the treated wastewater. Visually, the treated wastewater showed almost a comparable color with the color of tap water which has a color value of 28 Pt-Co (Figure 6).

This phenomenon occurs due to the entry of positively charged coagulant chemicals into wastewater containing negatively charged suspended solid particles. These negatively charged suspended solids are generally responsible for the coloration of wastewater. The ionic interaction between the positively charged coagulant chemicals and negatively charged suspended solid particles, destabilization occurs which could precipitate. This phenomenon could be described at Figure 7.

From the description above, it seems that the wastewater from P-2 treatment variation which using doses of 200 mg/L of 5% poly aluminum chloride (PAC) coagulant solution and 0.25 mg/L of 0.02% poly electrolyte (PE) flocculant solution, showed an optimum treated wastewater quality from all three treatment variat-

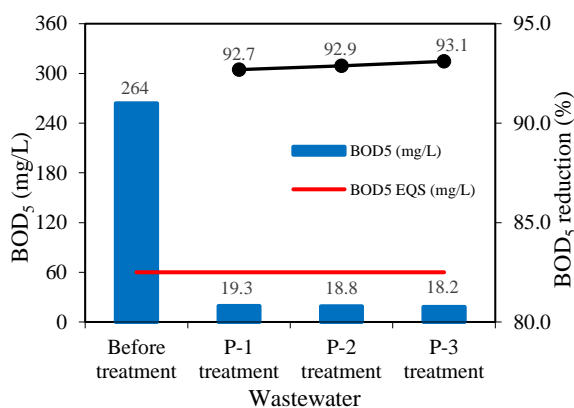


Figure 3. BOD₅ wastewater before and after treatment

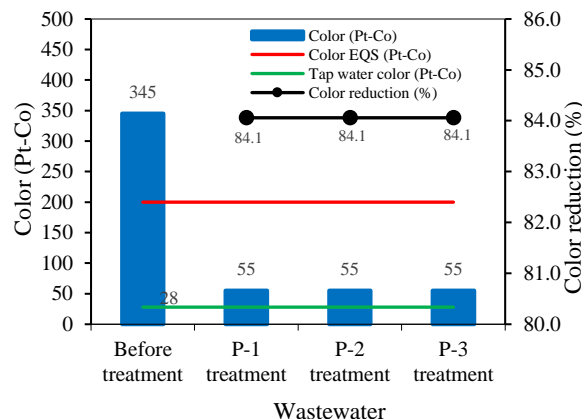


Figure 5. Color of wastewater before and after treatment

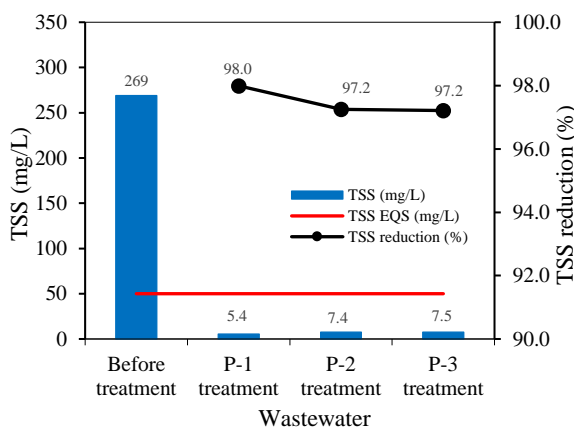


Figure 4. TSS of wastewater before and after treatment

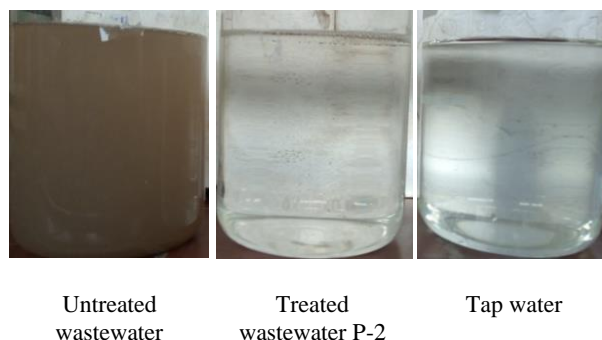


Figure 6. Color of untreated wastewater and treated wastewater compared with tap water

ions, as shown in Table 2. The quality of treated wastewater also complies with the quality standard requirements for the PSF industry which produces wastewater with a discharge of 100-1000 m³/day (Table 2).

PSF industrial wastewater treatment variation with this optimum dose was better than a similar study reported by Zainuddin et al. [20] for wastewater treatment from recycling PET bottles washing process using 4 mg/L of 4% FeCl coagulant solution and 0.8 mg/L of polyelectrolyte (PE) flocculant solution which could reduce COD by 58.28%. Furthermore, the optimum wastewater treatment results from this study almost comparable with the results reported by Mehmood et al. [18] using 1,400 mg/L of lime which could decrease the turbidity of wastewater by 94%, decreased COD of wastewater by 86%, decreased TSS of wastewater by 93%, and decreased color of wastewater by 91.6%.

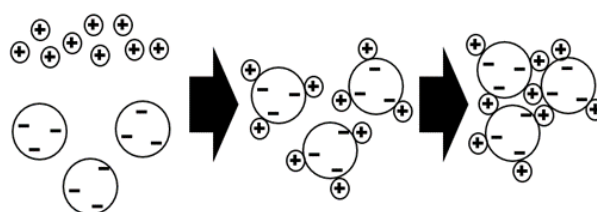


Figure 7. Phenomenon of coagulation [11, 16]

Table 2. Quality of treated wastewater by treatment P-2

No.	Parameter	Concentration	Effluent Quality Standards
1	BOD ₅ , mg/L	18.8	45
2	COD, mg/L	87.9	125
3	TSS, mg/L	7.4	40
4	Phenol, mg/L	0.26	0.5
5	Chromium, mg/L	0.05	1
6	Ammonia (NH ₃ -N), mg/L	5.4	8
7	Sulfide (S ²⁻), mg/L	0.06	0.3
8	Oil and Grease, mg/L	1.06	3
9	pH	7.1	6 - 9
10	Color, Pt-Co	55	200
11	Discharge, m ³ /day	< 100	100 - 1000

CONCLUSION

BOD₅, COD, TSS, oil and grease, and color parameters from wastewater of PSF industry which using recycled PET bottle as raw materials, were not complied with the quality standard requirements. The wastewater needs to undergo a series of treatment before being discharged into the environment to avoid negative impact. Chemical

treatment of PSF industry wastewater using 200 mg/L of 5% poly aluminum chloride (PAC) coagulant solution and 0.25 mg/L of 0.02% poly electrolyte (PE) flocculant solution could produce a treated wastewater complying with the effluent quality standard for textiles industry producing wastewater with a discharge of < 1000 m³/day. Decreasing of wastewater pollutants substances of PSF industry could be minimized its impact on the environment.

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Persian Abstract

چکیده

صنعت الیاف مصنوعی پلی استر، بطری پلی اتیلن ترفتالات را به ماده اولیه بازیافتی و به مواد نساجی با ارزش اقتصادی تبدیل کرده است. این مطالعه با هدف ارائه یک نمای کلی از تصفیه فاضلاب صنعت الیاف مصنوعی پلی استر در به حداقل رساندن تأثیر منفی آن بر محیط زیست انجام گردید. مطالعه تصفیه فاضلاب از صنعت الیاف مصنوعی پلی استر در تیمارهای شیمیایی-فیزیکی انجام شده است. آزمایش Jar Test با افزودن لخته کننده و انعقادی به ۱۰۰۰ میلی لیتر فاضلاب درون یک بشر ۱ لیتری انجام شده است. فاضلاب با ۳ منعقد کننده تصفیه شد و دوزهای لخته ساز در محدوده پلی آلومینیوم کلراید (PAC) ۱۷۵-۲۲۵ میلی گرم در لیتر و ۰.۲۵ PE میلی گرم در لیتر متفاوت بود. نتایج نشان داد که استفاده از دوز ۲۰۰ میلی گرم در لیتر محلول انعقادی ۵٪ PAC و ۰.۲۵ میلی گرم در لیتر دوز ۰.۰۲٪ محلول لخته ساز پلی الکترولیت می تواند فاضلاب تصفیه شده ای را تولید کند که با استانداردهای کیفیت پساب مطابقت داشته باشد. استفاده از این دوز بهینه می تواند باعث کاهش آلاینده های فاضلاب در صنایع الیاف مصنوعی پلی استر شود و می تواند تأثیر منفی آن را بر محیط زیست به حداقل برساند.