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The Efficiency Assessment of Poly-Aluminium Chloride (PAC) in Water Treatment Plant Process: A Case Study at Sultan Iskandar Water Treatment Plant, Johor

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Abstract

The rate of population growth and river pollution are significant factors contributing to the increase in water demand in Johor. Generally, this may affect the quality of water treated at one of the biggest water treatment plants in Johor namely Sultan Iskandar Water Treatment Plant (SIWTP). The coverage of SIWTP water supply is wide and comprise almost all area of Pasir Gudang and half of the Johor Bahru district. This situation indirectly affects consumer demand when the treated water is insufficiently supplied by the potable water supply provider due to the use of conventional coagulants in the water treatment plant process. Therefore, this is an initial study as the Poly-Aluminium Chloride (PAC) coagulant is still in the early stages of implementation at SIWTP. It is important to determine the performance of PAC coagulant in the coagulation-flocculation process of the water treatment plant. The PAC performance is compared to Aluminium Sulphate which is a common type of coagulant used in the treatment plant, in order to establish efficiency. A pH adjustment test, turbidity test and the residual Aluminium test were conducted for both coagulants and six jar test readings were recorded to plot the comparison graph between PAC and Alum coagulants. The results showed that PAC is more efficient with 83.74% as compared with Alum which has an efficiency rate of 83.35%. Even though the difference is too small, it is concluded that PAC has better performance and is more efficient compared to Alum due to its better coagulation performance. In addition, PAC produces lesser residual Aluminium and required a lesser amount of dosage. This may reduce cost and therefore save overall operating costs.

Keywords: PAC, Alum, coagulant, performance, efficiency, Sultan Iskandar WTP

1. Introduction

Water is an essential component for humans and other living things, including flora and fauna. The increasing number of residents directly influences the demand for water supply. This is to fulfil the water consumption of the community. However, the increase in demand is not offset by the availability of clean water due to the low water quality of water produced by the water treatment plant. This is because, small, suspended particles, known as colloids, cannot be naturally settled, or eliminated in water bodies due to their modest weight and stability. Therefore, it is necessary to have an alternative water treatment so that the clean water demand can be sufficient. In general, polluted water has a higher level of turbidity. The level of turbidity in raw water is important because

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it is referred to as an indication of water quality. Higher turbidity can make water appear cloudy, opaque or murky. This is because the existing chemical used in Sultan Iskandar Water Treatment Plant (SIWTP) is Aluminium Sulphate (Alum). Based on the previous study, the formation of floc produced by Alum is particularly fragile (McCurdy et al., 2004; Aziz et al., 2017; Kumar et al., 2020; Liu et al., 2021; Nti et al., 2021). This can make the process of flocculation insufficient. When this happens, the turbidity of the water can be higher.

Recently, a chemical known as a coagulant, namely Poly-Aluminium Chloride (PAC), is becoming an option or alternative to be used in the market. According to Kumar & Balasundaram (2017), Zhang et al. (2014, 2018), and Kim et al. (2022), PAC coagulant has better performance due to its effectiveness in treating a wide range of water as it can form flocs at a relatively low cost. This can assist the coagulation-flocculation process to operate sufficiently. Coagulation and flocculation are vital processes in water treatment whereby the colloidal matter is formed in a suspended solid to cause it to agglomerate. When the clump between suspended solid becomes large and heavier, it will naturally settle via gravitational settling at the bottom of the basins to form a floc. An effective turbidity removal is required in order to ensure the clarity of treated water and the removal of health-related contaminants. In general, the effectiveness can be measured with the rapid formation of flocs. Therefore, the aim of this study is to determine the effectiveness of PAC as an alternate coagulant using theoretical and laboratory evidence. Besides, this study will also evaluate the performance of PAC at various pH values and coagulant dosages. This is to find an optimal operational condition in the treatment process when dealing with various turbidity levels in the water. The influence of hydrated lime, as a coagulant aid that helps in the flocculation process, together with PAC, will also be determined.

2. Literature Review

The PAC performance can be measured on its base properties known as basicity. Basicity is one of the parameters that can affect the result of performance in the coagulation-flocculation process and influence the properties of PAC (McCurdy et al., 2004; Zand & Hoveidi, 2015; Aziz et al., 2017; Kumar & Balasundaram, 2017; Zhang et al., 2018). In general, basicity is a basic medium of PAC used to remove impurities or acidity from water. The efficiency of turbidity removal is increased with increasing the PAC basicity. Hence, the result indicates that higher basicity in PAC can benefit the turbidity removal process. This finding is supported by Zhao et al. (2015), which found that higher basicity consumption can improve turbidity removal in raw water. High basicity has been optimized for turbidity removal by controlling the formation of Aluminium ions in the PAC coagulant. Therefore, higher basicity can reduce the consumption of alkalinity in the treatment process, thus giving an impact on the pH of raw water. In practice, further in situ studies using this coagulant in water treatment are needed in order to investigate the best properties and performance that may be beneficial to the industry.

There are several previous studies have discovered the efficiency of PAC as a coagulant in treating wastewater. For example, a study conducted by Aziz et al. (2017) using PAC and Alum in the wastewater treatment plant of a hospital in Indonesia provides evidence that PAC is more effective than Alum. It also shows that PAC can perform well with a high turbidity level and a wide pH range from 7 to 8, when compared to Alum (Kumar & Balasundaram, 2017). Therefore, it is beneficial to explore the PAC performance in the water supply treatment process.

In the future, by taking into consideration the high tendency of natural disasters to be occurred such as floods, PAC can be one of the best options to be adopted. This is because many water treatment plants need to be closed due to the high turbidity (NTU) due to the flooding event. During the monsoon season in December 2021, many water treatment plants were closed. For example, the issue faced by the water treatment plant at Port Dickson of the low water pressure in some parts due to the problem of high raw water turbidity (NTU) at the Sungai Linggi Water Treatment Plant (Ahmed et al., 2014). The high-water turbidity rate (NTU) has forced production to be reduced from normal in order to meet national drinking water quality standards. This influences the water supply issue in the residential area. As a precaution, PAC is recommended for use at the SIWTP because it can efficiently reduce turbidity levels and has been shown to be more effective than Alum. In addition, this may reduce the potential of water shortages during disasters.

3. Study Area

This study was conducted at the Sultan Iskandar Water Treatment Plant (SIWTP). The SIWTP is located in Pasir Gudang, Johor. In general, there are two main plants in SIWTP. The water from Sungai Johor, Sungai Tiram, and Sungai Seluyut had been retained at the Upper Layang Dam as illustrated in Figure 1. The raw water from this reservoir has become the main source of intake for SIWTP. Based on the observations made at the Upper Layang Dam as shown in Figure 2, the development and agricultural activities have had an impact on the quality of water retained in the reservoir. This is due to agricultural runoff water containing ammonia, nitrates and phosphates entering the water catchment area. The water turned green colour, which caused algae to breed. Furthermore, the level of water quality is dropping as a result of the high turbidity level. The pH of water also becomes more acidic which is caused by various contaminants such as chemical fertilizer etc (Dongre, 2018).

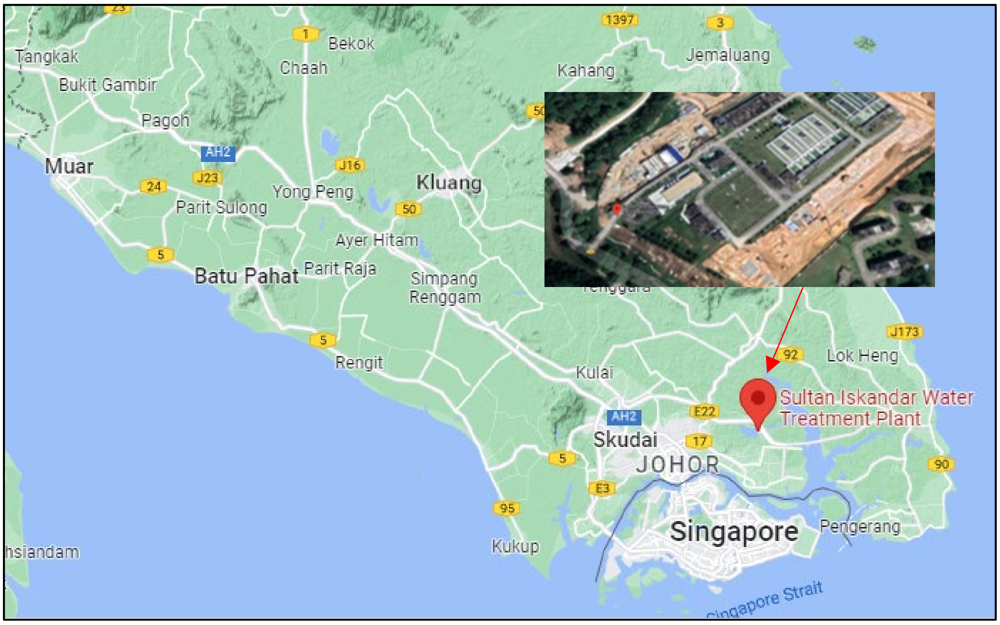

Figure 1. SIWTP as study area located at Pasir Gudang, Johor Malaysia (Source: Google Earth)

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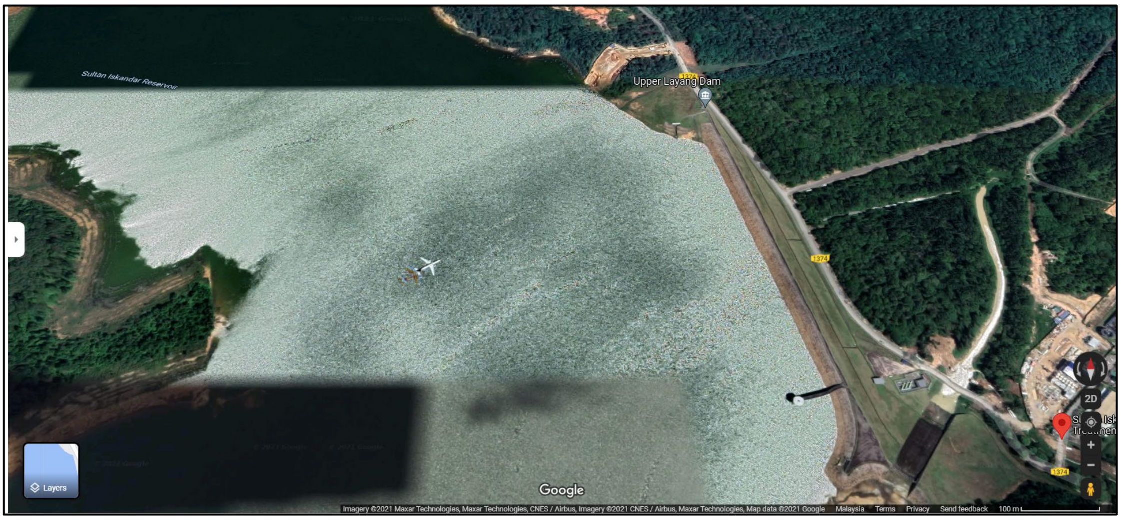

Figure 2. Location of the Sultan Iskandar Reservoir (Upper Layang Dam) where the development and agricultural activities influence the reservoir water quality (Source: Google Earth)

4. Methods

In this study, PAC and Aluminum Sulphate were the two types of coagulants used. The jar test method was used to simulate the mixing chamber tank at SIWTP. A pH adjustment test, turbidity test and residual Aluminium test were conducted to determine the effectiveness of the coagulant dosage. Mainly, the raw water sample was directly taken from the Upper Layang reservoir of the SIWTP.

In order to evaluate the effectiveness of coagulants, a comparison was made between two coagulants. The same procedure was conducted using both coagulants whereby a constant value of hydrated lime (5 mg/L) was used and added in the six-number of jar test for each type of coagulant mixture. The initial dosage used for PAC is between 2 mg/L and 50 mg/L, and the chosen dosage is from 20 mg/L. It is because, from the trial experiment, it has been observed that the floc only appears after 20 mg/L is added. Six readings were recorded to plot the comparison graph between PAC and Alum coagulants. From the plotting graph, the effectiveness of PAC was analysed by comparing the efficiency percentages of PAC and Alum. The efficiency percentage of PAC was calculated by using the formula in Equation 1. The calculation is using the turbidity result obtained from the jar test for both PAC and Alum. The complete data was then used to plot the graph.

$$\text{Efficiency Percentage} = \frac{(Initial\ turbidity - Final\ turbidity)}{Initial\ turbidity} \times 100\% \quad (1)$$

In general, the efficiency was calculated based on the turbidity measurement. When the value of turbidity is low, it shows the effectiveness of the amount dosage used. The dosage used has the ability to form a high volume of floc. In this study, the Ranhill SAJ Standard requirements as shown in Table 1 was referred to as the basis. This is because the findings may provide insight into the SIWTP operation.

Table 1. Ranhill SAJ Standard Requirements (Source: Report of Ranhill SAJ Standard, unpublished)

No.	Parameters	Unit	Raw Water	Sedimentation Water	Filtered Water	Treated Water
1	pH		5.5-9	5.5-6.7	-	6.5-7.8
2	Turbidity	NTU	1000	3-7	1	2
3	Color	TCU	300	-	-	13.5
4	Aluminium	mg/L	-	-	0.05	0.05
5	Iron	mg/L	1	-	-	0.2
6	Ammonia	mg/L	1.5	-	-	0.1
7	Manganese	mg/L	0.2	-	-	0.05
8	Fluoride	mg/L	-	-	-	0.40-0.06
9	Residual Chlorine	mg/L	-	-	-	0.2-5

5. Results and Discussion

In this experiment, aluminium-based compounds, and polymers such as PAC and Alum are used for coagulation-flocculation to treat most surface and infiltration water. This process is important in water treatment to reduce turbidity, colour, organic matter, and microorganism levels by creating aggregates and flocs from finely divided particles or dissolved substances (Mandal, 2014). Table 2 shows the comparison results between PAC and Aluminium Sulphate coagulants used to treat the water sample from six jars. The addition of 5 mg/L hydrated lime in the PAC mixture ranges from 20 mg/L to 26 mg/L, meanwhile for the Alum mixture, the addition of lime ranges from 42 mg/L to 52 mg/L. The pH in the PAC mixtures of all jars shows a consistent alkali value ranging from 6.47 to 6.54 except for the jar with 20 mg/L PAC, which shows 6.26. Besides, the pH value of the Alum coagulants decreases from 6.37 to 5.90 for each additional 5 mg/L of hydrated lime at each jar test. Overall, the pH of treated water using PAC coagulant lies within the range of 6.5 to 7.8, as shown in Table 2. On the other hand, Alum sufficiently lowered the pH but requires additional chemicals to adjust the pH to comply with the Ranhill SAJ standard.

In terms of turbidity, the lowest value is recorded at 1.26 NTU when the PAC is 23 mg/L. Meanwhile, the pH value of Alum coagulant is decreased from the initial dosage (42 mg/L) to the highest Alum dosage used in this study (52 mg/L). In addition, the lowest value of turbidity is 1.29 NTU, when 46 mg/L Alum is added to the mixture. Generally, for both coagulants, it was found that when the dosage of the coagulant exceeded the optimum value, charge reversal occurred, causing the turbidity and colour to reappear. Therefore, the lowest turbidity value indicates the optimum dosage of coagulant required for the jar test.

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Table 2. Comparison of optimum dosage between Aluminium Sulphate and PAC

Jar		Chemical Mixture (mg/ L)		Sedimentation Water			Efficiency of Optimum Coagulant (%)
		Lime	Dosage	pH	Turbidity (NTU)	Aluminium	
1	PAC	5	20	6.26	1.60	0.067	79.35
	Alum		42	6.37	2.36	0.070	69.55
2	PAC	5	22	6.54	1.45	0.048	81.29
	Alum		44	6.09	2.32	0.032	70.06
3	PAC	5	23	6.50	1.26	0.026	83.74
	Alum		46	6.00	1.29	0.030	83.35
4	PAC	5	24	6.47	1.32	0.021	82.97
	Alum		48	5.97	1.40	0.027	81.94
5	PAC	5	25	6.49	1.50	0.069	80.65
	Alum		50	5.92	1.48	0.080	80.90
6	PAC	5	26	6.50	1.74	0.078	77.55
	Alum		52	5.90	1.76	0.092	77.29

Besides, the results show that Alum which undergoes alkaline hydrolysis in water increases the residual Aluminium by 0.030 at 46 mg/L. The residual Aluminium may increase with an increase in coagulant dosage. Analysis of the relationship presented in Table 2 showed that both coagulants, PAC and Alum caused an increase in the concentration of Aluminium in the water following the coagulation process. However, at the optimum dosage, PAC indicates lower residual Aluminium with 0.026 at 23 mg/L compared to the Alum value. This is because, Alum coagulants could combine with residual Natural Organic Matter (NOM) during the coagulation process and significantly raise the residual level of Aluminium (Wang et al., 2010). Besides, it has been reported that improper coagulations of hydrolysing Aluminium coagulants ensure low efficiency of impurities removal and at the same time cause an excessive concentration of residual Aluminium in treated water. The higher residual Aluminium after the process may reduce disinfection efficiency (Kang et al., 2003). In addition, the capacity of the water distribution system may be reduced due to the clogging of residual Aluminium in the pipe network.

Figure 3 shows a graph of turbidity (NTU) versus coagulant dosage (mg/L) in this study. The data that was used to plot this graph is shown in Table 2. Based on the results, PAC achieves 1.26 NTU at a relatively lower dosage of less than 23 mg/L, whereas Alum achieves 1.29 NTU at a dosage of 46 mg/L. The trends observed in this study are consistent with the findings of Hoko & Makado (2011), which discovered that the general trend of both coagulants is that residual turbidity is reduced by increasing dosage until the optimum dosage is reached. The results also show that reducing the pH values for six jar samples with Alum coagulant is more effective than PAC. This is consistent with the findings of Tzoupanos & Zouboulis (2008). Another study by Gebbie (2006) reported that when Alum is dissolved in water, it may produce Aluminium hydroxide with the additional product of sulphuric acid. Then, the formation of sulphuric acid reacts with alkalinity in raw water to produce carbon dioxide, thus decreasing the pH value. However, PAC coagulants maintained the pH range (the range from 6.5 to 7.8) while Alum reduced it. This needs a pH correction for Alum at later stages of treatment, which may increase the requirement for hydrated lime. Therefore, this is beneficial in terms of cost because the acquired cost can be reduced by adjusting or improving the pH when using PAC since the adjustment and addition of hydrated lime have been decreased.

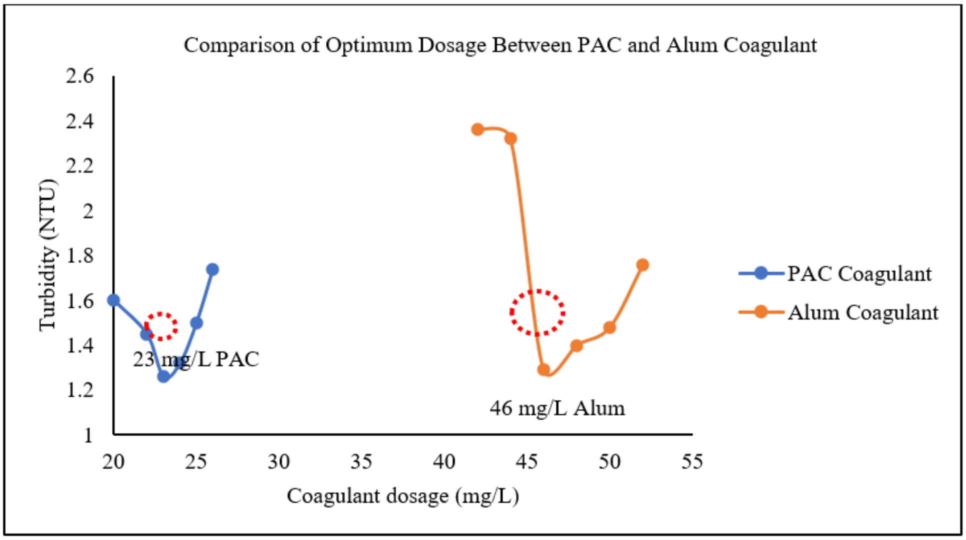

Figure 3. Graph of the comparison data of optimum dosage between PAC and Alum coagulant

Figure 3 shows the optimum dose of PAC and Alum coagulant. The point of minimum settled water turbidity represents the potential value of coagulant treatment and indicates the optimum coagulant dosage for jar test experiments. In addition, the graph shows that the optimum value of PAC is 23 mg/l. Meanwhile, the graph also indicates that the optimum value of Alum is 46 mg/L.

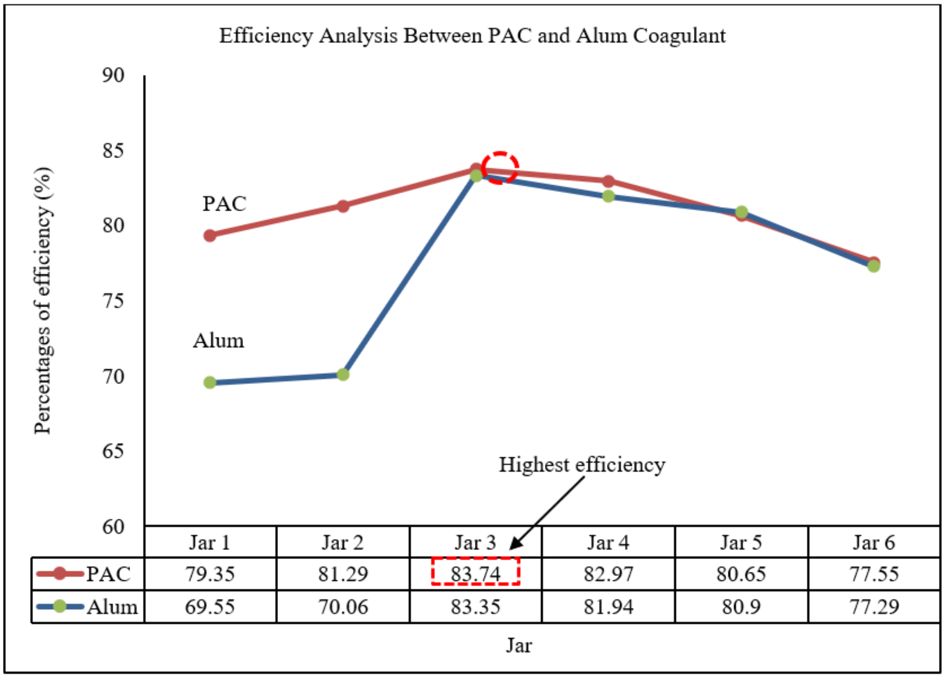

Figure 4. Graph of the efficiency analysis of coagulant

From the analysis, turbidity removal for PAC coagulant achieved a higher efficiency of 83.74% compared to Alum, which has the lowest efficiency of 83.35%, as shown in Figure 4. The efficiency was 83.74% at a dosage of 23 mg/L of PAC and 83.35% at a dosage of 46 mg/L of Alum. Both coagulants were found to significantly reduce water turbidity. However, in this study, PAC performs better in terms of reducing the turbidity of the raw water. This finding was supported by Tzoupanos & Zouboulis (2008), which discovered that PAC coagulants are highly effective in treating polluted water with higher turbidity. In addition, the advantage of using PAC over Alum is that PAC works well in the formation of flocs at pH 6.47, whereas Alum works better at pH 6.00. This is supported by previous findings, where the PAC pH range is wide (6 to 9) compared to the Alum which has a pH range of 6.5 to 7.6. In addition, treated water also has good quality and has a quicker reaction speed in clumping the suspended solid due to its liquid state (Kumar & Balasundaram, 2017). Furthermore, PAC can operate at any raw water turbidity level and produce lower residual Aluminium content.

6. Conclusions

In general, the slight difference between PAC and Alum percentages of turbidity removal efficiency is crucial to be observed in this experiment. This is because, based on the study, SIWTP faced an issue with higher turbidity and pH of the water, which was caused by environmental pollution. The source of intake water is channelled from the river which is located in the industrial hub area. Therefore, to cater for this problem, SIWTP requires a higher percentage of coagulant effectiveness, even though the difference between two coagulants is only 1%, which is considered significant.

In addition, PAC outperforms Alum in terms of turbidity removal. The turbidity removal efficiency of the initial dosage of both coagulants, PAC and Alum, was sufficient to meet sedimentation water limits of 3 to 7 NTU provided by the responsible water supply operator, Ranhill SAJ Sdn. Bhd. Therefore, when comparing the two coagulants, PAC with an optimum dosage of 23 mg/L is chosen as the best coagulant to be used in the water treatment process (flocculation-coagulation) over Aluminium Sulphate with a dosage of 46 mg/L. This is because a lower dosage of 23 mg/L PAC is required to achieve lesser turbidity and residual Aluminium of 1.26 NTU and 0.012, respectively. It can be concluded that the effectiveness of PAC to form a floc is faster and better than Alum. In addition, the usage of Alum in water treatment plants may increase operating costs and not be economic. This is because the coagulant of Alum must be supplied regularly due to the higher consumption. Therefore, the PAC alternative coagulants will be highly competitive in the treatment of industrial water at low dose levels.

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