Pemanfaatan Lumpur PDAM Aktif H_2SO_4 sebagai Adsorben dengan Penambahan Tawas untuk Mengurangi COD dan BOD pada Air Limbah Batik dari Kutawaru, Cilacap

Utilization of H_2SO_4 Activated PDAM Sludge as an Adsorbent with Alum Addition for Reducing COD and BOD in Batik Wastewater from Kutawaru, Cilacap

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ABSTRAK

Penelitian ini bertujuan memanfaatkan limbah lumpur PDAM Cilacap sebagai adsorben untuk mengolah air limbah industri batik asal Kutawaru, yang memiliki kadar Biochemical Oxygen Demand (BOD) dan Chemical Oxygen Demand (COD) melebihi baku mutu. Lumpur diaktivasi secara kimia menggunakan H_2SO_4 2 M, kemudian diaplikasikan melalui eksperimen skala laboratorium dengan variasi dosis tawas (1, 2, dan 3 g). Hasil pengolahan menunjukkan penurunan signifikan pada beban pencemar. Kadar BOD awal sebesar 1.800 mg/L turun menjadi 239-241 mg/L (efisiensi 86,6%), sementara kadar COD menurun dari 2.688 mg/L menjadi 348-449 mg/L (efisiensi 83,3%). Proses adsorpsi dan netralisasi juga berhasil menaikkan pH dari 3,0 menjadi 6,8-7,2 serta secara efektif menjernihkan warna limbah. Meskipun efluen belum sepenuhnya memenuhi baku mutu, lumpur PDAM teraktivasi terbukti menjanjikan sebagai alternatif adsorben yang berbiaya rendah dan ramah lingkungan untuk mereduksi polutan organik limbah batik.

Kata Kunci: Lumpur PDAM; aktivasi asam; limbah batik; adsorpsi; dosis tawas.

ABSTRACT

This research aims to utilize PDAM Cilacap sludge waste as an adsorbent to treat wastewater from the batik industry from Kutawaru, which has levels of Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) that exceed quality standards. The sludge was chemically activated using 2 M H_2SO_4, then applied through laboratory-scale experiments with variations in alum doses (1, 2, and 3 g). The treatment results showed a significant decrease in the pollutant load. The initial BOD level of 1,800 mg/L decreased to 239-241 mg/L (86.6% efficiency), while the COD level decreased from 2,688 mg/L to 348-449 mg/L (83.3% efficiency). The adsorption and neutralization process also succeeded in raising the pH from 3.0 to 6.8-7.2 and effectively clarified the color of the waste. Although effluent has not fully met quality standards, activated PDAM sludge has proven to be promising as a low-cost and environmentally friendly adsorbent alternative to reduce organic pollutants from batik waste.

Keywords: PDAM sludge; acid activation; batik wastewater; adsorption; alum dosage.

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INTRODUCTION

Batik production in Indonesia generates large volumes of wastewater containing dyes, wax residues, surfactants, and organic pollutants. These contaminants contribute to elevated BOD and COD levels and produce strong coloration that can severely impact receiving water bodies when discharged without adequate treatment (Fitriani & Nugroho, 2019; Apriyani, 2018; Rahmawati & Prasetyo, 2021). Such pollutants reduce dissolved oxygen, disrupt aquatic ecosystems, and often exceed Indonesian Class III water quality standards (Yuliana & Putra, 2023; Harahap et al., 2022; KLHK, 2019). This condition is prevalent in several batik producing areas, including Cilacap, where wastewater is commonly discharged into local rivers and drainage systems. In Indonesia, the management of industrial wastewater is regulated through national environmental legislation designed to protect ecosystems and public health. Maximum allowable limits for wastewater quality are stipulated in the Indonesian Ministry of Environment Regulation No. 5 of 2014, which sets national effluent standards for various industrial sectors. For the textile and batik industries, specific threshold values are provided to evaluate compliance and ensure that discharged wastewater does not exceed permissible pollutant concentrations. These regulatory limits, summarized in Table 1.

Table 1. Wastewater Quality Standards

No	Parameter	Maximum Level (Quality Standards)
1	BOD (mg/L)	85
2	COD (mg/L)	250
3	DO (mg/L)	-
4	TSS (mg/L)	60
5	pH	6,0-9,0
6	Grease (%)	5
7	Cr (mg/L)	2
8	Color concentration	-

Source **:** (Fidiastuti & Lathifah, 2018)

Parallel to this issue, drinking water treatment facilities (PDAM) generate substantial amounts of sludge as a byproduct of their coagulation and sedimentation processes. This sludge contains high concentrations of silica (SiO_2) and alumina (Al_2O_3), minerals known for their strong adsorption capability and their potential use in wastewater treatment (Wahyudi, 2020; Astuti & Handayani, 2020; Suryani & Maulana, 2018; Nuraini, 2021). Previous studies indicate that chemical activation, particularly acid or base activation, can enhance the porosity and surface reactivity of aluminosilicate-based materials, thereby improving their ability to remove dyes, organic pollutants, and suspended solids (Jariah & Cahyadi, 2023; Anggriawan et al., 2019). Harnessing PDAM sludge as an adsorbent offers a dual benefit: reducing solid waste accumulation while providing an affordable and accessible treatment material for small scale industries.

In the Cilacap region, especially in Kutawaru, where this research was conducted, batik wastewater exhibits extremely high organic loads. Direct measurements during this research revealed BOD levels of 1800 mg/L and COD levels of 2688 mg/L values significantly exceeding regulatory thresholds and classifying the wastewater as heavily polluted. High organic concentrations accelerate oxygen depletion and impair the ecological functions of receiving waters (Sari & Kusuma, 2022; Harahap et al., 2022; Itsnaini, 2021). These results are consistent with previous findings that batik wastewater contains persistent dye molecules, surfactants, and colloidal compounds that are difficult to remove through conventional treatment processes (Martini et al., 2020; Rahmawati & Prasetyo, 2021).

The development of low-cost treatment approaches is therefore essential, particularly for batik industries that lack access to advanced wastewater processing facilities. PDAM sludge, abundant in Cilacap, offers a promising alternative adsorbent. Activation using sulfuric acid increases pore development and surface activity, enhancing adsorption performance (Wahyudi, 2020; Jariah & Cahyadi, 2023; Anggriawan et al., 2019). When combined with alum as a coagulant, the adsorption coagulation mechanism becomes more effective in capturing dissolved and suspended pollutants (Martini et al., 2020). This research evaluates the performance of acid activated PDAM sludge together with alum in treating batik wastewater. The treatment successfully reduced BOD levels to 239 - 241 mg/L, COD to 348 - 449 mg/L, neutralized pH to 7, and changed wastewater color from dark brown to pale yellow. These findings confirm that activated PDAM sludge is a viable and environmentally friendly adsorbent for improving batik wastewater quality.

MATERIAL AND METHODS

This research consisted of three major stages: (1) Sampling of PDAM waste and preliminary analysis, (2) activation and characterization of PDAM sludge, and (3) adsorption testing to evaluate the effectiveness of the activated sludge combined with alum in reducing BOD, COD, and color levels in batik wastewater.

Materials and Equipment

The materials used in this research included raw PDAM sludge obtained from the Cilacap water treatment facility, batik wastewater samples collected from Kutawaru, 2 M sulfuric acid (H_2SO_4) for chemical activation, alum (tawas) as a coagulant, aquadest for washing, and filter paper. These materials were selected based on their availability and relevance to adsorption and coagulation processes.

The equipment used comprised an oven for drying, analytical balance, glassware (beakers, Erlenmeyer flasks, and graduated cylinders), a 250-mesh sieve, magnetic stirrer, pH meter, shaker, and filtration apparatus. Instruments for wastewater analysis included BOD and COD measurement systems following SNI standards, as well as a digital pH meter for acidity measurements. The selection of these tools followed established methodologies used in adsorption studies involving aluminosilicate based adsorbents.

Preliminary Analysis of PDAM Sludge

PDAM sludge was first prepared through drying and sieving to obtain uniform particle size. These preparation steps were conducted at the Chemical Engineering Laboratory of Universitas Nahdlatul Ulama Al Ghazali (UNUGHA) Cilacap, where the sludge samples were oven dried, crushed, and passed through a 250 mesh sieve.

After the physical preparation, the dried sludge samples were transported to the SBI (Solusi Bangun Indonesia) Laboratory, Cilacap, for chemical composition analysis. The testing focused on identifying key mineral constituents such as silica (SiO_2), alumina (Al_2O_3), and associated metal oxides, which are commonly reported in PDAM sludge characterization studies (Wahyudi, 2020; Astuti & Handayani, 2020; Nuraini, 2021). The resulting compositional data served as the basis for determining the suitability of the sludge as an adsorbent precursor and selecting the appropriate activation method.

Chemical Activation of PDAM Sludge

The chemical activation of PDAM sludge was conducted entirely at the Chemical Engineering Laboratory of Universitas Nahdlatul Ulama Al Ghazali (UNUGHA) Cilacap. A total of 65 g of dried PDAM sludge was mixed with 325 mL of 2 M H_2SO_4 and heated under controlled conditions to initiate the activation process. Afterward, the mixture was neutralized with aquadest, filtered, and dried to produce activated sludge suitable for use as an adsorbent. Acid activation is widely recognized for improving surface porosity, removing trapped impurities, and increasing the number of active adsorption sites in aluminosilicate materials (Wahyudi, 2020; Jariah & Cahyadi, 2023; Anggriawan et al., 2019). The activated sludge obtained from this step was then used directly in the adsorption experiments. All of the method in this diagram are shown in Figure 1:

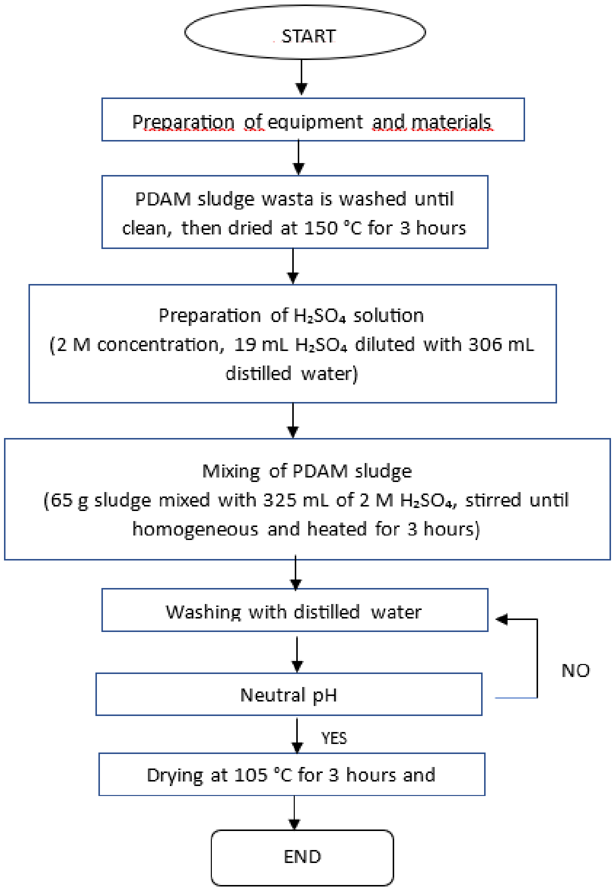

Figure 1. Diagram of the Method

Batik Wastewater Treatment Using Activated Sludge and Alum

Batik wastewater samples were collected from Kutawaru, Cilacap, and analyzed to determine initial BOD, COD, pH, and color values. The adsorption process involved mixing 200 mL of wastewater with 2 g of activated PDAM sludge and alum variations of 1 g, 2 g, and 3 g in separate beakers. Each mixture was stirred for approximately 30 minutes to ensure homogeneous dispersion. The beakers were then covered with aluminum foil to prevent contamination and left undisturbed for 24 hours to allow sedimentation and adsorption to occur.

After settling, the supernatant was separated and analyzed. pH measurements were conducted at the UNUGHA Chemical Engineering Laboratory using a calibrated digital pH meter. Meanwhile, the BOD, COD, and color analyses were carried out at the Environmental Agency (DLH) Laboratory of Cilacap, following the standardized SNI wastewater testing procedures. These analyses enabled the evaluation of treatment effectiveness by comparing pollutant concentrations before and after the adsorption coagulation process, consistent with prior studies employing mineral-based adsorbents and alum for wastewater treatment (Martini et al., 2020).

RESULTS AND DISCUSSION

Adsorbent Characterization

The initial characterization of PDAM sludge was conducted to determine its potential as an adsorbent. Laboratory analysis performed at Solusi Bangun Indonesia (SBI) Cilacap confirmed that the dried sludge contains significant levels of silica (SiO_2 = 40.21%) and alumina (Al_2O_3 = 24.98%), along with supporting oxides such as Fe_2O_3 and CaO. These mineral components are characteristic of aluminosilicate-based materials, which are widely recognized for their adsorption capability due to their porous structure and active surface sites (Wahyudi, 2020; Astuti & Handayani, 2020; Nuraini, 2021). The high silica–alumina content indicates that the sludge has strong potential as an adsorbent for removing organic pollutants from wastewater. In addition, the presence of metal oxides such as Fe_2O_3 may contribute to adsorption through surface complexation mechanisms, while CaO can enhance coagulation behavior when combined with alum during treatment. These characteristics further support the suitability of PDAM sludge as a low-cost adsorbent material. The components of PDAM Sludge are shown in Table 2.

Table 2. Components of raw sludge

No.	Component	Value (%)
1.	SiO_2	40.21
2.	Al_2O_3	24.98
3.	Fe_2O_3	12.82
4.	CaO	5.14
5.	MgO	1.68
6.	Na_2O	1.19
7.	K_2O	0.735
8.	SO_3	0.099
9.	Cl	-
10.	NA2OEQ	-

Effect of Acid Activation on Sludge Properties

Acid activation of PDAM sludge was performed using 2 M H_2SO_4. A total of 65 g of dried sludge was mixed with 325 mL of acid solution, followed by stirring, neutralization, filtration, washing to neutral pH, and oven drying. This process produced approximately 8 g of activated material. The significant mass loss observed during activation (approximately 87%) can be attributed to several factors. Sulfuric acid promotes the dissolution of soluble inorganic components such as calcium compounds, metal oxides, and other mineral impurities present in the raw sludge. These dissolved species are removed during washing and filtration. In addition, the neutralization process contributes to further mass reduction, while thermal treatment during oven drying removes moisture and volatile components. The combined effects of chemical dissolution, neutralization, and thermal dehydration result in a more purified and porous aluminosilicate structure. XRF analysis conducted at Solusi Bangun Indonesia (SBI) Cilacap confirmed that the raw sludge is dominated by SiO_2 (40.21%) and Al_2O_3 (24.98%), which are characteristic of aluminosilicate materials commonly used as adsorbents (Wahyudi, 2020; Astuti & Handayani, 2020; Suryani & Maulana, 2018; Nuraini, 2021).

Acid activation is known to remove impurities, enhance pore development, and expose active surface functional groups, thereby improving adsorption capacity (Jariah & Cahyadi, 2023; Anggriawan et al., 2019). Although direct structural characterization such as BET, SEM, or FTIR was not conducted in this study, the improved adsorption performance observed indicates that structural modification likely occurred during the activation process, consistent with findings reported in previous studies.

Wastewater Treatment Performance using Activated PDAM Sludge and Alum

The untreated batik wastewater exhibited extremely high pollution levels, with BOD of 1800 mg/L and COD of 2688 mg/L, far exceeding Indonesian wastewater quality standards. These values reflect the typical characteristics of batik effluents containing dyes, wax residues, surfactants, and alkaline chemicals used during the processing stages (Fitriani & Nugroho, 2019; Apriyani, 2018; Rahmawati & Prasetyo, 2021).

After treatment using 2 g of activated PDAM sludge combined with varying alum dosages (1 g, 2 g, and 3 g), significant reductions in pollutant concentrations were observed. BOD decreased to 239–241 mg/L (≈86.6% removal), while COD decreased to 348–449 mg/L (≈83–87% removal). These results indicate that the adsorption coagulation system effectively removes dissolved organic matter through a synergistic mechanism. The activated sludge provides active adsorption sites, while alum enhances coagulation flocculation processes, facilitating the aggregation and removal of suspended and colloidal particles (Yuliana & Putra, 2023; Fidiastuti & Lathifah, 2018; Martini et al., 2020).

Table 3. BOD Test Results

No.	Sample Code	Description	Result (mg/L)	Efficiency (%)	pH	Color
1.	X	Untreated batik wastewater	1800	-	14	Black
2.	D	H_2SO_4 Activated PDAM Sludge Adsorbent + 1 gram Alum	239	86,7 %	7	Yellow
3.	E	H_2SO_4 Activated PDAM Sludge Adsorbent + 2 gram Alum	240	86,6 %	7	Yellow
4.	F	H_2SO_4 Activated PDAM Sludge Adsorbent + 3 gram Alum	241	86,6 %	7	Yellow

The BOD results presented in Table 3 show a substantial reduction from 1800 mg/L in untreated wastewater to 239–241 mg/L after treatment. This corresponds to a removal efficiency of approximately 86.6%, indicating that the adsorption coagulation system is highly effective in reducing biodegradable organic matter.

Interestingly, the variation in alum dosage (1 g, 2 g, and 3 g) did not significantly affect BOD removal efficiency, as all treatments yielded nearly identical results. The lowest BOD value (239 mg/L) was achieved at 1 g alum, while slightly higher values (240–241 mg/L) were observed at higher dosages. This suggests that the system reached an optimal condition at the lowest alum dosage, and further addition of coagulant did not enhance performance.

This phenomenon can be explained by the saturation of available adsorption sites on the activated PDAM sludge and the formation of stable flocs at lower alum concentrations. Once equilibrium is reached, additional alum may lead to particle restabilization or inefficient aggregation, resulting in no significant improvement in pollutant removal.

Table 4. COD Test Results

No.	Sample Code	Description	Result (mg/L)	Efficiency (%)	pH	Color
1.	X	Untreated batik wastewater	2688	-	14	Black
2.	D	H_2SO_4 Activated PDAM Sludge Adsorbent + 1 gram Alum	348	87,1 %	7	Yellow
3.	E	H_2SO_4 Activated PDAM Sludge Adsorbent + 2 gram Alum	370	86,2 %	7	Yellow
4.	F	H_2SO_4 Activated PDAM Sludge Adsorbent + 3 gram Alum	449	83,3 %	7	Yellow

The COD results shown in Table 4 also demonstrate a significant reduction, from 2688 mg/L to 348–449 mg/L, corresponding to removal efficiencies of approximately 83–87%. However, unlike BOD, the COD removal shows a slight decreasing trend with increasing alum dosage.

The highest removal efficiency (87.1%) was achieved at 1 g alum, producing a COD value of 348 mg/L. As the alum dosage increased to 2 g and 3 g, COD values increased to 370 mg/L and 449 mg/L, respectively, indicating a decline in treatment efficiency.

This trend suggests that excessive alum dosage may negatively affect the adsorption coagulation system. Overdosing of coagulant can lead to charge reversal, destabilization of formed flocs, or increased residual dissolved solids, which may contribute to higher COD values. Therefore, the optimal alum dosage in this study is 1 g, where the balance between adsorption and coagulation mechanisms is most effective.

pH Test

The initial wastewater pH of 14, indicating strong acidity from batik processing chemicals, increased to near-neutral conditions (pH 6.8-7.2) after treatment. This pH adjustment resulted from the buffering interaction between alum, activated PDAM sludge, and acidic constituents in the wastewater. Achieving near-neutral pH is essential for meeting environmental discharge standards and reducing potential ecological impacts.

Table 5. Results of pH analysis with litmus paper

Sample	Results of pH Analysis	
	Value (mg/L) batik wastewater	Maximum Concentration (mg/L)
X	14	6.0 - 9.0
A	7	6.0 - 9.0
B	7	6.0 - 9.0
C	7	6.0 - 9.0

As shown in Table 5, the treatment system successfully reduced the pH from strongly alkaline conditions (pH 14) to neutral values (pH ≈7) across all variations. This indicates that the combination of acid-activated PDAM sludge and alum effectively neutralizes alkaline wastewater. The results also show that variation in alum dosage does not significantly affect pH adjustment, suggesting that the neutralization process is primarily influenced by the acidic nature of the activated adsorbent. The final pH values fall within the regulatory limit (6.0–9.0), indicating that the treated wastewater meets environmental discharge standards in terms of pH. Overall, the combined adsorption coagulation system using acid-activated PDAM sludge and alum demonstrated high efficiency in reducing organic load, improving pH, and enhancing color clarity. These findings confirm that PDAM sludge, a readily available and low cost material, can serve as an effective adsorbent for treating batik wastewater, particularly for small-scale industries lacking access to advanced treatment technologies.

CONCLUSION

This research demonstrates that acid activated PDAM sludge, when combined with alum, is highly effective for improving the quality of batik wastewater. The activated sludge exhibited strong adsorption capability, supported by its dominant silica-alumina composition, while alum enhanced coagulation and sedimentation processes. As a result, the treatment achieved substantial pollutant reductions, lowering BOD from 1800 mg/L to 239–241 mg/L and COD from 2688 mg/L to 348–449 mg/L, corresponding to removal efficiencies of approximately 83–87%. The treatment also successfully neutralized wastewater pH from 14 to around 7 and improved color from dark brown to pale yellow, indicating effective removal of chromophoric and suspended compounds.

Overall, the findings confirm that acid-activated PDAM sludge is a promising, low-cost, and environmentally friendly adsorbent for batik wastewater treatment. Its performance suggests strong potential for application in small to medium-scale batik industries lacking access to advanced treatment technologies. Future studies may include surface characterization (BET, SEM, FTIR) and optimization at pilot or continuous-flow scale to further enhance efficiency and support industrial implementation.

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