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RESEARCH TRENDS & GAPS ASSESSMENT - WASTEWATER TREATMENT WITH COAGULATION AND FLOCCULATION METHODS

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Abstract

Industrial activities can cause negative impacts, one of which is the result of the production process which can cause pollution and environmental damage if the company does not process B3 waste in accordance with applicable regulations. With increasing concern for the environment, many companies or other interested parties are required to process liquid waste. Therefore, this study aims to find out from several existing research journals about the effectiveness of wastewater treatment methods and processes Poly Aluminum Chloride (PAC) and Aluminum Sulfate (Alum). The analysis method uses several software to find out the results of research analysis from several existing scientific literature. By using blibiometric analysis, it was found that research on wastewater treatment mostly uses coagulation and flocculation methods which have developed every year. To improve the results of wastewater treatment, it is necessary to consider several influencing factors such as dose, speed and duration of stirring during the experiment. From the results of several previous studies, it was found that the use of Poly Aluminum Chloride (PAC) was the most effective compared to Aluminum Sulfate (Alum) by comparing the decrease in the results of testing the specified quality standard parameters (for example pH,COD, BOD, turbidity, TSS, etc)

Keywords: ***Aluminum Sulfate (Alum), Coagulation, Flocculation, Poly Aluminum Chloride (PAC), Wastewater Treatment***

INTRODUCTION

The increasing development of industry causes several positive and negative impacts. The positive effects that can be caused are an increasing economy, creating jobs, etc. In addition, industrial activities can cause negative effects, one of which is the result of the production process which can cause pollution and environmental damage if the company does not process B3 waste in accordance with applicable regulations.

There are several materials that can be used as coagulants to reduce turbidity in raw water, one of which is Polyaluminium chloride (PAC). Polyaluminium chloride (PAC) as a special salt in the manufacture of aluminum chloride which is able to provide stronger coagulation and flocculation power than aluminum sulfate and can be a substitute for alum and dukem because it has a strong adsorption rate, high floc formation rate even in small amounts, and has a fast sedimentation rate so that it can clear water quickly compared to using both materials. PAC can be used because it has strong coagulation ability, is suitable for use in waste processing, can work more effectively, is cheaper and easy to operate, so that PAC provides better results compared to other coagulants.

Isran et al. (2023) stated that the processing of wastewater at the Morowali Metal Industry Polytechnic the combination of coagulation-flocculation and filtration methods the results is better PAC coagulant concentration of 240 ppm in and using better media thickness 6 cm in filtration processing can reduce COD values by 95%, turbidity by 95.78%, TDS by 74.03%, and conductivity by 74.29%. Achmad et. al. (2022) stated that the processing of pH and color removal in Water Treatment Plant Unit Pekanbaru, use of Alum, Soda Ash, Polymer produces a pH of 4.68 and a color of 43 PtCo which does not meet the quality standards. The use of PAC, Soda

Ash, Polymer produces a pH of 7.97 and a color of 15 PtCo which meets the quality standards. Putri et. al. (2024) stated the use of PAC coagulant is more effective than Aluminum Sulfate in reducing COD and BOD, where in this study a concentration of 10% was used. However, in reducing TSS, both have the same effectiveness. This study shows that PAC and Aluminum sulfate can reduce TSS by up to 96.8%. The effectiveness of PAC and Aluminum sulfate in reducing COD parameters looks better, which is 94.1% compared to Aluminum Sulfate, which is 81.3%. Likewise, in reducing BOD parameters, the two coagulants have a PAC efficiency of 94.2%, which is better than Aluminum sulfate with an efficiency of 83.2%.

This study aims to identify and analyze Systematic Literature Network Analysis (SLNA), this method a tools for review analysis research. We can used Systematic Literature review (SLR) and Bibliometric Analysis (BA),. By considering this, this study also explains the most effective methods and chemicals for the processing of wastewater treatment waste. As well as considering various scientific literature that has been obtained from research in various countries.

RESEARCH METHODOLOGY

Conceptual framework of the methodologies

In researh, using Systematic Literature Network Analysis (SLNA) or Systematic Literature review (SLR) and Bibliometric Analysis (BA).

From the conceptual framework of the methodology above, the following research questions arise:

a. RQ1 What are the current research trends and gaps assessment in the topic of wastewater treatment?
b. RQ2 How effective using Poly Aluminum Chloride (PAC) and Aluminum Sulfate (Alum) for wastewater treatment?
c. RQ3 What factors affect the results of test parameters according to quality standards?

The next step is a strategy to determine the appropriate metadata from scientific databases. From Page et al. (2021) we can used the PRISMA 2020 methodological guidelines. The criteria for selection and identification and evaluation of studies will be described in the following subsection, "Data Collection." Database was used retrieved on April 15, 2025 from scopus metadata. The Scopus database we can collect in the next step data collection to get a database that matches the criteria

Data Collection

In this data collection steps briefly explained by entering several keywords into the Scopus database, namely "Wastewater treatment", "coagulation and flocculation", "Poly Aluminium Chloride (PAC)" and "Aluminium Sulfate (Alum)".

Table 1. Inclusion and pre-processing criteria for bibliometric analysis

Analysis		Pre-precocessing Criteria
Co-authorship authors	-	In full counting, the minimum number of documents of an author is set to 2, the minimum number of citations of an author is set to 10, and the map shows all set of networks
Co-authorship countries	-	In full counting, the minimum numbers of documents of a country are set to 2, the minimum number of citations of a country is set to 10
Citation documents	-	In full counting, the minimum numbers of citations of a document are set to 4, minimum number of citations of a country is set to 20
Co-occurrence author keywords	-	In full counting, the minimum numbers of occurrences of a keyword are set to 2, and the map shows only the most extensive set of networks
Co-occurrence terms	-	Binary counting, the minimum number of therms occurences is set to 15
Word clouds	-	Transformation: lowercase, remove accents, parse
Topic Modelling	-	HTML
Multidimensional scalling	-	Tokenization: regexp, pattern \w+
Marginal topic probability	-	Filtering: stopwords (English); numbers; document frequency 0.10–0.90; regexp; LDA is set to 7 for title and abstract, and 6 for author keywords

First, 180 documents identified so that filtering was needed including the year of publication was limited from 2014 to 2025 (114 documents). Manual filtering was carried out by sorting documents based on title and abstract suitability. Finally, just 65 documents found to be included for bibliometric analysis. As for the content analysis to answer the questions (RQ2 and RQ3), the documents found after the inclusion step were all studied in depth, with additional references added in the literature review task.

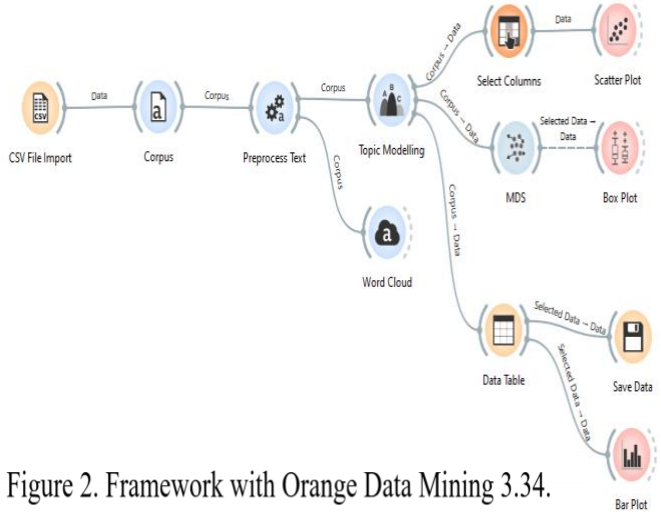


Figure 2. Framework with Orange Data Mining 3.34.

Data Analisys

In the research output software VOSviewer and Orange Data Mining 3.34 a comparison was made to obtain an overview of the research topic to be carried out. Before entering the analysis stage, a study is needed for mapping VOS, word cloud and topics (can be seen in Table 1). Table 1 will explain the sequence for the mapping process in more detail to find the data sources needed during the research.

a) VOS technique
Explanation of VOS technique with rends and gap research collected using metadata to be explained descriptively and can be visualized. In the next stage, several points to be analyzed such as author network, country, keywords, abstract, title can be reviewed first. From several visualization results that the VOS technique provides better results than other sets of metadata with distance-based maps.

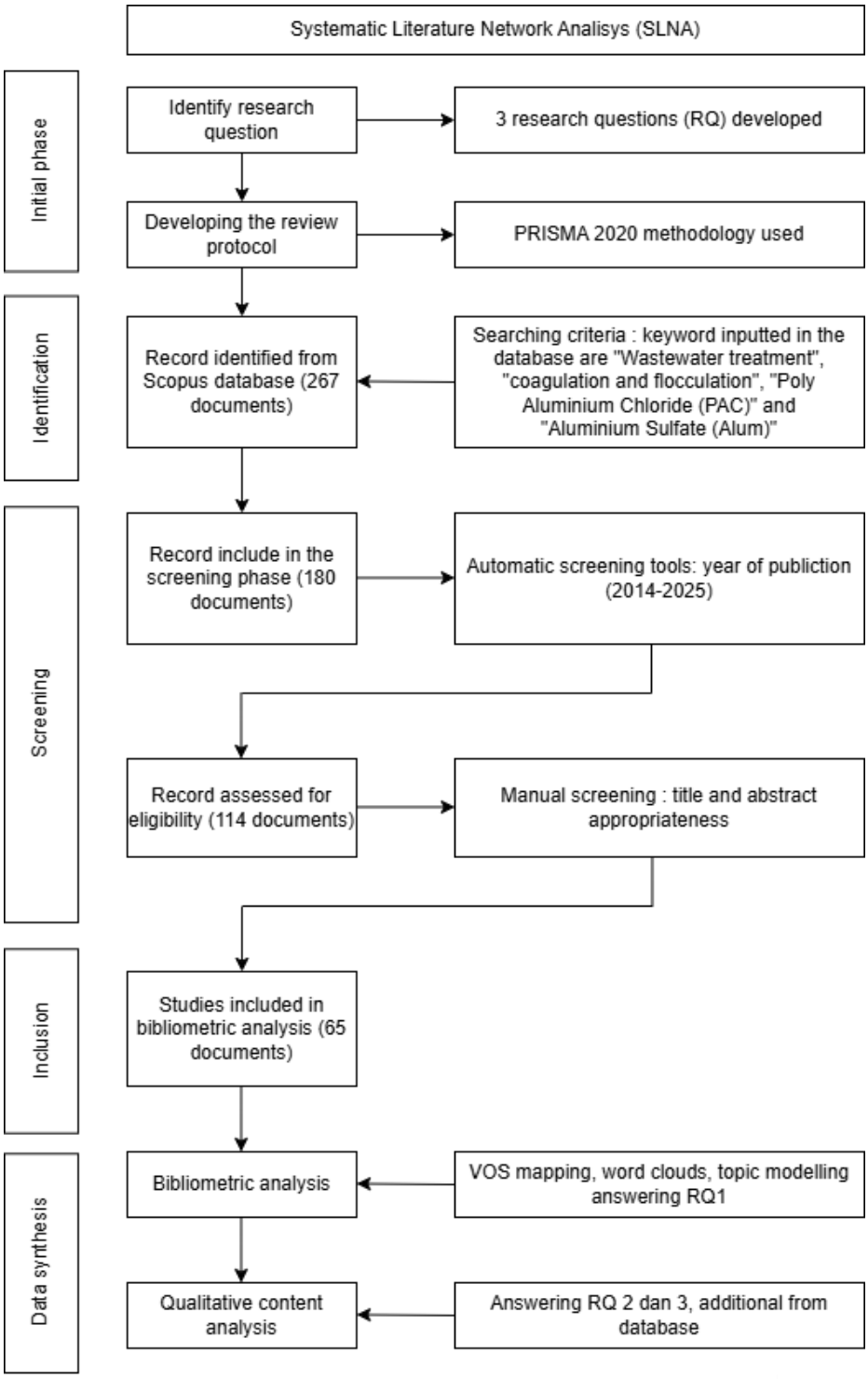


Figure 1. Conceptual framework of review methodologies.

Using similarity visualization (VOS) is an advantage of the VOSviewer software. In addition, it can display a collection of keywords and certain nodes based on their distance. The smaller the distance, the stronger the relationship between the two keywords or nodes. Therefore, keywords or nodes do not overlap in the VOS cluster map (van Eck and Waltman, 2010). The VOS map shows the relationship links between nodes and keywords. Links that have a higher value have a stronger connection, for example in two articles can show the same references, joint publications from two researchers, or the frequency of two terms appearing together in publications. Higher value links and thicker nodes indicate a strong relationship between two related nodes (Sawassi and Khadra, 2021).

This analysis can be conducted on the citation network, authors and countries. Just only the map authors and countries is displayed in the manuscript, while the results of co-citations and co-authorship are written in a table showing the most cited papers and the most productive authors in their fields such as in this study, namely citing wastewater treatment. This aims to find out and determine journals or articles that are different from the discussion of this topic. Several terms can be developed, such as the emergence of terms in the title and abstract that can be analyzed to understand the latest gaps and trends in this research. However, for some keywords, they can only represent the author, as well as the title and abstract of the metadata that has been collected. Keywords or terms that are included in research that have relationships and similarities can appear in the VOSviewer classification.

b) Topic model and word clouds

It can be seen in Figure 2, to visualize the corpus of several analyses such as topic models, word clouds can use VOSviewer. Feicheng and yating (2014 stated about word clouds on word size is defined as the frequency of words in the corpus. To find certain topics, you can use the central word in the cloud, while words that are smaller and further from the center are less frequently used. Meanwhile, to discuss latent topics in abstracts, titles or keywords that are further away, you can use Latent Dirichlet Allocation (LDA) in wastewater treatment studies. To create a list of keywords or terms with frequently used words together and group them into topics that frequently appear in each article based on the key terms used. (Li et al., 2021; Mohr and Bogdanov, 2013). LDA is different from the VOS technique because LDA is able to produce keywords that are the same or overlap with several other topics. LDA is also able to find several identified hidden or missing topics that cannot be detected by the VOS technique. Marginal topic probability (MTP) or MTP bar plots can be used to provide a visualization of topics in corpus text and sort out the strongest and weakest based on the output of the LDA model (Abayomi-Alli et al., 2022).

RESULT AND DISCUSSION

Bibliometric analysis results

In this section is a point to see the results of bibliometric analysis that includes several stages of identification, filtering, and inclusion. The analysis is focused on the results of VOS techniques, word clouds, and topic modeling (can be seen in figures 4,5,6,7,8).

a) Current research trends and status

At this stage of analysis, it begins by identifying research trends that have been collected in metadata through document publications. To evaluate research trends in order to understand the evolution and trends in scientific production. As shown in Figure 3, the number of publications in wastewater treatment research increased dramatically in 2017, decreased each year until 2024, and appeared to increase again in 2025. Therefore, as the commitment to the environment increases, research on wastewater treatment increases. Scientific literature on wastewater treatment can also be analyzed based on the journals that published the research, the country of affiliation of researchers (Figure 4). Based on the country affiliation with research contributors, China has the highest affiliation, followed by Indonesia, US, Poland, Turkey, Iran, Malaysia.

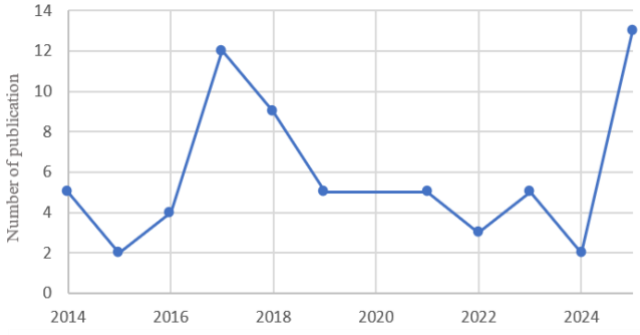


Figure 3. Scientific production of wastewater papers.

b) Title and Keywords (VOS Mapping)

Several findings can be generated based on the title and abstract text. Can be seen in Figure 5. The oldest terms are aluminum, filtration, efficiency, etc. which show that research before 2019 (purple cluster) is the method and materials used for liquid waste processing. Furthermore, research developed (green cluster) to explore the coagulation flocculation process, chemical water treatment, wastewater treatment, etc. Until 2021 (yellow cluster) and above, it developed with the addition of research for measuring water pollutants, chemical oxygen demand, turbidity removal, chemical removal, etc. According to the author's keywords in Figure 6, some interesting clusters and keywords can be generated. The newest keywords are ultrafiltration, floc properties, coagulation performance, response surface methodology, process optimization, coagulant aid, flocculation mechanism. The newest keywords show the influence on wastewater treatment process. In comparison, the oldest keywords talk about aluminum, filtration, efficiency. As shown in Figure 6(a), six keyword clusters can be generated. The furthest cluster group among the red clusters seems to discuss the coagulation flocculation management method. The light blue cluster is related to data processing or methodology using Response Surface Methodology (RSM) and environmental treatment optimization process. The green and dark blue clusters focus on wastewater treatment process (coagulation and flocculation) and the impact or test results. While the purple and yellow clusters discuss the chemicals used for wastewater treatment, namely poly aluminum chloride, etc.

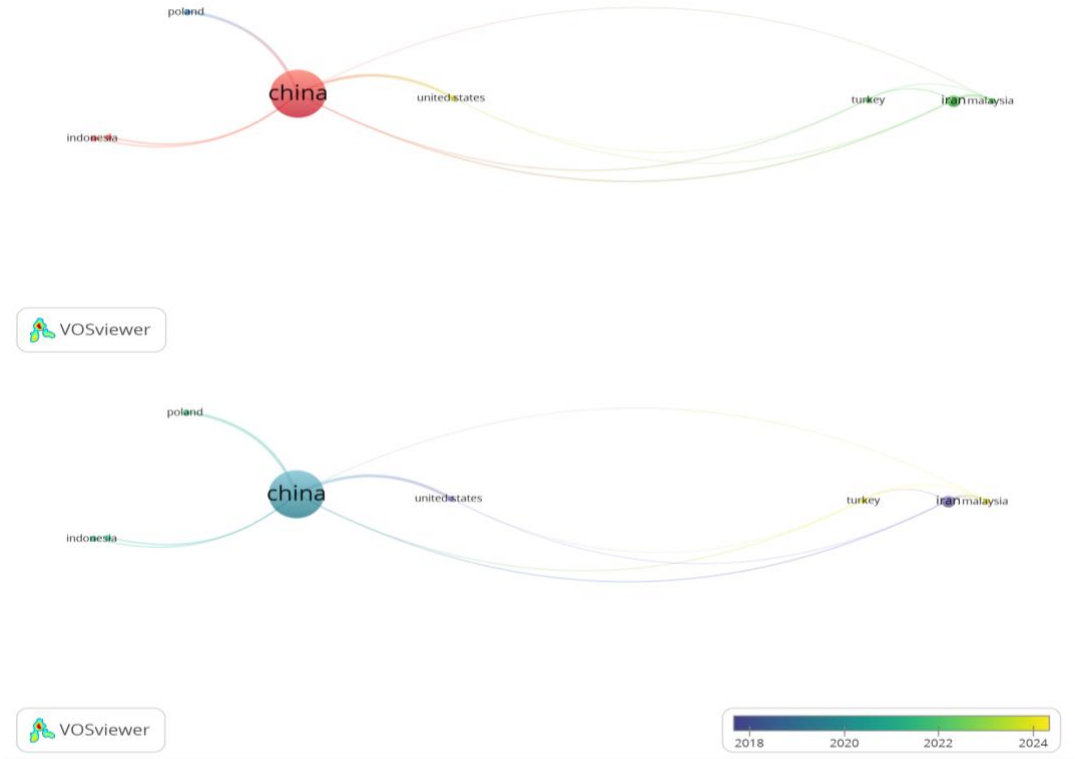
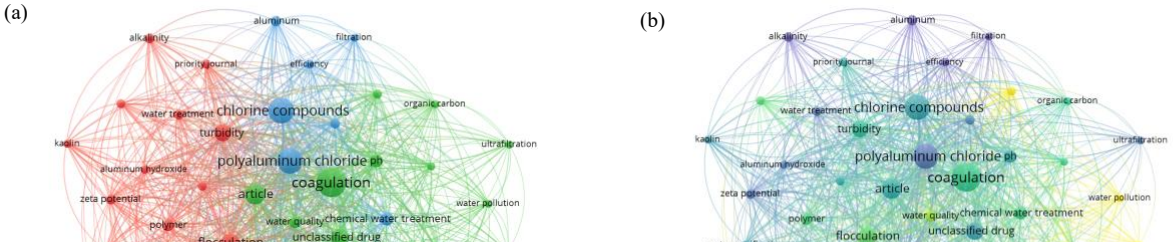


Figure 4. Co-authorship networks based on country affiliations: network visualization (a) and overlay visualization (b).



c) Word Clouds Model

In this step for word clouds of terms and keywords in Figure 7. Word clouds are used to represent the frequency of occurrence of keywords and terms in title abstracts based on their density in publications (Alnajem et al., 2021). Can we see in Figure 7(a), the highest frequency terms found in titles and abstracts are wastewater treatment (f = 57), coagulation and coagulant (f = 41), flocculation and flocculant (f = 19), and aluminum sulfate and poly aluminum chloride (f = 61).

In Figure 7(b), the most frequent terms found in author keywords are environmental engineering (f = 25), water (f = 14), journal (f = 19), and science (f = 17). The high frequency of poly aluminum chloride, aluminum sulfate, coagulation and flocculation indicate that these are the main themes or topics in the metadata. This can also indicate that the main focus of wastewater treatment is on the use of poly aluminum chloride, aluminum sulfate and the coagulation and

(a)

(b)

Table 2. List of generated topics by terms in title and abstract and author keyword

Topic Label	Terms in title and abstract	Topic label Author keywords	Topic label Author keywords
Topic 1 Processes of wastewater with coagulation treatment	Treatment, coagulation, water, removal, processes, wastewater	Topic 1 Polyaluminum chloride for coagulation and flocculation	Chloride, polyaluminum, coagulation, flocculation, high, surface, response, methodology
Topic 2 Optimization coagulation flocculation methode	Wastewater, treatment, coagulation, flocculation, optimization	Topic 2 Wastewater methode	Coagulationflocculation, water, organic, ultrafiltration, wastewater, dissolved
Topic 3 Wastewater treatment with aluminum chloride	Chloride, aluminum, treatment, coagulation, removal, wastewater	Topic 3 Wastewater methode and testing	Fouling, ultrafiltration, coagulation, flocculation, water, pH, fluoride, dimension
Topic 4 Wastewater treatment with coagulation removal	Treatment, wastewater, coagulation, removal, water	Topic 4 Coagulant mechanism with Poly Aluminum Chloride	Chloride, polyaluminum, wastewater, coagulant, mechanism, removal, floculant
Topic 5 Evaluation and analysis of floccution mechanism	Performance, evaluation, flocculation, mechanism, based, analysis	Topic 5 Optimization process wastewater treatment	Wastewater, coagulation, process, treatment, oxidation, floculant, removal, optimization,aluminum
Topic 6 Coagulation methode with polyaluminum chloride	Chloride, coagulation, polyaluminum, water, wastewater	Topic 6 Coagulation treatment	Coagulant, treatment, coagulation, PAC, turbidity, aluminum, oxidation
Topic 7 Processes of wastewater with coagulation treatment	Treatment, coagulation, water, removal, processes, wastewater		

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d) Topic modelling of title, abstract, and Keywords

Furthermore, for LDA topic modeling which can identify paticular corpus about several hidden and laten topics (Bhat et al., 2020). From Table 2, it can be seen that all the topics are also found in the VOS map (see Figure 5) There are the same keywords such as wastewater treatment, coagulation, flocculation, poly aluminum chloride, coagulant, flocculant, pH, turbidity, ultrafiltration, etc. However, there are some hidden keywords that only exist in the VOS map, namely water management, water pollution, chemical oxygen demand, etc.

We can be seen in Figure 8, topics 2 and 7the most significant MTP results in the title and abstract are in, which are related to Optimization of the coagulation flocculation method. From the other topics, the keywords that appear between topics 3 and 4 are almost the same, about wastewater treatment. While the author's keywords are in topic 4, namely the Coagulant Mechanism with Poly Aluminum Chloride. And the average is almost the same in topics 1, 5 and 6. Only contain topics 2 and 7 in the title and abstract, which are very similar. The third most prominent topic in the title and abstract is Topic 3 and 4, which are interpreted as factors that influence wastewater treatment management. This is followed by topics 5,6 and 1 about treatment methode.

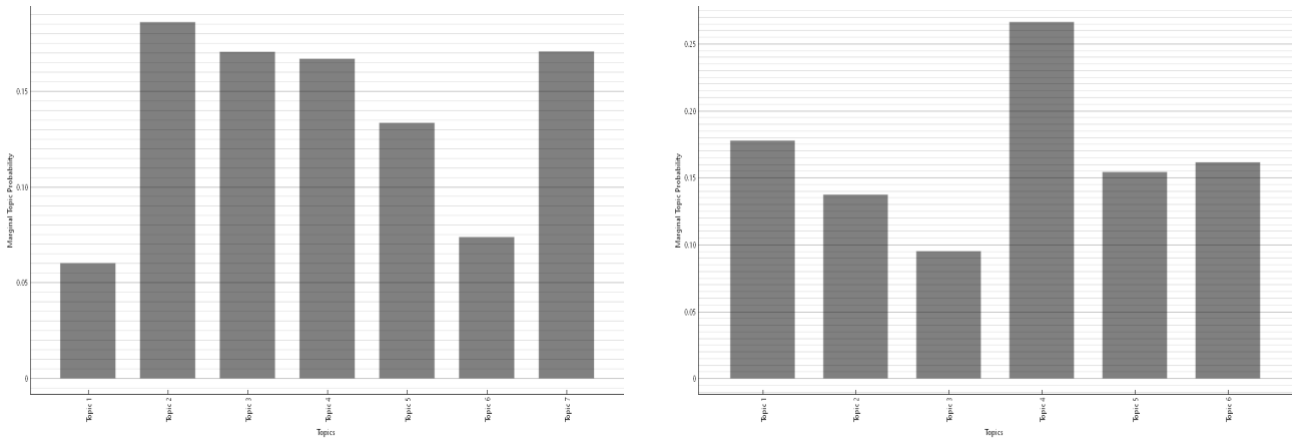

Figure 8. Marginal topic probability (MTP) of terms in title and abstract (above) author and keywords (below).

e) Wastewater Treatment

Waste is all waste produced by human and animal activities in the form of solids, sludge, liquids or gases that are discarded because they are no longer needed or wanted. B3 waste management is an activity that includes reduction, storage, collection, transportation, utilization, processing, and/or landfill. Everyone who produces B3 waste is required to manage the B3 waste they produce.

Coagulation and Floculation

The process of purifying water using coagulant or flocculant is one of the water treatment methods that is generally carried out at the beginning of the water treatment system. The addition of the coagulant/flocculant aims to form aggregates that form clumps that are bound to each other, namely between the coagulant/flocculant and the pollutant particles that are the target of elimination. The principle of the mechanism in this process is the creation of chemical coagulation which goes through the stages of destabilization of organic compounds which is continued by the process of binding pollutant particles that have been conditioned to be unstable so that they can form aggregates or colloids that separate from water molecules. The Coagulation Process can be carried out through the stirring stage between the coagulant and raw water and charge neutralization. The principle of coagulation is that in raw water there are solid particles, most of which are negatively charged. These particles tend to repel each other so that they remain stable in the form of colloids in water. Neutralization of the negative charge of solid particles is carried out by adding a positively charged coagulant to the water followed by rapid stirring. (Chen et al., 2015)

Andi et. al (2023) stated the research results that have been carried out show that this process can be used for various purposes including reducing organic pollutant content, reducing turbidity levels, dyes, and pathogens. Effective flocculant coagulant substances use PAC.

Coagulation is the process of destabilizing suspended particles and colloidal particles (including bacteria and viruses) by neutralizing their electrical charge so that the repulsive force between particles can be reduced and the material used to neutralize the charge is called a coagulant. While flocculation is the process of combining unstable particles after the coagulation process by slow stirring to form clumps or flocs so that they can be precipitated or filtered. (Rohana & Purwanti, 2019)

Jartest is a tool used to determine the level of turbidity of a sample. Jartest is usually used to evaluate coagulation-flocculation processes and determine the dosage of chemical additions. To reduce the level of pollutants in wastewater usually requires chemicals with a certain dosage. The use of jartest aims to optimize pollutant reduction by evaluating coagulants and flocculants.

Agents Effectiveness

Effectiveness is a measure of the success of achieving organizational goals. If the goal has been achieved, it can be said to be effective. The effectiveness indicator describes the range of consequences and impacts (outcomes) of program outputs in achieving program goals. The greater the contribution of the output produced to achieving the specified goals or targets, the more effective the work process of an organizational unit. In finding the effectiveness of the composition of materials for this study, there are two agents used to compare the results.

a) Poly Aluminium Chloride (PAC)

Poly Aluminum Chloride (PAC) is one of the effective coagulants used to bind flocs and form flocs into larger sizes. This is because PAC has an active Al_2O_3 content that binds flocs and reduces the zeta potential of colloids by releasing aluminum ions and binding anions in river water so that the repulsive force between colloid particles is reduced and the attractive force increases so that the flocs formed are larger and can settle by gravity. Poly Aluminum Chloride has the characteristics of a high positive electric charge so that PAC can easily neutralize the electric charge on the surface of the colloid and can reduce the repulsive force (electrostatic) between particles to the smallest possible so that the colloid particles can approach each other and form larger clumps or flocs.

Poly Aluminum Chloride (PAC) is a complex inorganic compound between hydroxyl ions (OH) and aluminum ions that undergo gradual chlorination. The chlorination reaction is a poly-neuclean (multinuclear atom) former with the general formula Aln (OH)mCl(3n-m). Or what is usually used for water treatment is PAC with the chemical formula $Al_{12}Cl_{12}(OH)_{24}$. PAC is in solid and liquid form as a monomer and polymer with a low molecular weight in the form of aluminum hydroxyl and soluble colloids. (Marlinda., et al. 2023)

b) Alumunium Sulfate (Alum)

Aluminum sulfate is a chemical compound with the formula $Al_2(SO_4)_3$ or better known as alum which is widely used in various industries, including as a coagulation agent in drinking water and wastewater treatment. helps to clarify water by binding particles and dirt so that they are easily removed. Alum is a white crystal and gelatinous which has properties that can attract small particles in water into larger particles in the form of flocs which become heavier and easier to settle.

Quality standard parameter

The standard quality parameters used in this study are the results of laboratory tests on pH, COD, BOD, turbidity and TSS.

a) Potential of Hydrogen (pH)

The definition of pH (Potential of Hydrogen) is the degree of acidity used to express the level of acidity or alkalinity of a solution. The pH quality standard used in accordance with the Regulation of the Minister of Environment Number 5 of 2014 is 6.0-9.0. pH an important role in the quality standards of liquid waste processing because an inappropriate pH can hinder the wastewater processing process and have a negative impact on the aquatic ecosystem, including the organisms that live in it.

This change in water pH is due to the greater the coagulant content added, the more H+ ions will be released into the water. The pH value of the addition of alum is relatively more stable than that of the PAC coagulant. This is due to the presence of H_2SO_4 compounds that affect H_2O compounds, thereby lowering the pH value of the water. Acidic solutions based on the activity of hydrogen ions (H+), H+ and OH– come from the ionization of H_2O molecules.

b) Chemical Oxygen Demand (COD) dan Biologycal Oxygen Demand (BOD)

Chemical Oxygen Demand (COD) is the amount of oxygen needed to decompose all waste materials contained in water, while Biological Oxygen Demand (BOD) is the oxygen needed by microorganisms to oxidize chemical compounds. The COD quality standard used in accordance with the Regulation of the Minister of Environment Number 5 of 2014 is 300 mg/L while for BOD is 150 mg/L.

If the ratio of coagulant addition can clarify wastewater, then the COD value or chemical oxygen demand can be reduced. However, the figures for the efficiency of reducing turbidity levels and COD content do not give the same results. This is because in wastewater there are not only organic compounds that are deposited, so the efficiency of COD removal is not the same as the efficiency of removing turbidity levels. COD is an important indicator to determine the level of organic pollutants in wastewater. COD measures the amount of oxygen needed to chemically oxidize organic substances in water, both easily and difficult to decompose. The higher the COD value, the more organic pollutants and the greater the potential for water quality degradation.

BOD gives an indication of the level of organic pollution in wastewater. If the BOD is high, it means that there is a lot of organic matter that needs to be broken down by microorganisms, which requires a lot of oxygen. High coagulant doses can clarify waste and reduce BOD values or biological oxygen demand.

c) Turbidity

Turbidity is the amount of suspended matter in water. Turbidity can be caused by various types of suspended material, the more suspended material the more turbid the water will look. Turbidity values are expressed in Nephelometric Turbidity Units (NTU). The turbidity quality standard used in accordance with the Regulation of the Minister of Health Number 32 of 2017 is 25 NTU. Turbidity is included in the wastewater quality standards because it can block sunlight, disrupt aquatic biota, and cause environmental pollution. High turbidity can also have an impact on water quality.

d) Total Suspended Solid (TSS)

Total Suspended Solid or total suspended solids in water are inorganic, organic, and liquid particles that cannot mix in water. The TSS quality standard used in accordance with the Regulation of the Minister of Environment Number 5 of 2014 is 400 mg/L. TSS (Total Suspended Solids) is included in the wastewater quality standards because high suspended solids content can have adverse effects on the environment and human health. TSS can cause water turbidity, block sunlight from entering, and disrupt the photosynthesis process of aquatic plants, which ultimately reduces oxygen in the water. In addition, TSS can also be a breeding ground for harmful bacteria and microorganisms. The TSS value can decrease due to the bonding of aluminum sulfate with colloidal particles to form flocs or particles with larger sizes. The particle clumps are easier to settle, so that the waste is free from floating solids and the appearance of the waste is clearer. This is what causes the TSS value to be lower than before processing.

Performance of treatment process

Hasan et. al (2020) stated the optimization process was carried out based on pH, coagulant dosage, mixing time and mixing speed. The optimal reduction efficiency for the color of the dye sample was 98.53%, while for

chemical oxygen demand it was 71.02%, for turbidity 85.89% and for total suspended solids 88.01%. The phytotoxicity concentration was 43.24%.

Xiang-juan et.al (2009) stated parameters affecting the process such as pH, dosage and settling time were determined using test tube experiments. 86.4% of color and 92.4% of chemical oxygen demand (COD) could be removed at pH 4, 50 mg/l H2O2, 25 mg/l FeSO4, and settling time of 30 minutes. Coagulation using polyaluminum chloride (PAC) and ferrous sulfate (FeSO4) was useful for improving the wastewater treated by the Fenton process in reducing floc settling time, increasing color and COD removal. The overall removal of color, COD, and suspended solids (SS) reached 100%, 93.4%, and 87.2% under certain conditions.

Audy et. al (2024) stated the use of PAC coagulant is more effective than Aluminum Sulfate in reducing COD and BOD, where in this study a concentration of 10% was used. However, in reducing TSS, both have the same effectiveness. This study shows that PAC and Aluminum sulfate can reduce TSS by up to 96.8%. The effectiveness of PAC and Aluminum sulfate in reducing COD parameters looks better, which is 94.1% compared to Aluminum Sulfate, which is 81.3%. Likewise, in reducing BOD parameters, the two coagulants have a PAC efficiency of 94.2%, which is better than Aluminum sulfate with an efficiency of 83.2%.

Shahin et.al (2009) stated about the research is under optimum conditions, COD removal of 62.8% was achieved using alum, while removal using PAC was 43.1%. Thus, the relatively low COD removal efficiencies of both PAC and alum reinforce the idea that coagulation-flocculation should be used as pre/post treatments for leachate treatment. In contrast, higher removal efficiencies for turbidity (94.0%), color (90.7%), and TSS (92.2%) were achieved using PAC than using alum (88.4%, 86.4%, and 90.1%) even though the alum dosage was almost five times higher than that of PAC. Therefore, this study revealed that PAC is more efficient in improving the physical characteristics of leachate than in removing COD; for this reason, PAC is recommended for wastewater treatment where COD is not a significant concern.

Ploypailin et. al (2024) stated about experimental results show that the in-line coagulation and flocculation system can effectively pretreat water to remove turbidity, offering advantages such as low energy consumption, shorter operating time, and higher removal efficiency compared to conventional methods at the same discharge rate. The proposed mathematical model is reliable. The process is promising as an easy-to-integrate alternative in compact water treatment plants and can be combined with other separation processes as a hybrid solution. Furthermore, further research and trials may be needed to validate the system performance in various scenarios and to ensure its reliability in various water sources and treatment contexts.

Omer et.al (2023) stated according to the results obtained in the study, the highest COD removal efficiency was obtained at 37% at pH = 7.0. Considering COD as the most important pollutant in PIWW, the contribution of independent variables to the process can be shown as pH > PACS dose > centrifugation time > revolutions per minute. In addition, according to the results obtained in the study, the highest color removal efficiency was found at 89% at pH = 8. The contribution of independent variables to the process can be given as pH > centrifugation time > PACS dose > revolutions per minute.

Behnam et.al (2023) state the result under optimal conditions, the amount of coagulant (17.5 ppm), flocculant (1 ppm), and agitator speed in fast mode (75 rpm) were reported, and the optimal sedimentation rate was 0.95 cm/min. The percentage of turbidity, total suspended solids, total dissolved solids, chemical oxygen demand, and biological oxygen demand of 100 (with an estimate of 0.01), 100 (with an estimate of 0.01), 53, 92, and 86% were obtained, respectively. All of these results were obtained at a confidence level of 0.95% with a confidence factor of 0.99%, which means that the experimental data are in good agreement with the modeling. In general, the combination of filtration method (Plackett-Burman) and response surface method (Box-Benkhen) can be applied to optimize the chemical coagulation process for wastewater treatment and processing.

CONCLUSION

This conclusion from bibliometric analysis can be drown from research on wastewater treatment has experienced significant growth years 2025 in recent years, with a surge in publications in 2014. The focus of research before 2019 was on wastewater treatment methods, while the latest term shows a growing shift in research to the results of testing wastewater quality standards. The analysis shows that several topics attract interest in wastewater treatment topics, including the use of more effective chemicals, factors affecting treatment success, etc. From research we also can be found gaps in the scientific literature on the impact of wastewater treatment on the surrounding environment. And thenfrom the bibliometric analysis wastewater treatment was limited to keywords entered in the Scopus database, which may result in bias and not reflect all publications on this topic. Although this limitation has been addressed by conducting a rigorous review in the next subsection using a narrative review, the

bibliometric analysis may not reveal all hidden gaps related to wastewater treatment study publications. Therefore, future studies should consider using other keywords to better visualize wastewater treatment studies.

Wastewater treatment is an effort to prevent environmental pollution, especially in the industrial sector. Therefore, this study reviews several studies that have been conducted on wastewater treatment that the use of poly aluminum chloride is more effective than aluminum sulfate and the specified standard quality parameters (for example pH, COD, BOD, turbidity, etc) produce better results using poly aluminum chloride

Dosage, speed, and time of stirring greatly affect the coagulation flocculation process because they affect the formation, size, and stability of flocs (clumps of particles) that separate small particles from water. The right dosage to ensure that the coagulant (a chemical that causes particles to lose their charge and come closer together) is effective in binding small particles and forming flocs. The optimal speed to help form larger and more stable flocs, making them easier to settle. Sufficient time to give enough time for particles to collide with each other, bond, and form larger flocs. In essence, the dosage, speed, and time of stirring must be optimized to obtain ideal flocs (large, stable, and easy to separate) in the coagulation flocculation process.

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REFERENCES

Abayomi-Alli, A., Abayomi-Alli, O., Misra, S., Fernandez-Sanz, L., 2022. "Study of the Yahoo-Yahoo hash-tag tweets using sentiment analysis and opinion mining algorithms". Information 13, 152.

Achmad F.R., Sri S., Anik S. 2022, "Pengaruh Variasi PAC, Soda Ash dan Polimer Terhadap Penyisihan pH dan Warna Pada Unit Instalasi Pengolahan Air Minum di Pekanbaru", Jurnal Ilmu Lingkungan, Vol.20, No.4:769-776.

Alibeigi-Beni, S., Habibi Zare, M., Pourafshari Chenar, M., Sadeghi, M., Shirazian, S., 2021. "Design and optimization of a hybrid process based on hollow-fiber membrane/ coagulation for wastewater treatment". Environ. Sci. Pollut. Control Ser. 28 (7), 8235–8245.

Alifah A.R., Arifin, Govira C.A., 2022, "Efisiensi Pengolahan Limbah Beton Ready-Mix Dengan Metode Elektrokoagulasi dan Adsorpsi", Vol.20, No.2:375-381.

Andi Asdiana I.S.Y., Herlina R., Fadlib, Melani G. 2023, "Optimasi Penambahan Polyalumunium Chloride (PAC) dan Waktu Pengadukan Terhadap Kualitas Air Baku (Raw Water) pada PPSDM Migas Cepu", Jurnal Teknologi Kimia Mineral, 2(1): 22-25.

Ardomoan S.S., Ferri F.G., Nurfitri W., Isna A. 2024, "Penerapan Metode Gabungan Netralisasi, Koagulasi, Filtrasi dan Adsorpsi dalam Pengelolaan Limbah Cair Laboratorium", Jurnal Teknologi Lingkungan Lahan Basah, Vol. 12, No. 1:097 – 105.

Ari S.S., Putri N.A.H., Sinta S.A., Dodit A. 2022, "Sistem Pengolahan Air Limbah PT Evonik Indonesia Plant Cikarang Wastewater Treatment System PT. Evonik Indonesia Cikarang Plant", Prosiding SAINTEK: Sains dan Teknologi,Vol.1, No.1.

Audy P.M., Dea K.F., Lisa A. 2024, "Efektivitas Koagulan PAC dan Aluminium Sulfat dengan Kombinasi Flokulan pada Limbah Cair Pabrik Sepeda Motor", Jurnal Sains dan Edukasi Sains, Vol.7, No.2:90-95.

Behnam Fayyaz Shahandashty, Narges Fallah, Bahram Nasernejad. 2023, "Industrial wastewater treatment: Case study on copper removal from colloidal liquid using coagulation", Journal of Water Process Engineering 53.

Bili´nska, L., 2017. "Decolorization of Textile Wastewater by Advanced Oxidation Processes (AOPs) under Industrial Conditions: Doctoral Thesis." Fundacja Rozwoju

Chaojian Ding, Aojie Xie, Ze Yan, Xiyuan Li, Hongfeng Zhang, Na Tang, Xiaocong Wang. 2021, "Treatment of water-based ink wastewater by a novel magnetic flocculant of boron-containing polysilicic acid ferric and zinc sulfate", Journal of Water Process Engineering, 40-101899.

Chen, W., Zheng, H., Teng, H., Wang, Y., Zhang, Y., Zhao, C., & Liao, Y. 2015, "Enhanced Coagulation-Flocculation Performance of Iron-Based Coagulants: Effects of PO43- and SiO32-". Modifiers.PLOSONE, 1-20.

Cukri Rahma dan Cukri Rahminiani. 2021, "Penggunaan Tawas ($Al_2(SO_4)_3$) dalam Menurunkan Kadar Total Suspended Solid Air Limbah Batubara", Jurnal Optimalisas, Vol.7, P. ISSN: 2477-5479 E. ISSN: 2502-0501.

Diego Gouveia Marques, Janaina de Melo Franco Domingos, Marcelo Antunes Nolasco, Valquíria Campos. 2025, "Textile effluent treatment using coagulation-flocculation and a hydrodynamic cavitation reactor associated with ozonation". Chemical Engineering Science 304.

Enze Li, Jing Dong, Yongsheng Jia, Zihe Pan, Hongzhou Lv, Zhiping Du, Guandao Gao, Fangqin Cheng. 2024, "Synergistic enhancement of pollutant removal from high-salt wastewater using coagulation-flotation combined process". Green Chemical Engineering.

Feicheng, M., Yating, L., 2014. "Utilising social network analysis to study the characteristics and functions of the co-occurrence network of online tags. Online Inf". Rev. 38, 232–247.

Fernando Hymnˆo de Souza, Bruno Segalla Pizzolatti, Maurício Luiz Sens. 2021, "Backwash as a simple operational alternative for small-scale slow sand filters: From conception to the current state of the art". Journal of Water Process Engineering 40

Gede H.C., Gilang G., Tri M. 2021, "Pengolahan Air Limbah Betalaktam Menggunakan Reagen Kaporit, PAC, dan Alum Sulfat", Serambi Engineering, Vol.6, No. 3, hal 2066 – 2075.

Hanbai Parka, Sung-il Lima, Hosun Lee, Dal-Sik Woo. 2016, "Water blending effects on coagulation-flocculation using aluminum sulfate (alum), polyaluminum chloride (PAC), and ferric chloride (FeCl3) using multiple water sources". Desalination and Water Treatment.

Hasan Shaheed, Radin Mohamed, Mohammed Al-Sahari, Nur Shaylinda M., Adel Al-Gheethi, Tuama Alomari. 2020, "Coagulation and flocculation of printing ink effluent using polyaluminium chloride (PAC): optimization and phytotoxicity study", Desalination Publications, 208:303–311.

Hassiba Zemmouria, Madani Drouichea, Amna Sayeh, Hakim Lounici, Nabil Mameri. 2012, "Coagulation Flocculation Test of Keddara's Water Dam Using Chitosan and Sulfate Aluminium". Procedia Engineering 33

Heloisa Pereira de S´a Costa, Meuris Gurgel Carlos da Silva, Melissa Gurgel Adeodato Vieira. 2021, "Biosorption of aluminum ions from aqueous solutions using non-conventional low-cost materials: A review". Journal of Water Process Engineering 40.

Isran A., Setiarto P., Makmur S., Fida I.U. 2023, "Pengolahan Limbah Cair B3 Laboratorium Kimia Menggunakan Metode Kombinasi Koagulasi-Flokulasi dan Filtrasi", Prosiding Seminar Nasional Teknologi Industri, e-ISSN 2964-1896.

Jiangting Wang, Weiying Xu, Jingjing Xu, Dong Wei, Hui Feng, Zhenghe Xu. 2016, "Effect of aluminum speciation and pH on in-line coagulation/diatomite microfiltration process: Correlations between aggregate characteristics and membrane fouling". Journal of Molecular Liquids 224 492–501.

Jinjun Deng, Zeyu Gu, Lingmin Wu, Ye Zhang, Yanbin Tong, Fankun Meng, Liqun Sun, Huili Zhang, Hongsheng Liu. 2023, "Efficient purification of graphite industry wastewater by a combined neutralization-coagulation-flocculation process strategy: Performance of flocculant combinations and defluoridation mechanism", Separation and Purification Technology, 326-124771.

Junhong Yi, Zanmei Chen, Defu Xu, Die Wu, Alan Howard. 2024,"Preparation of a coagulant of polysilicate aluminum ferric from foundry dust and its coagulation performance in treatment of swine wastewater". Journal of Cleaner Production 434.

Li, C., Liu, Z., Shi, R., 2021. "A bibliometric analysis of 14,822 researches on myocardial reperfusion injury by machine learning". Int. J. Environ. Res. Publ. Health 18, 8231.

Lingmin Wu, Yixiang Gao, Xiaofei Xu, Jinjun Deng, Hongsheng Liu. 2024, "Excellent coagulation performance of polysilicate aluminum ferric for treating oily wastewater from Daqing gasfield: Responses to polymer properties and coagulation mechanism". Journal of Environmental Management 356.

Manal F. Abou Taleb, Maha Ali Aljowni, Humaira Parveen, Sayeed Mukhtar. 2024, "Green coagulation and flocculation: Scenedesmus algal extractloaded chitosan/poly(vinyl alcohol) cryogels for effective water treatment". International Journal of Biological Macromolecules.

Marlinda, Rita Hartati, Yusi Hidjrawa, Kasmawati. 2023, "Optimalisasi Penjernihan Air PDAM Tirta Meulaboh Menggunakan Aluminium Sulfat (Tawas) dan Poly Aluminium Chloride (PAC)". Jurnal Optimalisasi Vol. 09, No. 01.

Mohr, J.W., Bogdanov, P., 2013. "Introduction—topic models: what they are and why they matter". Poetics 41, 545–569.

N. Fajri, M. Hadiwidodo, dan A. Rezagama. 2017, "Pengolahan Lindi dengan Metode Koagulasi-Flokulasi Menggunakan Koagulan Aluminium Sulfat dan Metode Ozonisasi untuk Menurunkan Parameter BOD, COD, dan TSS (Studi Kasus Lindi TPA Jatibarang)", Jurnal Teknik Lingkungan, vol. 6, no. 1, hal. 1–13.

Nada N. Abdulrazzaq, Baseem H. Al-Sabbagh, Haider A. Shanshool. 2021, "Coupling of electrocoagulation and microflotation for the removal of textile dyes from aqueous solutions". Journal of Water Process Engineering 40.

Nugeraha N., Sumiyati S., & Samudro G. 2010, "Pengolahan Air Limbah Kegiatan Penambangan Batubara Menggunakan Biokoagulan : Studi Penurunan Kadar Tss, Total Fe Dan Total Mn Menggunakan Biji Kelor (Moringa Oleifera)". Presipitasi, 7(9), 57–61.

Nurdiani. 2020, "Penentuan Optimasi Koagulan PAC dan Alum pada Air Limbah Tekstil Dengan Metode Jar Test". Warta Akab Vol. 44. No. 1.26-31.

Omer Apaydin, Ugur Kurt, Fatih Ilhan. 2023, "Investigation of the treatability of paint industry wastewater using hybrid coagulant poly-aluminum-chloride-sulfate". Desalination and Water Treatment.

Pengyu Dong, Jin Li, Akalu M. Woldeyohans, Dries Parmentier, Stijn W.H. Van Hulle. 2024, "Coagulation in combination with anaerobic digestion for enhancement of resource recovery from faecal sludge". Journal of Environmental Management 358.

Ploypailin Romphophak, Ratchanan Chamnanmor, Pattarasiri Fagkaew, Sermpong Sairiam, Pisut Painmanakul. 2024, "Modelling the predictive analysis of turbidity removal efficiency in the in-line coagulation and flocculation process". Chemical Engineering Research and Design 210.

Putri Nadia Berliana, Restu Hikmah Ayu Murti, Wahyu Dwi Utomo. 2023, "Kajian Pengelolaan Limbah Bahan Berbahaya dan Beracun (B3) PT. X". Jurnal Sains dan Teknologi.

Qi Li, Yanyan Zhong, Yalan Zhang, Wei Liu, Yuansong Tian, Tian Qin, Mengting Wu, Wenrong Xiong, Zhiqin Chen, Yuankai Zhou, Xiaohao Guo, Jinying Xu, Sunlin Chi, Yondong Zhang, Zhengyu Jin, Xianchuan Xie. 2025, "Simple synthesis and excellent coagulation performance of a novel red soil-based coagulant". Separation and Purification Technology 359.

Riskiana Nurjannah, Elida Novita, Sri Wahyuningsih. 2022, "Penentuan Dosis Koagulan pada Musim Hujan di PDAM Jember Unit Tegal Gede". Repository Universitas Jember Berkala Ilmiah Pertanian.

Rohana, H., & Purwanti, S. T. 2019, "Uji Optimasi Ekstrak Daun Ipomoea Batatas L . Yang Digunakan Sebagai Flokulan Dalam Pengolahan Air Untuk Praktikum Pada Mata Kuliah Kimia Analisis Lingkungan". Jurnal Inovasi Dan Pengelolaan Laboratorium, 9–20.

Rosalina Hasan dan Aisha Khoirunnisa. 2024 "Efektivitas Koagulan Aluminium Sulfat dan Poly Aluminium Chloride (PAC) pada Pengolahan Limbah Cair B3 PT X", Warta Akab, Vol.48, No.1, Hal:5-14.

Rosariawari F dan Muhammad M. 2013, "Efektifitas PAC dan Tawas Untuk Menurunkan Kekeruhan Pada Air Permukaan". Jurnal Ilmiah Teknik Lingkungan Vol.5.

Sarah Goudjil, Saadia Guergazi, Toufik Masmoudi, Samia Achour. 2021, "Effect of reactional parameters on the elimination of Congo Red by the combination of coagulation–floculation with aluminum sulfate". Desalination and Water Treatment.

Sawassi, A., Khadra, R., 2021. "Bibliometric network analysis of "water systems' adaptation to climate change uncertainties": concepts, approaches, gaps, and opportunities." Sustainability 13, 6738.

Shahandashty B.F., Fallah N., Nasernejad B. 2023, "Industrial wastewater treatment: Case study on copper removal from colloidal liquid using coagulation". Journal of Water Process Engineering 2214-7144.

Shahin Ghafari, Hamidi Abdul Aziz, Mohamed Hasnain Isa, Ali Akbar Zinatizadeh. 2009, "Application of response surface methodology (RSM) to optimize coagulation–flocculation treatment of leachate using poly-aluminum chloride (PAC) and alum". Journal of Hazardous Materials 163.

Shargi E.A dan Davarpanah L. 2022, "Optimization of chemical coagulation–flocculation process of detergent manufacturing plant wastewater treatment for full scale applications : a case study". Desalination and Water Treatment 262 38–53.

Sirikan Noonpui, Paitip Thiravetyan, Woranan Nakbanpote, Suchapa Netpradit. 2010, "Color removal from water-based ink wastewater by bagasse fly ash, sawdust fly ash and activated carbon". Chemical Engineering Journal 162 503–508.

Sisnayati, Eddyanto W., Yhopie, Selvia A. 2021, "Perbandingan Penggunaan Tawas dan PAC Terhadap Kekeruhan dan pH Air Baku PDAM Tirta Musi Palembang". Jurnal REDOKS Vol. 6 No. 2. 107-116.

van Eck, N.J., Waltman, L., 2010. "Software survey: VOSviewer, a computer program for bibliometric mapping". Scientometrics 84, 523–538.

Wei Chena, Huaili Zhenga, Jun Zhaia, Yili Wang, Wenwen Xue, Xiaomin Tang, Zhengan Zhang, Yongjun Sun. 2015, "Characterization and coagulation–flocculation performance of a composite coagulant:poly-ferric-aluminum silicate-sulfate". Desalination and Water Treatment 56 1776–1786.

Xiang-Juan Ma, Hui-Long Xia. 2009, "Treatment of water-based printing ink wastewater by Fenton process combined with coagulation". Journal of Hazardous Materials 162 386–390.

Xiaolong Wu, Xian Xiang, Xiaoxu Dong, Guangshuo Chai, Ziman Song, Yongxiang Wang, Jia Liu, Xinpu Han, Yajie Li, Hongbo Liu. 2021, "Profitable wastewater treatment by directly recovering organics for volatile fatty acids production". Journal of Water Process Engineering 40.

Yao, L., Zhang, Y., Wei, B., Li, L., Wu, F., Zhang, P., Bian, Y., 2016. "Concept over time: the combination of probabilistic topic model with wikipedia knowledge". Expert Syst. Appl. 60, 27–38.

Yasha Jathan and Eric A. Marchand. 2024, "Enhanced coagulation for removal of dissolved organic nitrogen in water: A review". Chemosphere 366.

Yonglei Wang, Wentao Sun, Luming Ding, Wei Liu, Liping Tian, Yinhe Zhao, Mengyu Zhang, Xuelin Wang. 2021, "A study on the feasibility and mechanism of enhanced co-coagulation dissolved air flotation with chitosan-modified microbubbles". Journal of Water Process Engineering 40.

Yoshihiko Matsui, Nobutaka Shirasaki, Takuro Yamaguchi, Kenta Kondo, Kaori Machida, Taiga Fukuura, Taku Matsushita. 2017, "Characteristics and components of poly-aluminum chloride coagulants that enhance arsenate removal by coagulation: Detailed analysis of aluminum species". Water Research 118.

Yutong Kang, Jie Wang, Zhenjun Li. 2024, "Enhancing pollutants removal in hospital wastewater: Comparative analysis of PAC coagulation vs. bio-contact oxidation, highlighting the impact of outdated treatment plants". Journal of Hazardous Materials 471.