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EFFECT OF BEVERAGE CAN WASTE–KOH RATIO ON ALUM PRODUCTION AS A COAGULANT FOR WATER TREATMENT

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ABSTRAK

Proses daur ulang limbah dapat menghemat energi, mengurangi eksploitasi sumber daya alam, serta meningkatkan nilai ekonomis limbah, salah satunya limbah kaleng minuman. Penelitian ini bertujuan untuk menentukan rasio optimum antara limbah kaleng minuman dan kalium hidroksida (KOH) dalam pembuatan tawas (aluminium sulfat) sebagai koagulan penjernih air. Metode yang digunakan terdiri dari lima tahap, yaitu preparasi, pelarutan, pengendapan alum, pencucian, dan pengeringan. Variabel rasio limbah kaleng terhadap larutan KOH 30% divariasikan sebesar 1%, 2%, 3%, 4%, dan 5%. Parameter yang dianalisis meliputi kadar aluminium dalam tawas, rendemen, dan efektivitas tawas dalam menurunkan kekeruhan air. Hasil menunjukkan bahwa tawas mampu menurunkan kekeruhan air limbah industri dari 55,6 NTU menjadi 16,4 NTU. Rendemen optimum diperoleh pada rasio 3% sebesar 68,91% dengan kadar aluminium 33,80% dan susut pengeringan 9,97%. Efektivitas penurunan kekeruhan ini mengacu pada standar turbiditas menurut SNI 6989.57:2008 dan Permenkes No. 32 Tahun 2017, di mana air bersih non-konsumsi idealnya memiliki kekeruhan di bawah 50 NTU. Dengan demikian, tawas hasil daur ulang ini menunjukkan potensi sebagai koagulan alternatif dalam pengolahan air limbah.

Kata kunci: Tawas, limbah kaleng minuman, koagulan, penjernih air

ABSTRACT

Recycling aluminum-based beverage can waste offers a sustainable approach to reducing energy consumption, conserving natural resources, and increasing waste valorization. This study aimed to determine the optimum ratio of beverage can waste to potassium hydroxide (KOH) in synthesizing alum (aluminum sulfate) as an alternative coagulant for wastewater treatment from a petrochemical industry in Anyer, Banten Province, Indonesia. Alum was synthesized through preparation, alkaline dissolution, precipitation, washing, and drying using beverage can waste to 30% KOH ratios of 1–5%. Performance evaluation included yield, aluminum content, drying loss, and coagulation effectiveness based on turbidity, pH, color, and odor.The results showed that recycled alum reduced turbidity from 55.6 NTU to 16.4 NTU, decreased pH from 7.39 to 7.22, and eliminated color and odor. The optimum condition was achieved at a 3% ratio, yielding 68.91% alum with 33.80% aluminum content and 9.97% drying loss. All treated water parameters met Indonesian non-potable clean water standards according to SNI 6989.57:2008 and Ministry of Health Regulation No. 32/2017, demonstrating the potential of recycled alum as a sustainable alternative coagulant.

Keywords: alum, aluminum recycling, beverage can waste, coagulant, wastewater treatment.

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INTRODUCTION

Beverage cans are extensively used for liquid packaging due to the favorable properties of aluminum, including low density, corrosion resistance, and high formability. In Asian markets, beverage cans typically contain aluminum with high purity (92.5–97.5%), making post-consumer cans a promising source of secondary aluminum for value-added applications, including aluminum-based coagulants for water treatment (Jones, 2018). Although inner can surfaces are coated with epoxy resin, aluminum degradation may still occur under acidic conditions, elevated temperatures, and humid environments, enabling aluminum recovery after disposal (Hatigoran, 2017; Seruga & Hasenay, 2000).

Used beverage cans represent a persistent inorganic waste stream with considerable environmental implications. Globally, only about 50% of aluminum cans are recycled, while the remainder accumulates in landfills or contaminates terrestrial and aquatic environments (The Aluminum Association, 2020). Moreover, primary aluminum production from bauxite is highly energy-intensive and generates substantial carbon emissions, reinforcing the importance of secondary aluminum utilization within a circular economy framework (Haque et al., 2022).

In water treatment applications, alum is one of the most widely used coagulants due to its effectiveness in reducing turbidity, color, and suspended solids. Potassium aluminum sulfate dodecahydrate ($KAl(SO_4)_2 \cdot 12H_2O$) is the standard alum compound, with aluminum sulfate ($Al_2(SO_4)_3$) serving as its primary precursor (Sitompul et al., 2017; Jalaluddin, 2005). Conventionally, aluminum sulfate is produced from bauxite, a non-renewable resource with finite availability despite significant reserves in Indonesia (Manuntun, 2008).

Recent studies have demonstrated the feasibility of synthesizing alum from aluminum-containing waste, including beverage cans, using alkaline and acidic reagents, with coagulation performance comparable to commercial alum (Ratih et al., 2022). However, existing research largely emphasizes synthesis feasibility and turbidity removal, while systematic optimization of the aluminum-to-alkali ratio and comprehensive quality evaluation relative to standard specifications remain limited.

Therefore, this study aims to investigate the effect of varying the ratio of used beverage cans to 30% potassium hydroxide on aluminum dissolution, alum yield, and product quality, while assessing its coagulation performance in actual industrial wastewater. The novelty of this work lies in the integration of process optimization with direct benchmarking against SNI 6989.57:2008, providing practical evidence for the potential application of recycled alum as a sustainable alternative coagulant for non-potable industrial water treatment.

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METHOD

Tools and Materials

The experimental work was conducted using an analytical balance, graduated cylinders, beakers, a hot plate, a glass stirring rod, a funnel, an oven, a turbidimeter, a pH meter, a magnetic stirrer, an inductively coupled plasma–optical emission spectrometer (ICP-OES), and an atomic absorption spectrophotometer (AAS). The chemicals and materials employed included post-consumer aluminum beverage can waste, distilled water, 30% (w/w) potassium hydroxide (KOH), 8 M sulfuric acid (H_2SO_4), 50% (v/v) ethanol, and Whatman No. 40 filter paper.

Procedure

Alum was synthesized from aluminum-based beverage can waste through sequential steps of preparation, dissolution, precipitation, washing, drying, and characterization. The cans were cleaned, dried, cut into small pieces, and weighed at 0.5–2.5 g, then reacted with 50 mL of 30% (w/w) KOH solution. Aluminum dissolution was conducted at approximately 80 °C for 60 min under continuous stirring, producing soluble aluminate species according to the reaction:

$$2Al + 2KOH + 6H_2O \rightarrow 2K[Al(OH)_4] + 3H_2$$

After cooling, the solution was filtered (Whatman No. 40), and the filtrate was slowly acidified with 15 mL of 8 M H_2SO_4 to induce alum crystallization. The mixture was allowed to stand for approximately 24 h, yielding potassium aluminum sulfate as described by:

$$K[Al(OH)_4] + H_2SO_4 + 8H_2O \rightarrow KAl(SO_4)_2 \cdot 12H_2O$$

The precipitate was filtered, washed with distilled water and 50% (v/v) ethanol, and oven-dried at 105 °C to constant weight. Qualitative and quantitative analyses were performed in accordance with SNI 6989.57:2008, including visual observation, yield determination, aluminum and iron contents, and loss on drying. Aluminum concentration was measured using ICP-OES (396.152 nm), while Fe content was determined by AAS (248.3 nm) after acid digestion. Loss on drying was calculated from the mass difference before and after heating at 105 °C for 2 h.

RESULTS AND DISCUSSION

Physical Characteristics of Alum

The physical characteristics of the synthesized alum were evaluated and compared with those of commercial alum, focusing on crystal form, color, and odor. The results of the visual observations are presented in Table 1.

Table 1. Physical Characteristics of Alum Sample

Physical Parameter	Synthesized Alum	Commercial Alum
Form	Fine powder	Crystalline
Color	Bright white	Slightly turbid white
Odor	Odorless	Odorless

Based on visual observations, the synthesized alum exhibited clear differences compared to commercial alum, particularly in form and color, which are relevant to its coagulation performance. The synthesized alum (left image) appeared as a fine white powder, whereas the commercial alum (right image) was crystalline with a slightly turbid white color.

These differences are attributed to variations in crystallization and drying conditions. Oven drying at 105 °C produced smaller crystals that readily disintegrated into fine particles, increasing the effective surface area of the coagulant. A higher surface area is advantageous for coagulation processes, as it facilitates faster dissolution and more efficient hydrolysis of aluminum species in water treatment applications. In contrast, commercial alum is produced through controlled industrial crystallization, resulting in larger and more ordered crystals (Mullin, 2001; Perry & Green, 2008).

Moreover, the absence of recrystallization or controlled cooling in the synthesized alum contributed to finer particle formation. The brighter white appearance indicates a lower level of impurities, particularly iron, which is consistent with the low Fe content obtained from chemical analysis. Reduced iron impurities are beneficial for coagulation efficiency and help prevent secondary color formation in treated water, as elevated Fe concentrations are known to cause turbidity and yellowish discoloration (Snoeyink & Jenkins, 1980).

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Figure 1. Comparison between the synthesized alum and commercial alum.

Aluminum Content in Alum

The alum product obtained in this study was analyzed to determine its aluminum (Al) content. The relationship between Al content and the ratio of beverage can waste to 30% KOH solution is presented in Table 2.

Table 2. Aluminum Content of Alum at Different Ratios of Beverage Can Waste to 30% KOH.

Beverage can waste (%)	Alum weight (g)	Volume (mL)	Dilution factor	Aluminum content	
				Analytical result (ppm)	Total (%)
1%	0,5078			1,026	10,10
2%	0,5161			2,293	22,21
3%	0,5005	50	1000	3,383	33,80
4%	0,5028			3,454	34,35
5%	0,5011			3,471	34,63

Alum Yield

The alum obtained from this study was evaluated in terms of yield. The relationship between alum yield and the ratio of beverage can waste to 30% KOH is presented in Table 3.

Table 3. Alum yield at various percentage ratios of beverage can waste to 30% KOH

Beverage can waste (%)	Can weight (g)	Experimental alum weight (g)	Theoretical alum weight (g)	Alum yield (%)
1%	0,5034	0,5427	1,3963	38,87
2%	0,9996	1,5925	2,7727	57,44
3%	1,5002	2,8673	4,1612	68,91
4%	1,9992	3,4105	5,5453	61,50
5%	2,5045	3,5794	6,9469	51,52

From the study involving the ratio of beverage can waste to 30% KOH as the independent variable, with the addition of 8 M H_2SO_4 as a fixed variable, the aluminum content and alum yield obtained are presented in Table 4 and Figure 2.

Table 4. Aluminum content and alum yield at different percentage ratios of beverage can waste to 30% KOH

Beverage can waste (%)	Volume of 30% KOH (mL)	Volume of 8M H_2SO_4 (mL)	Aluminum content (%)	Alum yield (%)
1%			10,10	38,87
2%			22,22	57,44
3%	50	15	33,80	68,91
4%			34,35	61,50
5%			34,63	51,52

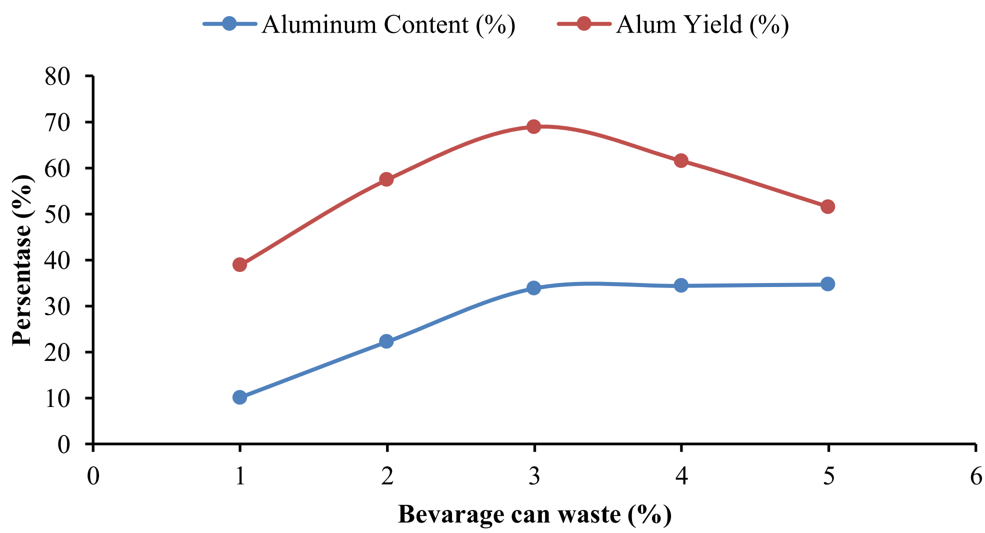

Figure 2. Relationship between aluminum content, alum yield, and the percentage ratios of beverage can waste to 30% KOH

Based on the above graph, the optimum condition for alum production from beverage can waste was achieved at a ratio of 3%.

Determination of Iron (Fe) Content

The iron (Fe) content was determined using alum synthesized under the optimum condition. A 0.2505 g alum sample was dissolved and diluted to a final volume of 50 mL. Instrumental analysis indicated an Fe concentration of 0.2528 ppm. Based on the calculation, the iron content of the synthesized alum was 50.46 ppm, corresponding to 0.005%.

Loss on drying (LOD)

Loss on drying was determined using alum synthesized under the optimum condition. The results of the loss on drying analysis of the experimental alum are presented in Table 5.

Table 5. Loss on Drying Analysis

Description	Weight (g)
Empty Container Weight	9.1694
Container + Alum (Initial)	9.4272
Container + Alum (Dry)	9.4015
Loss on Drying (%)	9.97

The alum produced under optimal conditions was subsequently evaluate against the Indonesian National Standard (SNI 6989.57:2008) for Technical Potassium Aluminum Sulfate, with the results summarized in Table 6.

Table 6. Comparison of alum content with SNI 6989.57:2008

Parameter	Unit	Result	Standard
Alum Content (Purity)	%	68.91	min. 93
Iron (Fe)	%	0.005	max. 0.01
Arsenic (As)	%	–	max. 0.0002
Heavy Metals	%	–	max. 0.003
Loss on Drying (LOD)	%	9.97	max. 2.0

The data in Table 2 indicate that increasing the percentage of beverage cans proportionally raised the aluminum content in the resulting alum up to a 3% ratio. Beyond this ratio (4–5%), aluminum content plateaued, suggesting that 50 mL of 30% KOH had reached its stoichiometric limit, and additional aluminum did not fully react (Hidayat et al., 2021; Haque et al., 2022; Ratih et al., 2022; Said & Rauf, 2019). This stagnation directly affected alum yield, with the highest yield of 68.91% at 3% ratio, decreasing at higher ratios (Tables 3

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and 4). These results indicate that a 3% ratio represents the optimum condition for aluminum dissolution, crucial for reaction efficiency, cost, and product quality (Mollah et al., 2004).

Adequate aluminum content is essential for coagulation, as Al^{3+} ions destabilize colloids through charge neutralization and floc formation, enabling adsorption of suspended particles, organic matter, and color-causing compounds (Sillanpää et al., 2018; Yang et al., 2020). The synthesized alum at the optimum ratio exhibited 68.91% purity, 0.005% Fe, and 9.97% loss on drying (Table 6). Low Fe content ensures minimal water discoloration and impurity risks (Snoeyink & Jenkins, 1980). However, purity and drying loss remain below SNI standards, likely due to non-aluminum compounds and incomplete purification (Hidayat et al., 2021; Siregar et al., 2020).

Despite not fully meeting SNI criteria, alum from beverage can waste shows promise as an alternative, environmentally friendly coagulant. Further process optimization and purification could enhance its potential for laboratory- to semi-technical-scale water treatment applications under circular economy principles.

CONCLUSION

Aluminum-based beverage can waste can be effectively utilized for alum production. The optimal can-to-KOH ratio of 3% produced a white, odorless alum powder with 33.80% aluminum content, 68.91% yield, low Fe content (±0.005%), and 9.97% loss on drying. The synthesized alum meets the key requirements of the Indonesian National Standard (SNI 6989.57:2008) for technical-grade potassium aluminum sulfate, demonstrating its potential as an alternative coagulant in water treatment and supporting sustainable aluminum waste utilization. Further studies are needed to validate its performance at larger operational scales.

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