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Characterization of Alum Sludge from Surabaya Water Treatment Plant, Indonesia

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ABSTRACT

A conventional water treatment plant (WTP) typically involves coagulation-flocculation processes to remove suspended particles and colloids in raw water. The process generates a large volume of alum sludge with high aluminum content, which is discharged into a river with improper treatment. The sludge may cause a potential risk to human health, and disrupt the life of river biota. The aims of this study were to determine the physical and chemical characteristics of alum sludge from Surabaya WTP, and to compare them with those of alum sludge from other plants in Indonesia and developing countries. The alum sludge sample was obtained from the Surabaya WTP in Indonesia. The results showed that the alum sludge had a pH value of 7.47, volatile solids of 12,696 mg/L, total suspended solids of 12,511 mg/L, chemical oxygen demand (COD) 9666.7 mg/L, biochemical oxygen demand (BOD) 1082.5 mg/L, and sludge volume index 114.18 mL/g. The sludge had high aluminum and iron concentrations. The aluminum content of the sludge was 1194 mg/L, iron 515 mg/L, chromium 0.217 mg/L, and copper 0.559 mg/L. Having a BOD/COD ratio of 0.1, the alum sludge contained high level of non-biodegradable organic matter.

Keywords: aluminum sludge, characteristics, comparison, water treatment

INTRODUCTION

The Surabaya water treatment plant (WTP) is one of municipal water supply companies in Indonesia, where conventional process is applied. The conventional WTP uses coagulation, flocculation, sedimentation, filtration, and desinfection process stages. The coagulation-flocculation process aims at removing suspended particles and colloids in raw water [Ahmad et al., 2016]. This WTP uses aluminum sulfate (Al_2SO_4), or alum, as coagulant. This is because alum is hydrolyzed readily in water to form neutral alum hydroxide in which colloid settles into precipitated hydroxide [Ahmad et al., 2016]. The use of Al_2SO_4 as a coagulant in water treatment process causes the sludge to contain aluminum, commonly referred to as alum sludge [Cherifi et al., 2016]. The process requires a particular amount of coagulant, which produces a large volume of sludge or residues [Keeley et al., 2014]. In general, the alum sludge from accelator drains in Indonesia is discharged directly into river without further treatment. The Surabaya WTP discharged about 626 m^3/day of alum sludge into the Surabaya river [Primadipta and Titah, 2017].

Previously, researchers reported that the alum sludge contained high aluminum concentration of 250 mg/L in dry weight of sludge [Primadipta and Titah, 2017; Liu et al., 2016]. Ahmad et al. [2016] added that the water content in wet alum sludge was about 80%, whereas Tantawy [2015] stated that the sludge contained hydroxide precipitates of heavy metals and organics Alum sludge has a neutral pH, low organic, and high aluminum, iron, calcium, and silica contents [Ahmad et al., 2016]. It also contained some heavy metals, such as chromium, cadmium, lead, zinc, and copper [He et al., 2014].

The alum sludge, which is discharged into rivers might cause siltation, potential risk to human health, and disrupt the life of river biota due to the high aluminum and heavy metal contents [Tantawy, 2015]. Alum sludge is commonly dumped in landfills after dewatering because of low cost operation [Keeley et al., 2014]. These authors further stated that the heavy metal contents in alum sludge were considered safe, because the concentrations were lower than those of industrial wastewater treatment sludge. However, the disposal of alum sludge in landfills should be avoided due to stringent environmental regulations. It relates to the impacts of heavy metal leakage from the sludge, and the need of extensive landfill area for disposal. The toxic effects of inorganic aluminum to some species occurred under the pH conditions of less than 6 [Mortula et al., 2009]. This study aimed at determining the physical and chemical characteristics of alum sludge from the Surabaya WTP and to comparing the results with those of alum sludge from other WTPs in Indonesia and other developing countries.

MATERIALS AND METHODS

Fresh alum sludge was collected from several accelator drains at the Surabaya WTP. The samples were collected using the grab method every two days over a two-week sampling period in 2018. The alum sludge was characterized according to the physical and chemical parameters. The measured physical parameters were temperature, sludge density, pH, moisture content, volatile solids (VS), total suspended solids (TSS), total solids (TS), total dissolved solids (TDS), and sludge volume index (SVI). The measured chemical parameters were Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), alkalinity, aluminum, iron, lead, chromium, and copper concentrations. These analyses were performed in triplicate, according to the standard methods as shown in Table 1 [APHA, 2012]. The Al, Fe, Pb, Cr, and Cu concentrations in the dried sludge were measured using *X-Ray Fluorescence* (XRF) instrument Thermo Scientific 9900 Series XRF.

RESULTS AND DISCUSSION

Table 2 shows the physicochemical characteristics of the alum sludge. The results were compared with the effluent standards according to the State Ministry for the Environment

Table 1. Sludge characterization methods

No.	Parameter	Methods/Instruments	Sources
1	Temperature	Thermometer	APHA, 2012
2	pH	pH meter	
3	Moisture content, VS, TS, TSS, TDS	Gravimetric	
4	SVI	Imhoff cone	
5	BOD5	5 day BOD test	
6	COD	Open reflux, titrimetric method	
7	Alkalinity	Titration method	
8	Al, Fe, Pb,Cr, Cu	X-Ray fluorescence (XRF)	

Decree No. 5/2014 concerning Quality Standards of Wastewater, and Goverment Regulation No. 20/1990 concerning Water Quality Management and Water Pollution Control.

The comparison of alum sludge characteristics from WTPs in Indonesia and other developing countries is shown in Table 3. Table 4 shows raw water characteristics for every WTPs.

Temperature, density, and pH

The average temperature of the alum sludge was 25.33°C during the sampling period in rainy season 2018. The typical temperature of alum sludge from some WTPs in Indonesia and in Morocco was in a range of 26.33–28.9°C (Table 3). The measured temperatures reflected the influence of the regional climate with a value not far from the ambient air temperature of 25–27°C.

The average density of alum sludge was 0.97±0.02 ton/m^3 (Table 2). This value was slightly different from those in other WTPs in Indonesia and Malaysia of 1.01 and 0.83 ton/m^3, respectively. The highest density was that of Pejompongan WTP in Jakarta of 1.01 ton/m^3. Alum sludge density was important for the performance of a sludge dewatering system. As the density increases, dewatered solids concentrations increase likewise. The alum sludge density is influenced by raw water quality. It appears to increase along with the turbidity of the raw water.

The alum sludge has an average pH value of 7.47±0.004 (Table 2). This value is in accordance to typical pH of alum sludge from some WTPs in Indonesia and the other compared countries, which were in a range of 6.0–7.5 (Table 3). This value met the effluent standards for pH of 6–9 (Table 2).

Total suspended solids and volatile solids

The TSS concentration of the alum sludge was 12,511±235.66 mg/L (Table 2). This value was far above the effluent standards for TSS of 200 mg/L (Table 2). The high value of TSS in alum sludge was influenced by raw water quality, which had a high TSS content of 1000 mg/L (Table 4). TSS content in Surabaya River was highly exceeded from the stream standards of water class I of 50 mg/L (Table 4). The highest TSS in alum sludge of 39,000 mg/L was reported from Bouregreg WTP in Morocco. This value was influenced by the high TSS of the raw water from R'dom River of 421 mg/L.

Together with the characteristics of alum sludge from Bouregreg WTP in Morocco, the average VS value was the highest (12,696±263.3 mg/L) (Table 3). This might be caused by heavy industrial and domestic waste pollution in sources [El Rhaouat et al., 2014]. The ratio of VS/TSS of the sludge sample is 1.01. This value represents the sludge characteristic which has high organic content higher than the 0.5 limit [He et al., 2014]. This condition must be considered in recovering aluminum from the WTP sludge. In turn, the VS/TSS ratio of the sludge from Bouregreg WTP, Morocco was 0.32. This value represents the higher mineral contents than that of the organics.

BOD and COD

The average BOD and COD values of the alum sludge were 1082.5±106.1 mg/L and 9666.7±942.8 mg/L, respectively (Table 2). These values were higher than those of Pejompongan WTPs I (22.13 mg/L; 416 mg/L) and II (12.8 mg/L; 174.72 mg/L) in Jakarta (Table 3). It was influenced by the discharge of domestic and industrial wastewater along the river. These results showed that the BOD and COD values of the alum sludge in some Indonesian WTPs highly exceeded the effluent standards of 50 mg/L and 100 mg/L, respectively (Table 3).

The BOD/COD ratio of alum sludge was 0.11, which indicated that the organic matter in the alum sludge was not of biodegradable form.

Table 2. Results of characterization of alum sludge from Surabaya WTP

No	Parameters	Results				Effluent standards [*]
		1	2	3	Average	
1	Temperature (°C)	25	25	26	25.33 ± 0.58	-
2	Density (g/mL)	0.99	0.95	0.98	0.97 ± 0.02	-
3	pH	7.47	7.46	7.47	7.47 ± 0.004	6 – 9
4	Moisture content (%)	99.1	98.4	99.8	99.08 ± 0.005	-
5	Volatile solids (mg/L)	12,330	12,816.7	12,940	12,696 ± 263.3	-
6	Total solids (%)	0.9	1.6	0.2	0.9 ± 5.89	-
7	Total suspended solids (mg/L)	12,300	12,393.3	12,840	12,511 ± 235.66	50
8	Total dissolved solids (mg/L)	346.4	370.4	341.5	352.76 ± 12.615	1000
9	Total fixed solids (mg/L)	10,623.3	11,036.7	11,226.7	10,962 ± 251.9	-
10	COD (mg/L)	11,000	9000	9000	9666.7 ± 942.8	10
11	BOD (mg/L)	1186.6	936.8	1124.1	1082.5 ± 106.1	2
12	Sludge volume index (mL/g)	100.8	136.9	104.9	114.18 ± 16.142	-
13	Alkalinity as HCO_3^- (mg/L)	62.5	75	75	70.83 ± 5.892	-
14	Al (mg/L)	-	-	-	1194	-
	% (DW)				12.61	
15	Fe (mg/L)	-	-	-	515	0.3
	% (DW)				5.54	
16	Pb (mg/L)	-	-	-	ND	0.03
	% (DW)				ND	
17	Cr (mg/L)	-	-	-	0.217	0.05
	% (DW)				0.0023	
18	Cu (mg/L)	-	-	-	0.559	0.02
	% (DW)				0.0059	

ND – not detected; DW – dry weight;
[*] Decree of State Ministry for the Environment of the Republic of Indonesia No. 5/ 2014 concerning Quality Standards of Wastewater.

On the basis of this ratio, the physicochemical technology is required for the alum sludge treatment. The BOD/COD ratio value provides an important indication of the pollution origin of the raw water source. This value can also be used to determine the proper technology for sludge treatment [El Rhaouat et al., 2014].

Aluminum and Other Metal Contents in Dewatered Alum Sludges

The results of XRF analyses of the dried sludge showed very high aluminum and iron concentrations of 12.61% (or 1194 mg/L fresh sludge) and 5.54% (or 515 mg/L fresh sludge), respectively (Table 2). These values are much higher than the effluent standards for aluminum (0.2 mg/L) and iron (5 mg/L). The most common metal component in dewatered alum sludge in all WTPs is aluminum. The concentration ranges from 15.41 to 1,194 mg/L (Table 3). High aluminum concentrations of alum sludge in some WTPs in Indonesia and in other developing countries occurred because of the use of Al_2SO_4 in flocculation and coagulation process. The second main metal constituent in the sludge was iron, which might have originated from soil sediment. The high iron content in drinking water sludge

Table 3. Comparison of physicochemical characteristics of alum sludge from WTPs in Indonesia and other Developing Countries

Parameter	Sludge characteristics								
	Surabaya WTP, Indonesia (*)	Tirta Pakuan, Bogor, Indonesia [1]	Cibinong, Indonesia [2]	Buaran, Jakarta, Indonesia [2]	Pejompongan I, Jakarta, Indonesia [1]	Pejompongan II, Jakarta, Indonesia [1]	Semanggar WTP, Malaysia [3]	Ghaziabad WTP, India [4]	Bouregreg WTP, Morocco [5]
Temperature (°C)	25.33 ± 0.58	-	27.5	-	28.8	28.9	-	-	27
Density (kg/m^3)	0.97 ± 0.02	-	-	-	1.01	1.01	0.83	-	-
pH	7.47 ± 0.004	7.13	6.69	-	6.68	6.74	6	6.82	7.5
Moisture content (%)	99.08 ± 0.005	50.68	-	-	-	-	28.67	89.78	-
Volatile solids (mg/L)	12,696 ± 263.3	-	-	-	3520	2360	1570.33	2660	12,700
Total solids (%)	0.9 ± 5.89	-	-	-	-	-	-	-	-
Total suspended solids (mg/L)	12,511 ± 235.66	-	-	-	2910	3560	-	-	39,000
Total dissolved solids (mg/L)	352.76 ± 12.61	-	-	-	135.71	128.57	-	-	-
Total fixed solids (mg/L)	10,962 ± 251.9	-	-	-	-	-	-	-	-
COD (mg/L)	9666.7 ± 942.8	-	-	-	416	174.72	-	-	-
BOD (mg/L)	1082.5 ± 106.1	-	-	-	22.13	12.8	-	-	-
Sludge volume index (mL/g)	114.18 ± 16.14	-	-	-	-	-	-	-	-
Alkalinity as HCO_3^- (mg/L)	70.83 ± 5.89	-	-	-	-	-	-	-	-
Al (mg/L)	1194	92	144	86	-	-	15.41	143.8	29
Fe (mg/L)	515	34	55	34	8	12	8.85	52	17
Pb (mg/L)	ND	0.011	0.029	0.029	-	-	0.044	0.03	0.10
Cr (mg/L)	0.217	-	-	-	-	-	0.018	0.02	0.01
Cu (mg/L)	0.559	0.82	-	-	-	-	0.02	0.04	0.001
Raw water sources and type of coagulants									
Raw water source	Surabaya River [6]	Ciliwung River	Ciliwung River	Tarum Kanal Barat River	Tarum Kanal Barat River	Tarum Kanal Barat River	Johor River [7]	Ganga River [1]	R'dom River [8]
Type of coagulant	Al_2SO_4	Al_2SO_4 and ferric chloride ($FeCl_3$)	Al_2SO_4 and ferric chloride ($FeCl_3$)	Al_2SO_4 and ferric chloride ($FeCl_3$)	Al_2SO_4 and Polyaluminium chloride (PACl)	Al_2SO_4 and Polyaluminium chloride (PACl)	Al_2SO_4	Polyaluminium chloride (PACl)	Al_2SO_4

was influenced by silicate structure in soil, which became the major conctituents of dried hydroxide sludge [He et al., 2014].

The chromium and copper concentrations in the dried sludge were of 0.0023% (or 0.217 mg/L) and 0.0059% (or 0.559 mg/L), respectively (Table 2). These concentrations met the effluent standards (Table 2).

Impacts of alum sludge

Aluminum, TSS, BOD, COD of alum sludge from Surabaya WTP were highly exceeded the effluent standards. As a consequence, a direct discharge into surface water might cause negative environmental impacts. Dissolved aluminum in the form of Al^{3+} has high toxicity. Many ecological risks were caused by the aluminum in the dissolved form [Po et al., 2012]. Hidayati et al. [2013] added that high aluminum content in the alum sludge is toxic to aquatic biota and humans, as it might be bioaccumulated and biomagnified through food chain. However, the toxicity decreases because aluminum forms stable complexes with low solubility in the rivers with neutral pH.

The high suspended solids in the alum sludge may cause siltation and high turbidity in rivers [Ippolito et al., 2011]. The high turbidity can prevent sunlight penetration, which disrupts the growth of aquatic plants as oxygen supplier. Consequently, it may reduce dissolved oxygen in surface water and affect the aquatic biodiversity [Zhao et al., 2007; Ippolito et al., 2011]. Additionally, the oxygen concentration decline in surface water can also be caused by the high BOD and COD levels in the sludge. This is because of oxygen consumption by microorganisms to decompose the organic pollutants.

On the basis of the above-mentioned hazards of the alum sludge to the aquatic environment, it is important to carry out a proper treatment prior to discharge or disposal. A number of sludge treatment methods have been developed, such as dewatering followed disposal into landfill [Ahmad et al., 2016], land application [Ippolito et al., 2011], coagulant recovery [Nair and Ahammed, 2015], and aluminum recovery [Reddy and Zhang, 2016].

CONCLUSIONS

The alum sludge of Surabaya WTP showed high concentrations of aluminum, TSS, BOD and COD, which far exceed the quality standards. These characteristics are generally comparable to those of other WTPs in Indonesia and developing countries, which may have adverse impact on the environment. Therefore, it is necessary to carry out sludge treatment prior to disposal.

Table 4. Raw water characteristics for every WTPs

Parameter	Raw water characteristics						
	Surabaya River, Indonesia [1]	Ciliwung River, Indonesia [2]	Tarum Kanal Barat River, Indonesia [2]	Johor River, Malaysia [3]	Ganga River, India [4]	R'dom River, Morocco [5]	Stream Standards [6]
Turbidity (NTU)	179	27.5	278	26.8	18	391	-
Total suspended solids (mg/L)	1000	341	49.81	20.65	281	421	50
Total dissolved solids (mg/L)	600	435.5	284	-	406	1148	1000
BOD (mg/L)	3.41	2.1	4.84	2.55	13.5	353	2
COD (mg/L)	16.75	35.2	9.42	54.69	54.5	539.5	10
Al (mg/L)	0.01	0.04 [8]	-	0.06	0.08	<0.2	0.2 [7]
Fe (mg/L)	9.98	0.05	0.26	1	11.9	-	0.3
Pb (mg/L)	2.89	-	<0.03	0.05	0.18	0.01	0.03
Cr (mg/L)	0.12	0.01	0.04	0.05	0.07	0.06	0.05
Cu (mg/L)	0.11	0.02	<0.02	0.02	0.05	0.03	0.02
WTPs	Surabaya WTP	Tirta Pakuan, Bogor and Cibinong WTPs	Buaran and Pejompongan I/II WTPs, Jakarta, Indonesia	Semanggar WTP, Malaysia	Ghaziabad WTP, India	Bouregreg WTP, Morocco	-

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