**Int. j. adv. multidisc. res. stud.** 2023; 3(4):936-942

**Received:** 27-06-2023
**Accepted:** 07-08-2023

International Journal of Advanced Multidisciplinary Research and Studies

ISSN: 2583-049X

# Analysis of the Optimum Dosage of Poly Aluminum Chloride (PAC) Coagulant to Reduce Turbidity and TDS in the Raw Water of the Bengawan Solo River During Morning and Afternoon at Semanggi Water Treatment Plant, Perumda Surakarta

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**Abstract**

The Bengawan Solo River serves as a surface water source utilized by the PDAM Kota Surakarta for clean water treatment. In the process of water treatment, one of the most critical steps is coagulation-flocculation. Through this process, colloidal particles responsible for turbidity are destabilized, leading to their agglomeration and subsequent autonomous settling. Given the fluctuating turbidity of water during the rainy and dry seasons, it becomes imperative to conduct research to determine the optimal dosage of Poly Aluminium Chloride (PAC) coagulant during morning and afternoon periods. The primary objective of this study is twofold: firstly, to ascertain the average percentage reduction of turbidity and total dissolved solids (TDS) in raw water at the Semanggi Water Treatment Plant; secondly, to establish the requisite dosage of PAC coagulant necessary to achieve the turbidity and TDS quality standards mandated for drinking water. The research method employed in this study involved a scale-down approach utilizing the jar test apparatus, which served as a means of coagulation-flocculation and sedimentation processes.

The research findings indicate that, on average, the efficiency of turbidity reduction during the morning was 96.74% and TDS reduction was 50.80%. In the afternoon, the efficiency of turbidity reduction was 98.01%, and TDS reduction was 53.76%. The optimum dosage of PAC coagulant required to achieve the Turbidity Standard in the Indonesian Ministry of Health Regulation No. 492/MENKES/ PER/ IV/ 2010 for both morning and afternoon periods was found to be 15.71 mg/l and 15.28 mg/l, respectively.

**Keywords:** River Water, Poly Aluminium Chloride (PAC), Coagulation-Flocculation, Turbidity, TDS

## 1. Introduction

Clean water and drinking water are essential necessities for society. Additionally, clean water plays a crucial role in the agricultural and industrial sectors. Therefore, the Regional Drinking Water Company (PERUMDA) holds a vital role in fulfilling the needs for clean water and drinking water in a specific region (Wityasari, 2015) [1]. The Drinking Water Treatment Plant (IPA) located in the Semanggi region is managed by the Regional Drinking Water Company (PERUMDA) of Surakarta City (Hereafter, Perumda Kota Surakarta). Perumda Kota Surakarta operates three Drinking Water Treatment Plants (IPA), namely IPA Semanggi, IPA Jebres, and IPA Jurug. The water sourced from the Bengawan Solo River is utilized by PERUMDA Surakarta for the production of clean and drinking water. The raw water at IPA Semanggi, originating from the Bengawan Solo River, passes through urban areas, which is estimated to result in high water turbidity. Poly Aluminum Chloride (PAC) is employed as the coagulant in the Semanggi IPA. However, an analysis of the effectiveness and economic value of this coagulant has not been conducted. Therefore, this study is carried out to address this issue. The rationale for this research is supported by the findings of Sugiarto (2007) [2], who compared the use of Poly Aluminum Chloride (PAC) in IPA Semanggi. The research demonstrated that the utilization of PAC coagulant was more effective in terms of water quality and cost aspects. Generally, in water sources such as wells or rivers, turbidity occurs due to the influence of the surrounding environment. This phenomenon is possible due to the presence of dissolved substances in the soil or surface water infiltration that have been contaminated by organic or inorganic materials that are not filtered by the soil. The primary concern in conventional drinking water treatment is to remove turbidity and other contaminants present in the raw water. The focus of conventional water treatment is on how to eliminate water turbidity and other pollutants found in the raw water, such as rivers

(Winarni, 2003) [3]. Turbidity is an optical property that occurs due to light scattering by dispersed particles in water, forming colloids, which are fluids with finely dispersed particles that remain suspended in a medium (Qalbih, 2021) [4]. The level of water turbidity is one of the parameters used to assess the suitability of water for consumption. According to the Indonesian Ministry of Health Regulation No. 492 of 2010 on the requirements for safe drinking water, safe drinking water must meet the physical, microbiological, chemical, and radioactive requirements stated in the mandatory and additional parameters. This regulation stipulates that the maximum acceptable level of water turbidity for drinking water is 5 NTU. Water turbidity levels can be measured using a turbidity meter. Coagulation refers to the destabilization produced by compressing the electric double layers surrounding all colloidal particles, while flocculation refers to destabilization through the adsorption of large organic polymers and the subsequent formation of particle-polymer-particle bridges (Webber, 1972) [5]. The main materials causing river water turbidity are clay and mud sediments, fine organic and inorganic substances, algae, and microscopic organisms (Minnesota Pollution Control Agency, 2008) [6]. Water turbidity is caused by the suspension of chemical and biological particles, leading to water pollution in the raw water supply and aesthetic issues in the drinking water supply system. High water turbidity can cause health problems due to the presence of pathogenic bacteria. High water turbidity leads to increased use of disinfectants during the disinfection process (WHO, 2017) [7]. Natural factors that can cause increased water turbidity include surface water flow from heavy rainfall, resuspension of sediment from the riverbed due to turbulent rain, suspended small organisms in pond water (plankton, algae, cyanobacteria), dead organic matter in the water column, wood ash from forest fires reaching the river's surface, algal growth during summer in lakes and slow-moving rivers. On the other hand, human-induced factors contributing to water turbidity include erosion of the watershed due to changes in land use, such as construction, agriculture, forestry, and urban development, which result in soil being carried away in surface water runoff. Improper disposal of untreated wastewater and algal growth due to the use of fertilizers can also lead to increased nutrient levels in slow-moving water bodies like lakes or rivers (EPA, 2021) [8]. Total Dissolved Solids (TDS) always refers to the quantity of dissolved substances in water. TDS includes salts, minerals, metals, calcium, and other organic and inorganic compounds. In simple terms, TDS represents the total amount of dissolved solid materials present in water (In, 2019) [9]. TDS measurement involves evaporating an evaporation dish at a temperature of 180 degrees Celsius and weighing the residue (Baird, Eaton, and Rice, 2017) [10].

Coagulants are known to be highly effective in removing dissolved residues during the water purification process. One type of coagulant used is Poly Aluminum Chloride (PAC), and there are many other common types of coagulants. PAC is a complex organic compound containing hydroxyl ions and chlorine-activated aluminum ions, forming polynuclear compounds with the general formula Alm(OH)nCl(3m-n) (Sofiah, 2015) [11].

Poly Aluminum Chloride (PAC) is utilized as the coagulant in the Semanggi IPA. However, an analysis of its effectiveness and economic value has not been conducted yet. Therefore, this research is conducted to analyze the aforementioned aspects. The basis for this study is the findings of Sugiarto's research (2007 Sugiarto (2007) [2]), which compared the usage of Poly Aluminum Chloride (PAC) as a coagulant in IPA Semanggi of PERUMDA Surakarta. Sugiarto's study concluded that the utilization of PAC coagulant was more effective in terms of water quality and cost aspects.

Through field surveys conducted by the researcher, it was found that the process of determining the optimum dosage of coagulant at PDAM Semanggi is not being conducted adequately, at least once a day. With this fact in mind, the researcher became interested in investigating how to determine the optimum dosage of coagulant daily, during both morning and afternoon periods. Based on these considerations, the researcher proposes the following research title: **"Analysis of the Optimum Dosage of Poly Aluminum Chloride (PAC) Coagulant to Reduce Turbidity and TDS in the Raw Water of the Bengawan Solo River during Morning and Afternoon at IPA Semanggi, PERUMDA Surakarta."**

## 2. Research Methods

The chosen research method was descriptive analysis. The descriptive analysis method serves to describe or provide an overview of the object under investigation through collected data or samples as they are, without conducting analysis and drawing general conclusions.

### Time and Place

1. Research Site

This research was conducted in the Environmental Engineering Laboratory, Environmental Engineering Study Program, Faculty of Engineering, Universitas Kristen Teknologi Solo.

2. Research Period

The research was conducted in March 2023, lasting for 7 days in the morning and evening.

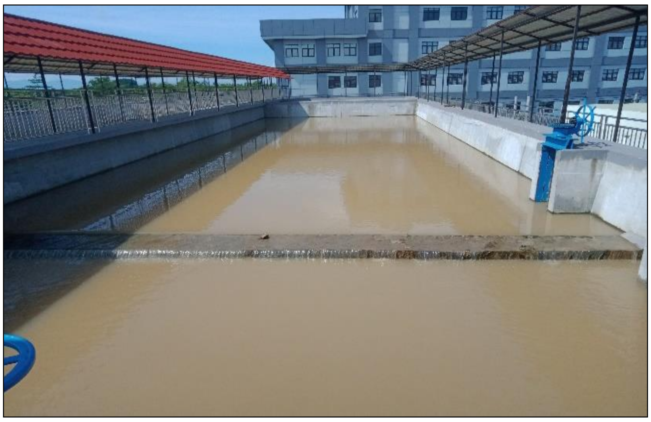


**Fig 1:** Sample Collection Site at the presedimentation tank

### Tools and Materials

1. Materials

The materials used in this research included raw water samples from the Pre-Sedimentation tank, Poly Aluminum Chloride (PAC), and Aquades (purified water).

2. Tools

The research also utilized various equipment, such as the Jar Test apparatus, Calculator, Turbidity Meter, Beaker Glass, Jerry Can, pH Meter, Stopwatch, Total Dissolved Solid (TDS) Meter, Measuring Pipet, and Stirrer.

To determine the optimum dosage of the coagulant Poly Aluminum Chloride (PAC) used to reduce turbidity in raw water, the researchers conducted jar test experiments.

The following steps were followed in conducting the jar test: Prior to conducting the jar test, the parameters of the raw water to be treated, namely turbidity and TDS, were measured. The jar test was performed on the raw water samples following these steps:

1. The raw water sample was divided into 6 beakers of 1000 ml capacity each, commonly known as jar test glasses.
2. Each jar test glass was then dosed with different amounts of Poly Aluminum Chloride (PAC) coagulant, with dosage ratios of 12, 13, 14, 15, 16, and 17 ml.
3. After adding the PAC coagulant, rapid stirring was performed at 140 rpm for 1 minute.
4. Subsequently, the stirring speed was reduced to 40 rpm for 10 minutes to simulate the coagulation-flocculation process. The stirring was then stopped to observe the settling process.
5. The settling process was allowed to proceed for 20 minutes.
6. After the 20-minute settling period, the turbidity parameter of the water resulting from the jar test was measured to determine which jar with the addition of PAC (Poly Aluminum Chloride) has the most optimum dosage.

## 3. Findings and Discussion

### 3.1 Result

The samples used in this research were taken from the surface of the Pre-Sedimentation Tank at the Semanggi Water Treatment Plant (IPA Semanggi), which draws its raw water from the Bengawan Solo River. The purpose of collecting samples from the Pre-Sedimentation Tank is because the raw water in this tank has undergone sedimentation of suspended particles, leaving behind only colloidal particles. As a result, the turbidity parameter values are relatively stable and do not experience significant fluctuations. The sample preparation process involved rinsing the sample three times with the sample water to remove any organic and inorganic materials that are not part of the sample, ensuring that the sample remains uncontaminated. The prepared sample was then collected in a container with an appropriate amount of water.

After collecting the samples, the research parameters, such as turbidity, pH level, and total dissolved solids (TDS), were analyzed. Turbidity was measured using a Turbidity Meter, total dissolved solids was measured using a TDS Meter, and the pH level was measured using a pH Meter. Measuring these initial parameter values serves the purpose of documenting the quality of the raw water, providing a baseline for comparison with the variables to be investigated in the research.


**Fig 2:** Raw water sample before coagulation-flocculation process

### 3.2 Data Analysis Technique

The data used for the analysis in this project was obtained from laboratory testing using the jar test method. Subsequently, observation and data analysis activities were conducted. The observation activities involved the process of studying changes in specific conditions of the observed materials carried out in the laboratory. In this research, observations were conducted over the course of one week, both in the morning and afternoon, at the Laboratory of Universitas Kristen Teknologi Solo. The analyzed data from this research are presented in Table 1.

**Table 1:** Morning jar test result for turbidity and Ph

| Day no. | Optimum Dosage of PAC (mg/l) | Initial turbidity data | Coagulation-Flocculation process result | Efficiency | Standard quality values | pH |
|---|---|---|---|---|---|---|
| Thursday, 2 March 2023 | 17 mg/l | 167 NTU | 5 NTU | 97.01% | 5 NTU | 7 |
| Friday, 3 March 2023 | 14 mg/l | 190 NTU | 6 NTU | 96.84% | 5 NTU | 6 |
| Saturday, 4 March 2023 | 17 mg/l | 113 NTU | 3.01 NTU | 97.25% | 5 NTU | 5.9 |
| Sunday, 5 March 2023 | 16 mg/l | 188 NTU | 4.29 NTU | 97.71% | 5 NTU | 6.9 |
| Monday, 6 March 2023 | 15 mg/l | 120 NTU | 5 NTU | 95.83% | 5 NTU | 7 |
| Tuesday, 5 March 2023 | 17 mg/l | 191 NTU | 5.1 NTU | 95.3% | 5 NTU | 6 |
| Wednesday, 8 March 2023 | 14 mg/l | 190 NTU | 5.23 NTU | 97.24% | 5 NTU | 6.9 |

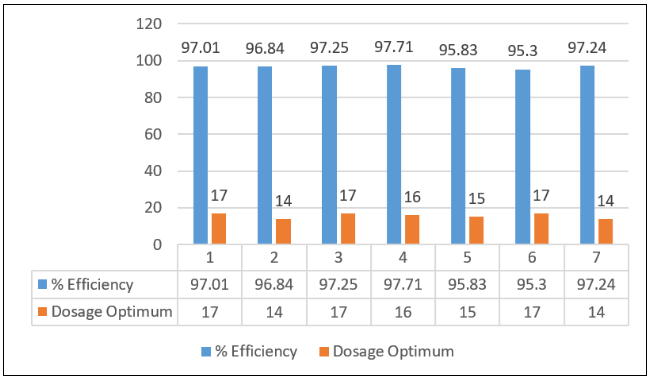



**Fig 3:** The relationship between the optimum dosage of PAC coagulant and the efficiency of turbidity reduction in the morning

In the morning jar test results presented in Table 1, it can be observed that the initial turbidity parameter data had varying values ranging from 113 NTU to 191 NTU. After undergoing the coagulation-flocculation process, there was a reduction in turbidity values ranging from 3.01 NTU to 6 NTU. From Fig 3, it is evident that the efficiency of the coagulation-flocculation process varies between 95.3% and 97.71%. The table also shows that the results of the coagulation-flocculation process are below the standard drinking water quality, which is 5 NTU, although not all of them experienced reductions in line with the drinking water quality standard, as indicated on days 2, 6, and 7, in accordance with the regulations stated in the Minister of Health Regulation No. 492/MENKES/PER/IV/2010 on the requirements for drinking water quality. Additionally, from Table 1, it is evident that the pH values remained stable and were within the acceptable range according to the established drinking water quality standards. These pH values indicate that the coagulation-flocculation process can occur optimally, providing favorable conditions for the process to work effectively.

**Table 2:** Afternoon jar test result for turbidity and Ph

| Day no. | Optimum Dosage of PAC (mg/l) | Initial turbidity data | Coagulation-Flocculation process result | Efficiency | Standard quality values | pH |
|---|---|---|---|---|---|---|
| Thursday, 2 March 2023 | 15 mg/l | 227 NTU | 5 NTU | 97.79% | 5 NTU | 5 |
| Friday, 3 March 2023 | 17 mg/l | 227 NTU | 5 NTU | 97.79% | 5 NTU | 5 |
| Saturday, 4 March 2023 | 16 mg/l | 202 NTU | 5 NTU | 97.52% | 5 NTU | 6 |
| Sunday, 5 March 2023 | 16 mg/l | 208 NTU | 5 NTU | 97.59% | 5 NTU | 6 |
| Monday, 6 March 2023 | 14 mg/l | 281 NTU | 5.01 NTU | 98.21% | 5 NTU | 7 |
| Tuesday, 7 March 2023 | 14 mg/l | 222 NTU | 5.02 NTU | 97.74% | 5 NTU | 7 |
| Wednesday, 8 March 2023 | 15 mg/l | 279 NTU | 1.54 NTU | 99.44% | 5 NTU | 6 |

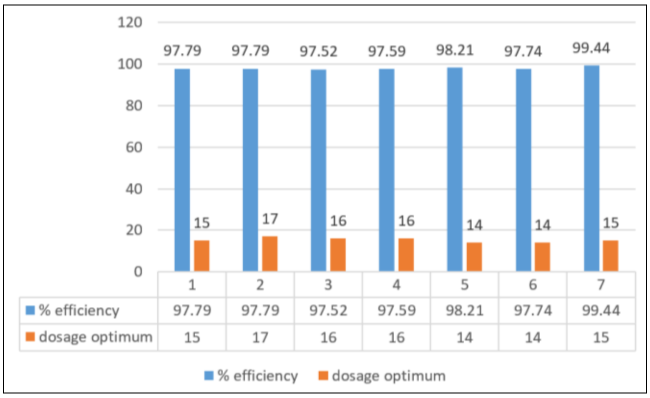


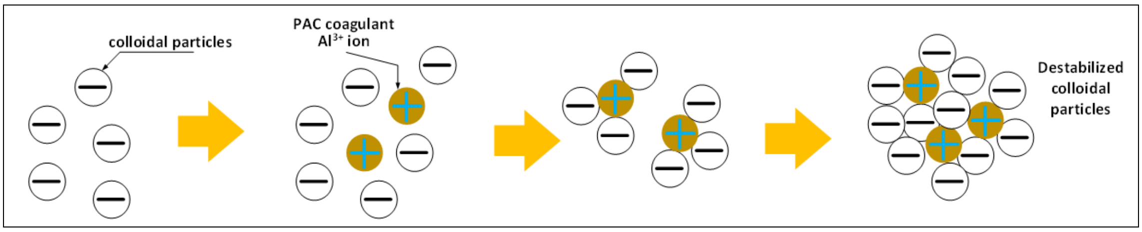

**Fig 4:** The relationship between the optimum dosage of PAC coagulant and the efficiency of turbidity reduction in the afternoon

From the results presented in Table 2 of the afternoon jar test, it is evident that the initial turbidity parameter data had varying values ranging from 202 NTU to 281 NTU. After undergoing the coagulation-flocculation process, there was a reduction in turbidity values ranging from 1.54 NTU to 5 NTU. In Fig 4, the coagulation-flocculation process exhibits treatment efficiency that varies significantly, ranging from 97.52% to 99.44%. Table 2 also shows that the results of the afternoon coagulation-flocculation process are below the standard drinking water quality, which is 5 NTU, although not all of them experienced reductions in line with the drinking water quality standard, as indicated on days 5 and 7, in accordance with the regulations stated in the Minister of Health Regulation No. 492/MENKES/PER/IV/2010 on the requirements for drinking water quality. Additionally, from Table 2, it is evident that the pH values remained stable and were within the acceptable range according to the established drinking water quality standards, allowing for an optimal coagulation-flocculation process.

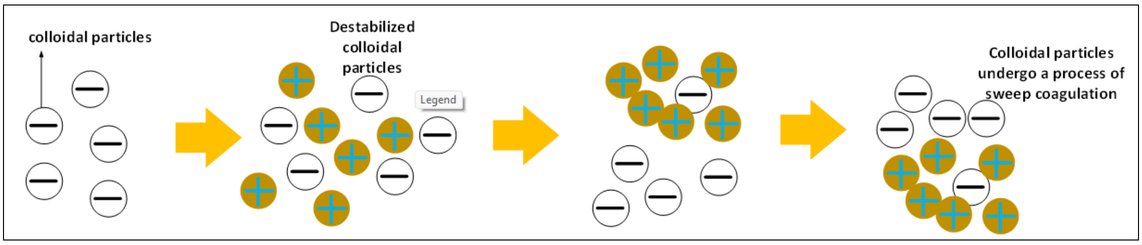
Based on the theory of coagulation-flocculation, it is a water treatment process that destabilizes colloidal particles, and flocculation is the subsequent process where the destabilized particles form larger aggregates. The coagulation-flocculation method is influenced by several factors such as the type and dosage of coagulant, pH, and stirring speed.

These factors affect the effectiveness of the coagulation process. In this study, the coagulation-flocculation value decreased due to the process being conducted in accordance with the factors that can influence the coagulation-flocculation process. One of the factors that contribute to the reduction in turbidity is time. The fluctuations in turbidity are caused by the presence of suspended and dissolved organic and inorganic materials (e.g., mud and fine sand), as well as plankton and microorganisms.

The mechanisms of the coagulation-flocculation process to destabilize colloidal particles causing water turbidity can be explained by three processes: charge neutralization, sweep coagulation, and bridging polymers.




a.

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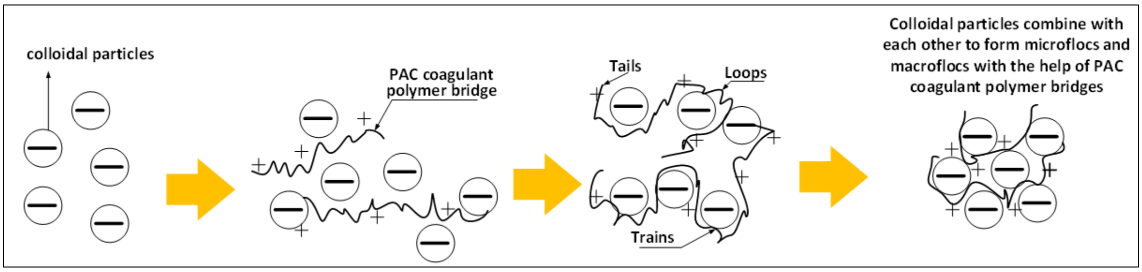


c.

**Fig 5:** Coagulation-Flocculation process a. Charge Neutralization, b. Sweep coagulation c. Bridging Polymer (Kurniawan *et al*., 2020) [12]

The neutralization of colloidal particle charges is achieved by adding PAC coagulant with the aim of forming soluble hydrolyzed $Al^{3+}$ cations and metal hydroxide flocculation $Al(OH)_3$ (Bolto, 2006) [13]. When coagulant is added to water, several hydrolysis species are formed. These positively charged species depend on the pH conditions. The positively charged species will attach to the negatively charged particles of the colloidal particles, reducing or neutralizing their negative charge. This neutralization of colloidal particles leads to a reduction in the repulsive forces between them (American Water Works Association, 2011) [14]. As depicted in the figure above, the colloidal particles that cause water turbidity are generally negatively charged. When PAC coagulant is added to the river water, it forms $Al^{3+}$ cations. These $Al^{3+}$ cations attach to the surface of the colloidal particles, reducing their ability to repel each other but causing attractive van der Waals forces between the colloidal particles and the $Al^{3+}$ cations from the PAC coagulant.

The colloid trapping mechanism typically involves the addition of a sufficient amount of coagulant that precipitates as hydrous metal oxide. The amount of coagulant used often exceeds the quantity needed to neutralize the colloidal particle charges. Charge neutralization can occur, but a significant portion of the colloidal particles are washed away by the treated water and entrapped by the $Al(OH)_3$ (hydrous deposition oxide floc) ions. This mechanism is known as sweep coagulation (Zeta Meter Inc, 1993) [15]. The sweep flocculation of the colloidal particles formed during the flocculation process significantly influences the final results of the jar test, where the ability of Al(OH)3 to trap colloidal particles is directly related to the size of the flocs formed during the flocculation process (Wulan *et al*., 2010) [16]. The hydroxyl groups in the PAC coagulant can undergo stronger adsorption on the colloidal particles, leading to the formation of flocs and binding or combining with the colloidal particles, known as sweep flocculation (Ives, 1978) [17]. This situation occurs in PAC coagulants, which are polymers based on Al with long chains and large amounts of charges capable of adsorbing colloidal particles. As shown in the above figure, Al3+ ions will combine to form flocs to adsorb destabilized colloidal particles (Putri and Soewondo, 2010) [18].

Polymer bridging is preceded by polymer adsorption. Due to the strong affinity between the long-chain polymer and colloidal particles, the long-chain polymer can attach to the surface of colloidal particles. Parts of the polymer will adhere to the colloidal particles, while other parts form loops and tails. These loops and tails are the main structures where the loop acts as a polymer connecting bridge, and the tail allows the attachment to other colloidal particles, forming larger flocs (Nimesha *et al*., 2021) [19]. As depicted in the figure, when PAC coagulant is added to water, it will produce monomers and polymers in the form of $[AlO_4Al_{12}(OH)_{24}(H_2O)_{12}]_7^{+}$, which functions as a bridge between destabilized colloidal particles to form microflocs and macroflocs, allowing them to settle due to their weight during the sedimentation process.

**Table 3:** Morning jar test result for total dissolved solid (TDS)

| Day no. | Optimum Dosage of PAC (mg/l) | Initial TDS parameter data | Coagulation-Flocculation process result | Standard quality values | Efficiency |
|---|---|---|---|---|---|
| Thursday, 2 March 2023 | 14 mg/l | 11.25 ppm | 1.06 ppm | 500 ppm | 90.57% |
| Friday, 3 March 2023 | 16 mg/l | 61.23 ppm | 50.01 ppm | 500 ppm | 18.32% |
| Saturday, 4 March 2023 | 15 mg/l | 29.17 ppm | 13.00 ppm | 500 ppm | 55.43% |
| Sunday, 5 March 2023 | 14 mg/l | 26.39 ppm | 19.20 ppm | 500 ppm | 27.24% |
| Monday, 6 March 2023 | 15 mg/l | 86.26 ppm | 45.00 ppm | 500 ppm | 47.83% |
| Tuesday, 7 March 2023 | 17 mg/l | 84.36 ppm | 57.09 ppm | 500 ppm | 32.32% |
| Wednesday, 8 March 2023 | 17 mg/l | 83.06 ppm | 13.34 ppm | 500 ppm | 83.93% |

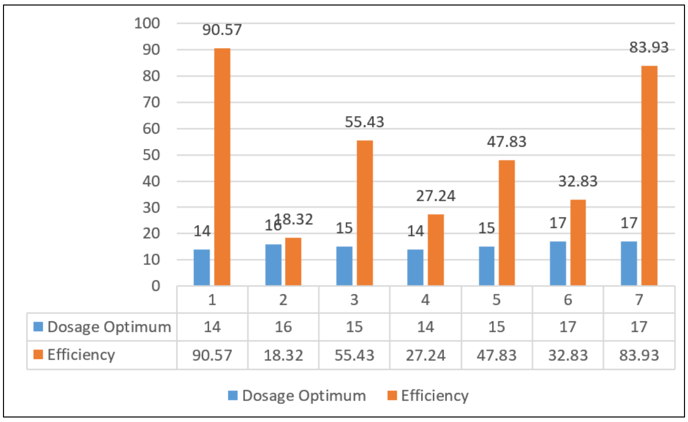


**Fig 6:** Relationship between the Optimum Dosage of Poly Aluminium Chloride (PAC) Coagulant and the Efficiency of Coagulation-Flocculation Process (%) to Reduce TDS in the Morning

In the results from Table 3 above, the jar test conducted in the morning for seven days shows that the initial values of total dissolved solids (TDS) vary from 11.25 ppm to 86.26 ppm. After the coagulation-flocculation process, there is a reduction in TDS values, ranging from 1.06 ppm to 57.09 ppm. The efficiency of the treatment process, as shown in Graph 6, varies from 18.32% to 90.57%. As shown in Table 3, it is worth noting that the TDS values obtained from the coagulation-flocculation process are below the standard quality requirements, which is 500 ppm, with values ranging from 1.06 ppm to 57.09 ppm, as per the regulation stated in the Minister of Health Number 492/MENKES/PER/IV/2010 regarding the requirements for drinking water quality. Moreover, the pH values remain stable and within the range of the set standard quality. The pH values shown in Table 3 are within the optimal range for the coagulation-flocculation process to occur effectively.

**Table 4:** Afternoon jar test result for TDS parameter

| Day no. | Optimum Dosage of PAC (mg/l) | Initial TDS parameter data | Coagulation-Flocculation process result | Standard quality values | Efficiency |
|---|---|---|---|---|---|
| Thursday, 2 March 2023 | 13 mg/l | 29.36 ppm | 20.26 ppm | 500 ppm | 30.99% |
| Friday, 3 March 2023 | 16 mg/l | 31.10 ppm | 19.21 ppm | 500 ppm | 38.23% |
| Saturday, 4 March 2023 | 16 mg/l | 60.23 ppm | 21.04 ppm | 500 ppm | 65.06% |
| Sunday, 5 March 2023 | 15 mg/l | 36.15 ppm | 25.00 ppm | 500 ppm | 30.84% |
| Monday, 6 March 2023 | 16 mg/l | 73.01 ppm | 25.30 ppm | 500 ppm | 65.34% |
| Tuesday, 7 March 2023 | 14 mg/l | 83.24 ppm | 15.20 ppm | 500 ppm | 81.73% |
| Wednesday, 8 March 2023 | 16 mg/l | 48.36 ppm | 17.33 ppm | 500 ppm | 64.16% |

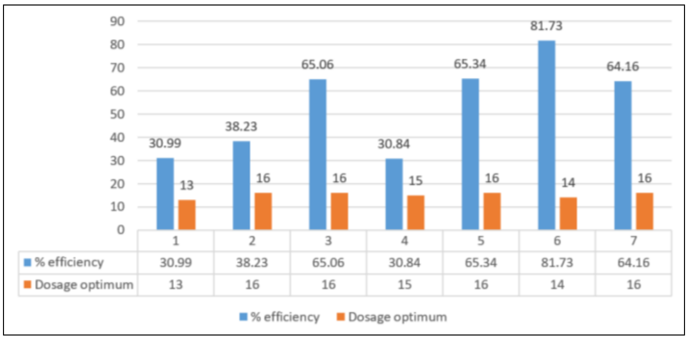


**Fig 7:** Relationship between the Optimum Dosage of Poly Aluminium Chloride (PAC) Coagulant and the Efficiency of Coagulation-Flocculation Process (%) to Reduce TDS in the afternoon

In the results from Table 4 above, the jar test conducted in the evening for seven days shows that the initial values of total dissolved solids (TDS) vary from 29.36 ppm to 83.224 ppm. After the coagulation-flocculation process, there is a reduction in TDS values, ranging from 15.20 ppm to 25.30 ppm. The efficiency of the treatment process, as shown in Fig 7, varies from 30.84% to 81.73%. It is important to note that the TDS values obtained from the coagulation-flocculation process are below the standard quality requirements, which is 500 ppm, with values ranging from 15.20 ppm to 25.30 ppm, in accordance with the regulation stated in the Minister of Health Number 492/MENKES/PER/IV/2010 regarding the requirements for drinking water quality. Additionally, the pH values remain stable and within the range of the set standard quality. The pH values shown in Table 4 are within the optimal range for the coagulation-flocculation process to occur effectively.

## 4. Conclusion

Based on the research conducted over seven days in the morning and evening, it can be concluded that the average efficiency of the coagulation-flocculation process in the morning resulted in a reduction of turbidity by approximately 96.74% and total dissolved solids (TDS) by about 50.80%. In the evening, the coagulation-flocculation process showed an average reduction of turbidity by approximately 98.01% and TDS by about 53.76%. The optimum dosage of PAC coagulant required to lower the turbidity of raw water to meet the Turbidity Quality Standard according to the Minister of Health Regulation No. 492/MENKES/PER/IV/2010 for both morning and evening applications is 15.71 mg/l and 15.28 mg/l, respectively.

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