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Formulation of Digested Beverage Cans and Iron Plate Wastes as a Coagulant for Adequate Hygiene of Fresh River Water

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Abstract— In terms of hygiene and sanitation, ensuring the availability of qualified water for those purposes remains challenging to perform under certain conditions. Accordingly, efforts to provide simple water processing technology are ongoing and innovatively developed. This study displayed an innovative approach to producing coagulants for water processing by utilizing metal salts obtained synthetically from used beverage cans and iron plates through the electrolysis principle and characterized using Fourier-transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), and Scanning Electron Microscopy - The Energy Dispersive X-ray (SEM-EDX), subsequently. After mixing with calcium hypochlorite and adding to water sample, subsequently, the coagulant showed the ability to reduce the turbidity level and several categories of impurities, i.e., nitrate, nitrite, dissolved Manganese, Cr^{6+} ion, and microbial levels. Future research and development in formulating coagulants derived from digested beverage cans and iron plate wastes hold significant potential to advance sustainable and efficient water treatment technologies, ensuring improved hygienic quality of fresh river water while contributing to waste valorization and environmental protection.

Keywords— *Alum; Coagulant; Ferric sulphate; Hygiene sanitation; Metal digestion.*

1. INTRODUCTION

Water quality standards impact public health. Water quality is assessed based on physical, chemical, and biological conditions and must meet specific standards for its intended use [1,2]. High-quality water is characterized by some physical parameters, including taste, odor, color, and temperature, as well as chemical parameters, such as pH, hardness, nitrate, nitrite, iron, and fluoride [3]. Regulation of the Minister of Health of the Republic of Indonesia Number 32 of 2017 states that water for sanitary and hygiene purposes is essential for maintaining personal hygiene, such as bathing and brushing teeth, as well as for washing food ingredients, cutlery, clothing, and drinking water raw water by meeting the requirements [4]. Sanitary hygiene water used for daily needs differs from drinking water. According to the Indonesian Minister of Health Regulation No. 2 of 2023, sanitary hygiene water is assessed based on physical, chemical, and biological indicators [5]. In the scope of river water by the community, the river water quality is determined by comparing it with the established standards, and pollution is indicated if it does not meet the threshold for its intended use [6]. Water classification considers physical, chemical, biological, and radioactive factors [7], and can be evaluated based on water clarity, odor, and ecosystem health [8]. River water quality is critical for supporting aquatic life and human needs, such as drinking water, agriculture, and industry [9].

Population growth, industrial development, and increased living standards can decrease river water quality [10], which certainly impacts water quality for sanitary hygiene needs. Water contaminated by urine, feces, and pathogens can cause disease if it does not meet hygiene standards [11]. In addition to potential contamination from human activities along riverbanks, erratic weather can cause river water quality to vary, such as during the dry season river water tends to be more turbid and dirtier because the water is mixed with

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aquatic sediments like sand, compounded by pollutants that are not carried away by the current [12]. Pollutants can enter the soil and contaminate the river water. Conversely, during the rainy season, turbidity may increase caused by mud and suspended solids due to erosion and sediment flow [13]. Therefore, it is imperative to develop technologies aimed to reduce or remove pollutants in river water. Various water-cleaning technologies have been developed. One of the most effective methods is to use membranes. Membranes can filter impurities, bacteria, and viruses from water very effectively. However, this method is expensive and requires significant energy. An alternative method is filtration combined with coagulation-flocculation. Filtration can filter out large impurities, while coagulation-flocculation can bind smaller particles and make them settle so they can be separated from the water. Nevertheless, traditional coagulation-flocculation methods usually use expensive chemicals that can be harmful to the environment [14].

The coagulation-flocculation method is another approach that can be elected to precipitate and control solid impurities contained in water into flocs or colloidal clumps that are easily separated [15]. Coagulation and flocculation involve adding chemicals to water or waste to form flocs that help particles settle faster [16]. In medical terms, coagulation refers to the formation of clots [17]. This process relies on the attraction between negative and positive ions, with organic substances, microorganisms, and bacteria acting as negative ions [18]. The coagulation process helps colloidal particles form soft flocs by neutralizing their charge through the addition of electrolytes [19], which occurs when the charge concentration is strong enough to attract colloidal particles [20]. Coagulation is used in industries, such as wastewater treatment, drinking water purification, and food production, where chemicals are added to aggregate solid particles to form precipitates for removal [21].

Flocculation follows coagulation, where microflocs clump together to form macroflocs through slow stirring and time [22]. This process promotes rapid floc settling and can be measured based on the floc size and structure [23]. The result is destabilization of particles and colloids [24]. Coagulants are chemicals that accelerate the coagulation process, aiding in the formation of clumps or accumulation of particles [25,26]. In wastewater treatment, coagulants, such as aluminum sulphate or polyelectrolytes help agglomerate solid particles into larger, heavier sludge for easier removal [27-29]. In drinking water purification, coagulants help collect particles, bacteria, and dissolved materials for more efficient filtration or sedimentation [30].

In terms of materials that act as coagulants, used cans can be processed into effective coagulants that bind small particles and purify water. This method aims to improve access to clean water for people with limited safe and healthy water. Iron(III) sulphate ($Fe_2(SO_4)_3$), a yellow or gray-white granule, is a hygroscopic coagulant used in air purification to remove turbidity and contaminants through coagulation-flocculation [30]. It reacts with ions, such as hydroxide and carbonate to form iron hydroxide ($Fe(OH)_3$) precipitates, which bind dissolved particles into larger clumps. After mixing, gentle stirring can facilitate flocculation, increasing the size of the flocs so that they more easily settle. Importantly, iron(III) sulphate forms heavier, more insoluble clumps than alum.

Meanwhile, calcium hypochlorite ($Ca(ClO)_2$), also known as chloride of lime, is commonly used in powder, pellet, tablet, or briquette. It is primarily used in water treatment and disinfection [31]. It is widely used to disinfect water, accelerate iron release, and ensure water biologically and chemically safe [32]. At a dose of ± 3 mg, it can reduce the biological parameters in river water by ± 90% [33]. Used in most drinking water systems in the United States, calcium hypochlorite can effectively kill bacteria, viruses, and algae, making it an ideal option for disinfection [34]. While it is commonly used in swimming pools, calcium hypochlorite is also used in drinking water and wastewater systems worldwide due to its cost-effectiveness, stability, and solubility [35].

In this study, used cans were synthesized into alum and $Fe_2(SO_4)_3$ from iron plates that function as coagulation-flocculation agents. However, coagulation-flocculation can only precipitate impurities in water, so it is necessary to add calcium hypochlorite $Ca(ClO)_2$ to eradicate bacteria or microbiology contained in water so that it is safe for consumption. A mixture of the three materials is expected to provide optimal results for treating river water into sanitary hygiene water. The water quality parameters tested in this study are mandatory chemical parameters in the environmental health quality standards for sanitary hygiene.

2. EXPERIMENTAL SECTION

2.1. Materials

The materials used included beverages can waste, KOH, H_2SO_4, $Ca(ClO)_2$ ethanol. All materials were purchased from Merck, Darmstadt, Germay with Analytical Grade Reagent quality.

2.2. Instrumentation

The instruments used included FTIR (Shimadzu Prestige 21), XRD (Shimadzu XRD-7000), and SEM-EDX (JEOL JSM-6510).

2.3. Synthesis Alum from Beverage Cans

To ensure the uniformity of material ingredients and thickness, beverage cans were specifically selected from a particular brand. Then, they were cleaned with sandpaper to remove any paint stuck to the cans. Once cleaned, the cans were cut into 1 x 1 cm coupons and immersed in a KOH 30%solution. The mixture was gently mixed on the ice batch until the aluminium coupons were completely dissolved. Afterward, 8M H_2SO_4 was quickly poured to the solution and cooled under 3 °C, until crystallization occurred. The crystals were continuously rinsed with 50% ethanol. After drying, the crystals were characterized using FTIR and XRD.

2.4. Coagulant Formulation

Coagulant formulation began with the synthesis of $Fe_2(SO_4)_3$. Iron plates were electrolyzed using graphite electrodes, which were immersed in 3M H_2SO_4. The electrolysis was conducted with an electrical current of 1.0 A and a voltage of 6.3 V. After $Fe_2(SO_4)_3$ solutions were formed, they were concentrated under 90 °C until completely dried. **Table 1** displays the composition of each component in the coagulants.

Table 1. The components of developed coagulant

Code	Alum (g)	$Fe_2(SO_4)_3$	$Ca(ClO)_2$
A	2.0	1.0	1.0
B	1.0	2.0	1.0

2.5. Sampling

Water sampling was conducted in areas with minimal contamination of household and industrial wastes. Consequently, a particular sampling point in a river located in the training ground of Indonesian military activities, Kawasan Indonesia Peace and Security Center (IPSC), was selected for water sampling due to restricted access. Water samples were acquired and stored in a clean jerry can, subsequently. The samples were directly delivered to the laboratory for analysis to prevent significant changes in the chemical and microbial parameters.

2.6. Water Quality Testing

To observe the coagulation condition, a coagulant was added to a 250 mL water sample and gradually mixed for 5 and 25 min in rapid and slow stirring, respectively. After 60 min of sedimentation, the mixture of water and coagulant was filtered using the Whatman 42 paper. The filtrates were stored in a clean container and delivered to testing facilities to evaluate water quality.

3. RESULT AND DISCUSSION

3.1. Synthesis of Alum

The can coupons were dissolved exothermically in a 30% KOH solution to produce a greyish liquid [36]. The dissolution ended when the hydrogen bubbles had disappeared. Following this, 8M H_2SO_4 was continuously added to the filtrate to discard impurities and effectively convert $2K[Al(OH)_4]$ into hydrated $Al(SO_4)_3$ [37]. This dissolution and acidic treatment successfully produced alum from beverage cans.

The FTIR results (**Fig. 1**) produced a graph displaying several peaks within the wavenumber range of 4000-400 cm^{-1}. Two types of bonds were identified: S=O stretching and O-H stretching bonds. O-H stretching bonds were observed at 2854.65, 2924.09, and 3410.15 cm^{-1}, while S=O stretching bonds were detected at 1095.57 cm^{-1}. These bonds are associated with the structure of alum compounds, which contain O-H groups from hydrates and S=O groups from sulphates. The FTIR results indicate that the synthesized alum is compatible with the synthesized compound.

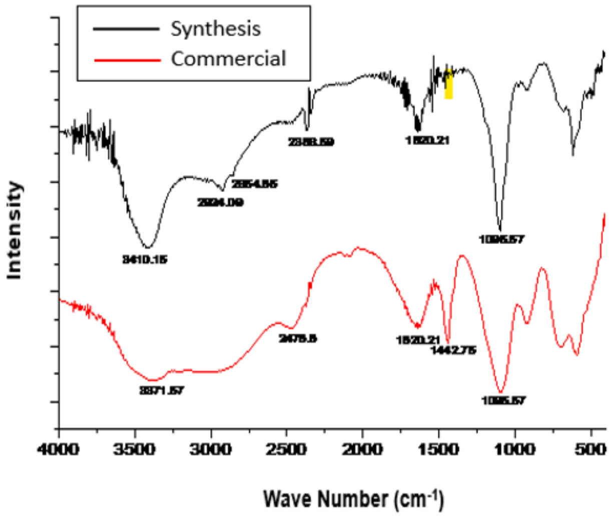

Fig. 1. FTIR result chart of synthesized and commercial alum

The SEM results (**Fig. 2a-2b**) also show that the produced alum crystals are octahedral. Based on the EDX spectrum (**Fig. 2c-2d**), the synthesized alum shows peaks corresponding to its main elements: aluminum (Al), potassium (K), sulphur (S), and oxygen (O). **Table 2** presents the EDX quantities, detailing the ratios of these elements by the chemical formula of alum. The comparative data of alum elements obtained showed that the synthesized alum had a higher potassium (K) content compared to commercial alum, according to the chemical formula of synthesized alum.

Table 2. Elemental ratio of synthesized and commercial alum

Element	Synthesized Alum	Commercial Alum
C	3.71±0.13	7.62±0.30
N	1.11±0.19	5.72±0.40
O	49.23±0.25	44.51±0.67
Na	-	0.43±0.10
Al	9.99±0.37	11.34±0.34
S	16.54±0.57	30.18±0.64
K	19.42±0.56	0.21±0.21
Total	100.00	100.00

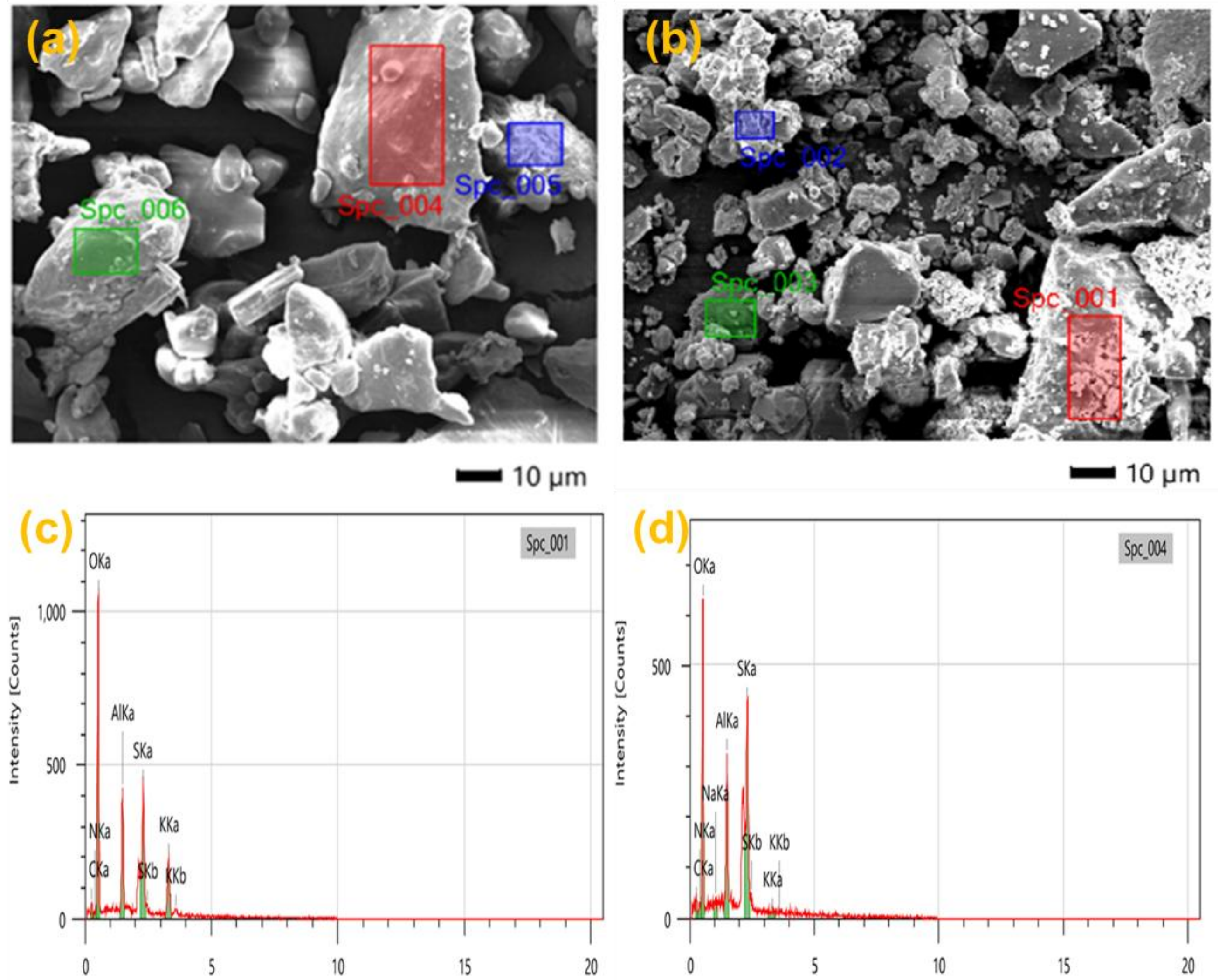

Fig. 2 SEM image of (a) synthesized alum and (b) commercial alum, and EDS peak of (c) synthesized alum and (d) commercial alum

3.2. Electrolysis of Iron Plates

Electrolysis is used to synthesize $Fe_2(SO_4)_3$ using an electric current to break down the raw materials into their desired components. This process occurs in an electrolysis cell consisting of two electrodes: an iron electrode as the anode and a carbon electrode as the cathode. Both solutions were submerged in an electrolyte solution (H_2SO_4). To completely convert the iron plate into $Fe_2(SO_4)_3$, electrolysis was conducted for 6 h. **Figure 3** shows the setup of the electrolysis system used for producing $Fe_2(SO_4)_3$.

After being precipitated, the $Fe_2(SO_4)_3$ was filtered and dried in an oven at 105 °C until a brownish crystal of $Fe_2(SO_4)_3.5H_2O$ was produced. This rhombic crystal has interesting features of hygroscopic and adsorption properties.

The FTIR test results for synthetic and commercial ferrous sulphate (**Fig. 4**) demonstrates similar patterns. The S=O group in the synthesized ferrous sulphate was identified at 1087.85 and 1141.86 cm^{-1}, while in commercial ferrous sulphate it was only detected at 1126.43 cm^{-1}. In addition, an O-H group in the hydrate was observed at around 3200-3400 cm^{-1}. Therefore, it can be concluded that the synthesized ferrous sulphate has a better quality than the commercial one as it contains more S=O functional groups. A more detailed comparison of synthetic and commercial ferrous sulfate is presented in **Table 3**.

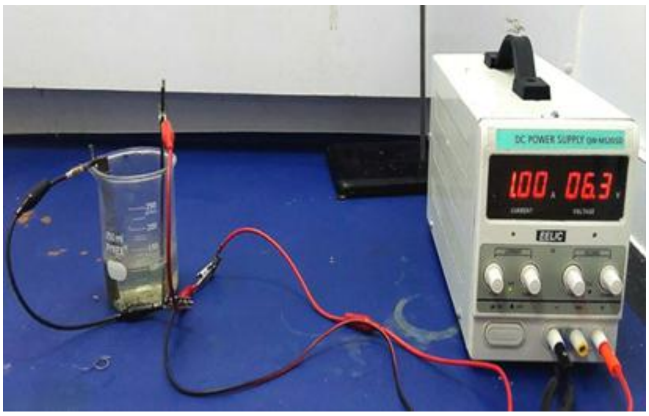

Fig. 3 Electrolysis of iron plates immersed in the sulphuric acid solution

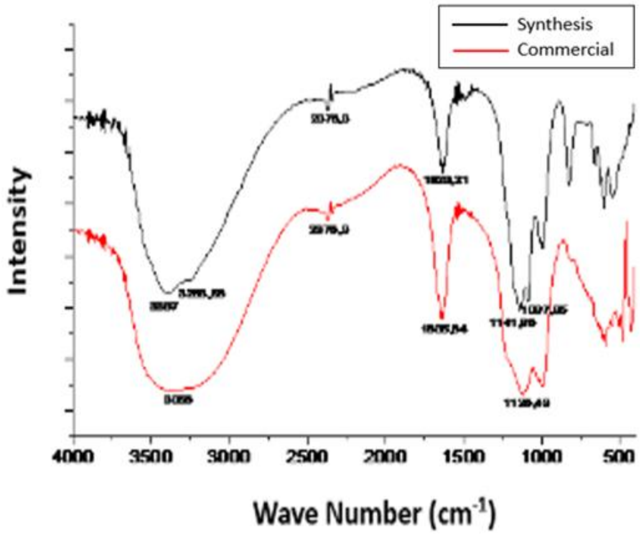

Fig. 4 Electrolysis of iron plates immersed in the sulphuric acid solution

Table 3. Comparison of synthesized and commercial ferric(III) sulphate spectra

Wavenumber Synthesis (cm^{-1})	Wavenumber Commercial (cm^{-1})	Bond Type
1087.85	-	S=O
1141.86	1126.43	S=O
1620.21	1635.64	-
2376.3	2376.3	-
3263.56	3232.7	O-H
3387	3356.14	O-H

3.3. The Formulation of Coagulant

In **Table 1**, it is described that the coagulant is mainly formulated by three components, i.e., alum from beverage cans, $Fe_2(SO_4)_3$ from electrolyzed iron plates, and calcium hypochlorite. It is important to note that, unlike alum and Ferric(III) sulphate that were synthesized during this work, calcium hypochlorite was provided as a finished product. In the formulation stage, the amount of Alum and Ferric(III) sulphate was varied to obtain optimal coagulant properties. **Fig. 5** displays the appearance of the coagulant prepared in this work.

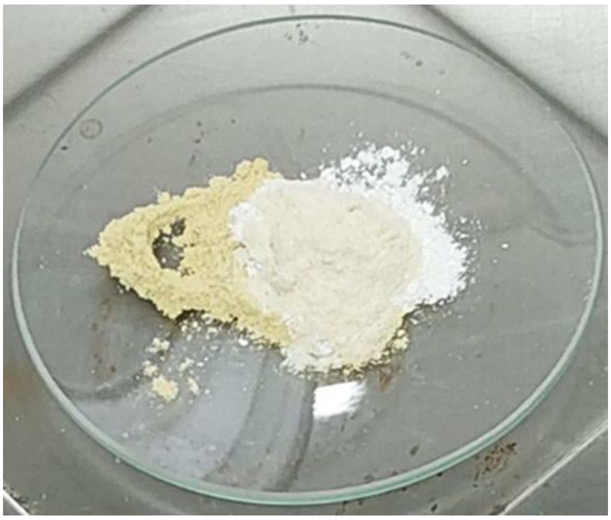

Fig. 5 The appearance of the mixture of powdered Alum, $Fe_2(SO_4)_3$, and calcium hypochlorite

Table 4. Result of application the coagulant to river water quality

No	Parameter	Value	(coag. A)	(coag. B)	Quality standards**)	Method
1	Temperature (°C)	27,1	27,1	27,1	Air temperature ± 3	SNI 06-6989.23-2005
2	Total dissolved solids (TDS) (mg/L)	280	210	280	<300	SNI 6989.27:2019
3	Turbidity *) (NTU)	1,14	1,07	1,14	<3	SNI 06-6989.25:2005
4	Color *) (TCU)	6	5	6	10	SNI 6989.80.2011
5	Smell	odorless	odorless	odorless	odorless	SNI 3554:2015
6	Degree of acidity (pH)	7,50	7,50	7,50	6,5 - 8,5	SNI 6989.11:2019
7	Nitrate, (As NO^{3-}) (mg/L)	0,16	0,14	0,16	20	SNI 6989.79:2011
8	Nitrite, (As NO^{2-}) (mg/L)	<0,005	<0,005	<0,005	3	SNI 06-6989.9-2004
9	Iron (Fe) (dissolved) (mg/L)	<0,002	<0,002	<0,002	0,2	SNI 6989.82:2018
10	Manganese (Mn) (dissolved) (mg/L)	0,016	0,011	0,016	0,1	SNI 6989.82:2018
11	Hexavalent chrom ($Cr^{6+)}$ *) (mg/L)	0,022	0,015	0,022	0,01	SNI 6989.71-2009
12	*Escherichia coli* (CFU/100 ml)	<1,00	<1,00	<1,00	0	SM APHA 23 Ed. 9222J,2017
13	Total Coliforms (CFU/100 ml)	<1,00	<1,00	<1,00	0	SM APHA 23 Ed. 9222J,2017

3.4. Effectiveness of Coagulant to Water Quality

Visual observation of the action of both coagulants showed that coagulant B could collect particles within the water sample into the visible form of aggregates. Meanwhile, coagulant A did not provide similar conditions. There was barely a difference in the brief visual observation results between the untreated water sample and the water sample that had been proceeded with coagulant A. **Fig. 6** depicts the differences among the water samples.

Table 4 shows that the river water samples do not meet the sanitation hygiene requirements because several parameters exceed predetermined quality standards, such as temperature, Mn, Cr^{6+}, *Escherichia coli*, and total coliform. After being coagulated, almost all parameter levels decreased close to the requirements as water for hygiene sanitation. Samples coagulated with coagulant B experienced an increase in total dissolved solids (TDS) due to excess iron(III) sulphate, which added inorganic salts and caused a yellowish colour.

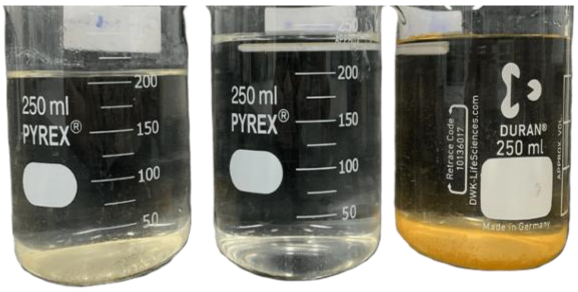

Fig. 6. Comparison of coagulant properties, i.e., control (left), coagulant A (middle), and coagulant B (right)

However, several parameters did not meet standards, such as manganese (Mn) and 6 valence chrome (Cr^{6+}). Both manganese and Cr^{6+} levels cannot meet minimum criteria for several reasons, such as pH, insufficient oxidizer, and coagulants that do not fully react with manganese to form a precipitate [38]. This finding implies further optimization of the formulation or adding other components to the coagulant.

CONCLUSION

Coagulants made from iron (III) sulphate and alum effectively removed particles, dissolved substances, heavy metals, organic materials, and microorganisms via coagulation. Formula A, which used alum and iron (III) sulphate in a ratio of 2:1, had proven to be the most effective. After coagulation, the river water met environmental health standards for hygienic sanitation, indicating that coagulation technology could effectively improve contaminated river water to meet environmental health quality standards.

SUPPORTING INFORMATION

There is no supporting information in this paper. The data that support the findings of this study are available on request from the corresponding author (ES)

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CONFLICT OF INTEREST

The authors declared that no conflicts of interest regarding the publication of this article. The authors confirm that the paper is free of plagiarism.

AUTHOR CONTRIBUTIONS

MG and ES conducted the experiment and analyzed data. MFPK, HR and APL wrote and revised the manuscript. All authors agreed to the final version of this manuscript.

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