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Optimization of Chemical Dosage in External Water Treatment Plant

Yulisa Nurvera Silaban[a], Gani Supriyanto[b], Rengga Arnalis Renjani[c]

[a]*Departement of Agricultural Engineering, Faculty of Agricultural Technology, Stiper Agricultural University Yogyakarta, Indonesia*
[b]*Chemical Engineering Department, Engineering Faculty, Universitas Sebelas Maret, Surakarta, Indonesia 57126*

*Corresponding author: yulisasilaban@gmail.com

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ABSTRACT. This research focuses on determining the optimal doses of aluminum sulfate ($Al_2(SO_4)_3$) and soda ash (Na_2CO_3) in the water treatment process at the External Water Treatment Plant (EWTP). Improper use of chemicals can lead to waste and negative environmental impacts. Therefore, the jar test method was employed to evaluate the effect of various dose ratios on water quality parameters, including pH, Total Dissolved Solids (TDS), and turbidity. The study results indicate that the combined doses of alum and soda ash significantly impact all three water quality parameters. The optimal point is achieved at an alum:soda ash dose ratio of 1.24–1.26. This ratio provides the best balance between increasing pH, decreasing turbidity, and controlling TDS. Consequently, this research offers important recommendations for enhancing the efficiency and sustainability of the water treatment process.

1. INTRODUCTION

Water is a vital resource for various industrial sectors, including manufacturing facilities. In a factory environment, water is not only used for consumption but also serves as a feed for Boilers, in the production process, for engine cooling, and for sanitation purposes [10]. The quality of the water used has a significant influence on operational efficiency and the quality of the final product. Therefore, proper water treatment is crucial to ensure the water meets the established quality standards.

However, in the treatment of water in factories, there are various problems faced, research shows that reservoir water as a source of raw water often does not meet the necessary quality standards. The main problem faced is the high level of turbidity and acidic pH, which can disrupt the production process and cause damage to the equipment [3]. Additionally, the use of chemicals in water treatment processes is often not optimized, which can result in waste and negative environmental impacts [6]. This study proposes the optimization of the dose of chemicals, especially alum and soda ash, in the water treatment process at the external water treatment plant. With proper dosage adjustment, it is expected to improve water quality, neutralize pH, and reduce turbidity, so that the water produced meets the standards for domestic and industrial purposes [8].

According to [1], the optimal dose of PAC coagulant to reduce turbidity is 1-3 ml, with best results when it rains. The study showed that PAC was more effective than alum and succolite in reducing turbidity (in NTU units). These findings underscore the importance of selecting coagulants and setting proper process parameters in water treatment. Although the information from Khairunnisa (2023) is an important foundation, the main focus of this study is to optimize the dosage of chemicals in the context of water treatment in factories. The novelty of this research lies in a more specific approach in optimizing the dosage of alum and soda ash, as well as analyzing their impact on pH, TDS, and turbidity. It is hoped that this research can make a significant contribution to improving the efficiency of water treatment in factories and minimizing its environmental impact.

The purpose of this study is to analyze the effect of variations in the dosage of alum and soda ash on changes in pH, TDS, and turbidity in the water treatment process. In addition, this study aims to determine the optimal dose that can meet the water quality standards required for domestic and industrial purposes. Thus, the results of this study are expected to provide useful recommendations for plant managers in an effort to improve the quality of water used

2. MATERIALS AND METHODS

In this study, we used several important measuring tools. To measure the level of turbidity, we use the EUTECH TN-100 IR Portable Turbidity Meter. The pH measurement was carried out with the pH Meter HI 1230 B/HI 1230B, while the Total Dissolved Solids (TDS) level was measured using the TDS Meter Myron L 532t1. The materials we use include raw water as the main sample, as well as two types of chemicals: Aluminum Sulfate ($Al_2(SO_4)_3$) and Soda Ash (Na_2CO_3).

The water quality testing process begins with water sampling in the dry season from a representative location using clean bottles. After collection, initial measurements were taken for pH, Total Dissolved Solids (TDS), and turbidity parameters. pH measurement is carried out with a pH Meter probe, TDS is measured using a TDS Meter, and turbidity is measured with a Turbidity Meter. Furthermore, jar test experiments were carried out to observe the effect of coagulants on water quality. Raw water samples were prepared in beaker glass with varying doses of coagulant/flocculant added. The stirring process is carried out in stages, starting with rapid stirring followed by slow stirring, before the sample is allowed to settle.

After the *jar test experiment* was carried out, the data obtained were analyzed to determine the optimal dose of alum and soda ash. The dosage ratio is calculated by the formula:

$$A = \frac{Al}{Sa} \tag{1}$$

where, A = Comparison
Al = Aluminum Dosage
Sa = Soda Ash Dosage

To analyze the study's results, we tabulated pH, TDS, and turbidity measurements and then graphed them to identify trends in water quality changes. Furthermore, statistical tests were conducted to determine if there was a significant difference between doses. The analysis process begins with a test for normality and homogeneity. If the data shows a normal and homogeneous distribution, we use *an independent sample t-test*. However, if the data are abnormal or inhomogeneous, the Mann-Whitney U test is applied to compare the two treatment groups.

3. RESULTS AND DISCUSSION

3.1. Raw water quality

Good water quality is characterized by several properties, including being tasteless, colorless, and odorless. Based on the standards that have been set, water quality that meets the good criteria has a pH in the range of 6.5 to 8.5 (Permenkes RI, number 907/MENKES/SK/VII/2022). The quality of the raw water obtained from the reservoir is presented in Table 1.

Table 1. Raw Water Quality Test Results and Standards

No.	pH	Standard	TDS (ppm)	Standard (ppm)	*Turbidity* (NTU)	Standard (NTU)
1.	5,99	6,5 - 7,6	40	> 100	53,1	≤ 1
2.	5,99	6,5 - 7,6	36	> 100	46,6	≤ 1
3.	5,95	6,5 - 7,6	36	> 100	39,5	≤ 1
4.	5,99	6,5 - 7,6	40	> 100	37,6	≤ 1
5.	5,94	6,5 - 7,6	40	> 100	43,3	≤ 1
6.	5,89	6,5 - 7,6	40	> 100	56,1	≤ 1
Average	5,96	6,5 - 7,6	38,67	> 100	46,03	≤ 1

Source: Secondary Data, 2024

Based on Table 1, the average test results for the pH parameters of raw water showed a value of 5.96, which was below the set standard (6.5-7.6). This indicates that the water is acidic. Furthermore, in the TDS parameter, the average obtained was 38.67 ppm, which was also well below the specified standard (>100 ppm). The turbidity parameter had an average value of 46.03 ppm, which was below the standard (≤ 1 ppm). This high level of turbidity can negatively impact the content of dissolved oxygen in water [5]. Additionally, high turbidity also indicates the presence of suspended particles, which can originate from soil erosion, organic matter, or other pollutants.

3.2. Comparison of alum and soda ash dosage against pH

The change in the dosage of Alum and Soda Ash to pH can be seen in Figure 1.

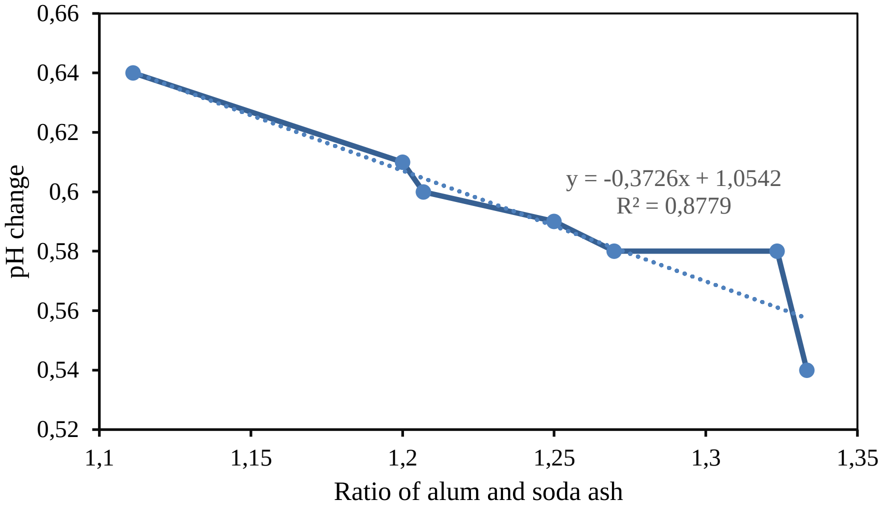

Figure 1. Changes in alum and soda ash dosage to pH

The graph above shows a decrease in pH, accompanied by an increase in the use of alum, although the use of soda ash is in smaller amounts. However, the effectiveness is evident in the increase in pH. At a ratio of 1.11, the increase in pH reached 0.64, while at a ratio of 1.33, the increase in pH was only 0.54. Based on the linear regression equation showing that every increase in the ratio of alum and soda ash leads to a decrease in the increase in pH, it can be concluded that there is a negative relationship between the ratio of alum and soda ash to the increase in pH that the higher the ratio, the lower the pH is measured. The chemical reactions of Sodium Carbonate (Na_2CO_3) to neutralize the pH are:

$$Na_2CO_{3(s)} + 2HCl_{(aq)} \rightarrow 2NaCl_{(aq)} + H_2O_{(l)} + CO_{2(g)}$$

In this process, sodium carbonate reacts with hydrochloric acid to produce sodium chloride, water, and carbon dioxide gas. This reaction helps to neutralize the pH of the solution, which is acidic in nature. Soda ash is known to be very soluble, so it effectively increases the pH of water when used [9]. On the other hand, alum has the property of 0% basicity, which actually causes a decrease in the pH of raw water upon its addition.

Table 2. Statistical analysis of the effect of alum and soda ash dosage on pH

Independent Samples Test											
Levene's test for equality of variances				t-test for equality of means							
F			Sig.	t	df	Significance		Mean difference	Std. error difference	95% confidence interval	
						One-side p	Two-sided p			Lower	Upper
The effect of alum and soda ash dosage on pH	Equal variances assumed	4.214	0.063	20.914	12	<0.0001	<0.001	0.65000	0.03108	0.58228	0.71772

The results showed a t-value of 20.914 with a very low p-value (< 0.001) in both tests, regardless of whether the same variance was assumed or not. These findings clearly indicate a very significant difference between the average pH produced by the dose of alum and soda ash. This means that both doses significantly affect the pH of the water. Thus, managers can adjust the dosage of these chemicals more accurately to achieve the desired pH level of the water.

3.3. Comparison of alum and soda ash dosage against TDS

The comparison of the Dosage of Alum and Soda Ash to TDS can be seen in Figure 2. From the graph presented, it is clear that the increase in the ratio of alum to soda ash is positively correlated with an increase in TDS. Specifically, TDS shows an increase from 31.3 to 80, while the ratio varies between 1.11 and 1.37. Although there was a slight decline between the ratios of 1.32 and 1.33, this did not change the overall upward trend. An R^2 value of 0.9597 indicates that 95.97% of the variation in the increase in TDS can be explained by changes in the ratio of alum and soda ash. This indicates a strong and positive correlation between the two variables. This phenomenon aligns with Aditya Syahputra's (2020) explanation, which states that the soda ash's soda properties, which are easily soluble in water, are the primary cause of the increase in dissolved solids (TDS) levels during experiments. The process of dissolving soda ash during stirring directly contributes to the increase in TDS in raw water. So, the more soda ash is added, the higher the TDS value will become.

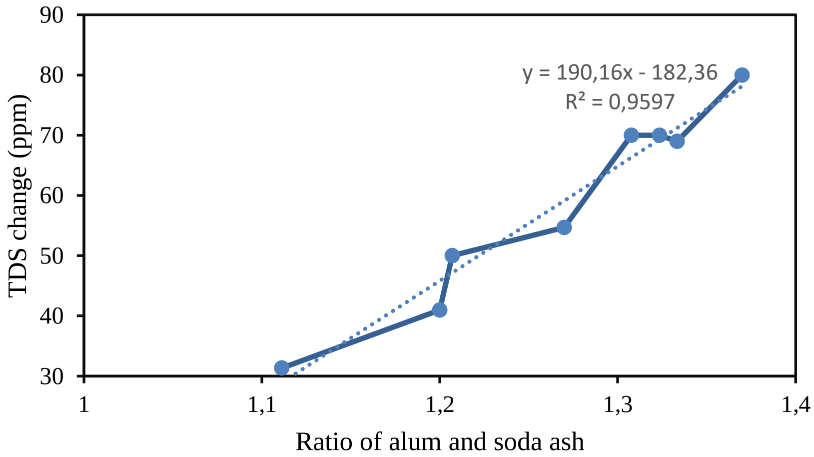

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Table 3. Statistical analysis of the effect of alum and soda ash dosage on TDS

	Effect of alum and soda ash dosage on TDS
Mann-Whitney U	.000
Wilcoxon W	36.000
Z	-3.363
Asymp. Sig. (2-tailed)	<.001
Exact Sig. [2*(1-tailed Sig.)]	<.001b

Based on statistical analysis, a very significant difference was found. This is shown by the Mann-Whitney U value of 0.000 and a p-value of less than 0.001. In addition, the Z-value of -3.363 further strengthens the evidence of a strong difference. From these findings, it can be concluded that the dosage of alum and soda ash significantly affects the level of Total Dissolved Solids (TDS) in water. This difference is most likely due to the unique chemical properties of each material, which directly impacts the amount of solids dissolved in the water.

3.4. Comparison of alum and soda ash dosage against turbidity

The effect of Alum and Soda Ash Dosage on pH can be seen in Figure 3. Based on the graph, the decrease in turbidity increases with the increase in the concentration of alum and soda, although there are fluctuations in some concentrations. At a ratio of 1.11, the decrease in turbidity was 39.0, while in a comparison of 1.37, the decrease in turbidity reached 52.7. However, there are fluctuations at some points such as in the comparison of 1.27 and 1.33. This illustrates that there are other factors beyond the dose of alum and soda ash that may affect turbidity.

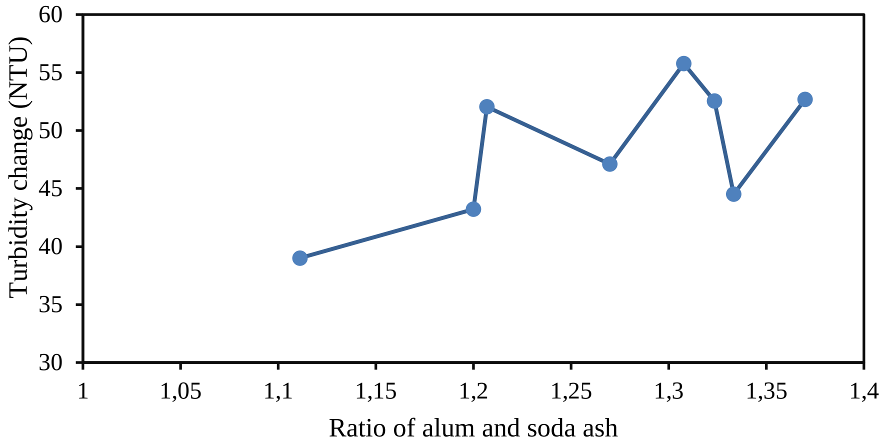

Figure 2. Effect of alum and soda ash dosage on turbidity reduction

. The chemical reactions to aluminum sulfate ($Al_2(SO_4)3$) chemicals to reduce turbidity are:

$(Al_2(SO_4)3) \rightarrow 2(Al_3) + 3SO_4^{2-}$

Al_3 + colloid(-) → floc(+)

In an effective dosage range, the coagulation and neutralization effects can be well managed. Alum ($Al_2(SO_4)_3$) acts as an agent capable of dispersing positively charged colloids. These colloids then bind to finely charged particles in water. This process effectively neutralizes the particle charge, which further forms small flocs that settle more easily. Thus, the level of turbidity in raw water can be significantly reduced (Noraida 2018).

Table 4. Statistical analysis of the effect of alum and soda ash dosage on turbidity

	Effect Of Alum and Soda Ash Dosage on Turbidity Reduction
Mann-Whitney U	0.000
Wilcoxon W	36.000
Z	-3.363
Asymp. Sig. (2-tailed)	<.001
Exact Sig. [2*(1-tailed Sig.)]	<.001b

Because the turbidity parameter is abnormally distributed and has heterogeneous variance, data analysis was carried out using the Mann-Whitney U Test. In addition, the Z-value of -3.361 also reinforces the evidence of strong differences between the two treatment groups. Therefore, the dosage of alum and soda ash significantly affects the level of turbidity of the water. This difference is most likely due to each chemical's unique ability to precipitate turbidity-causing particles present in the water.

3.5. Analysis of the amount of chemical doses to the volume of water

The water volume of each treatment is 500 ml, but the dosage of the chemical varies between 90–173 mg/l. Since the volume of water is fixed, the difference in dosage causes the actual amount of chemicals to be put in is also different. The calculation is:

Total chemical (mg) = Dose (mg/l) × Volume of water (l) (2)

For example: 95 mg/l × 0.5 l = 47.5 mg

173 mg/l × 0.5 l = 86.5 mg

Based on the calculations, an increase in dosage in mg/l means that the actual amount of chemicals added to the water is also increasing. So, even if the volume of water remains 500 ml, the water treatment will vary according to the dosage given. Higher concentrations of chemicals can indeed speed up and strengthen reactions. However, keep in mind that high doses do not always produce the best effects due to the presence of a saturation point of effectiveness. This has a direct effect on the effectiveness of water treatment processes, such as coagulation, flocculation, or precipitation. According to (Ningsih and Harmawan 2022), the metal ions will be hydrolyzed by aluminum sulfate coagulants, producing aluminum hydroxide flocs and hydrogen ions. Furthermore, these hydrogen ions will react with the alkalinity of the water, causing a decrease in the pH value. This reaction can be described as follows:

$Al_2(SO_4)3.18H_2O \rightarrow 2Al_3 + 3SO_4^{2-}$
$2Al_3 + + 2Al_3 + 18\ H_2O \rightarrow 2Al(OH)3 + 6H+ + 3SO_4^{2-} +12\ H_2O$

3.6. Dosage interactions with water quality changes

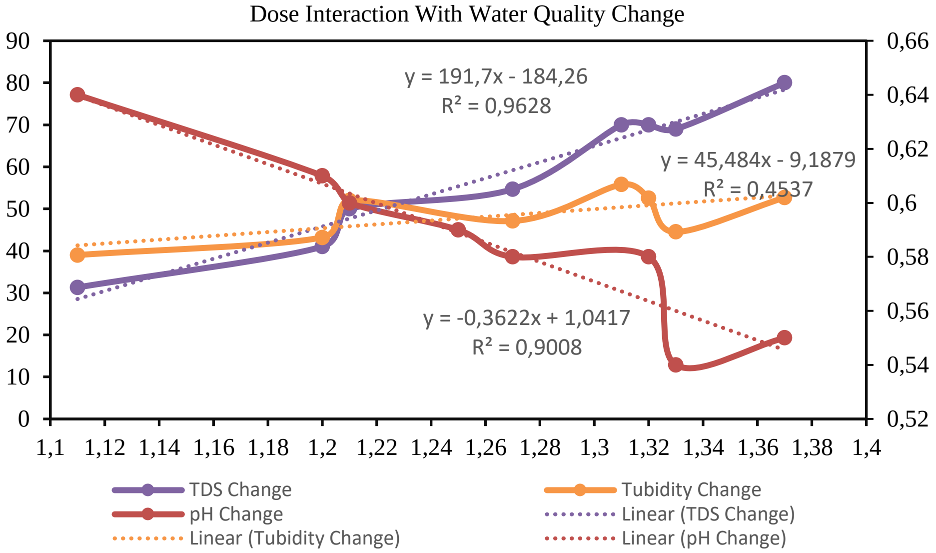

Figure 4. Optimum Dosage

Doses of alum and soda ash interact in a complex manner that can affect pH, TDS and turbidity, when low doses may not be enough to flocculate the particles so that pH and TDS remain low but turbidity is relatively high, when moderate doses reach optimal balance where turbidity decreases significantly but pH and TDS begin to increase due to the addition of chemical compounds and when high doses of TDS continue to increase in line with the decrease in turbidity and pH indicating that chemicals contribute more to TDS than turbidity reductions as well as pH increases. The optimal dose point is in the approximate ratio between 1.24 to 1.26 from the ratio of alum and soda ash where at that point is the intersection between pH and TDS and turbidity.

4. CONCLUSION

Based on the results of the study, reservoir water used as a source of raw water has not met quality standards for domestic and industrial purposes because it has an acidic pH and a high level of turbidity. The addition of soda ash has been shown to increase the pH of water, while the use of alum is effective in reducing the level of turbidity. However, the combination of the two chemicals also causes an increase in the amount of dissolved solids (TDS) in the water. The higher the dosage ratio of alum and soda ash, the greater the effect on changes in pH, TDS, and turbidity. However, there are other factors that also affect water treatment results. The optimal dose point is in the approximate ratio between 1.24 to 1.26 from the ratio of alum and soda ash where at that point is the intersection between pH and TDS and turbidity.

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