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Design Proposal Pre-Chlorination Process in Water Treatment (Study Case: WTP 2 PT. Jababeka Infrastruktur, Cikarang)

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Abstract. PT Jababeka Infrastruktur's Water Treatment Plant (WTP) 2 is a water treatment facility that aims to serve clean water needs. This company uses an open system where chlorine is injected directly into the raw water intake, this allows for waste of chlorine which is wasted due to evaporation. The current injected dose in pre-chlorination is 7 - 7.5 mg/L with a residual chlor of 0.7 mg/L. The residual chlor, according to WHO, is still outside the standard criteria, where the standard set is in the 0.2 - 0.5 mg/l range. The dose injected in pre-chlorination should be more optimal because, in the secondary data of the WTP 2 laboratory test report, the content of nitrate, nitrite, ammonia, and total iron parameters is low. **Objectives:** This study aims to determine the chlorination breakpoint graph pattern formed, determine the chlorine dose breakpoint in the water treatment process, and recommend the optimum dose of pre-chlorination and pre-chlorination system with a closed basin. **Method and results:** This study used laboratory analysis on raw water samples. Then, the water samples were given chlorine treatment with a dose range of 0 – 15 mg/L. After being treated, the samples were analyzed for pH, turbidity, ammonia, nitrate, nitrite, and total iron. **Conclusion:** The chlorination breakpoint graph is linear, as evidenced by the low reducing agent. The breakpoint was achieved at 0.9 mg/L of chlorination dose for raw water turbidity 30.5 NTU. The recommended optimum dose in the breakpoint dose range of 1.1 mg/L and the pre-chlorination unit is a two-line chlorination unit with a closed design with a mixer inside.

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1 Introduction

PT Jababeka Infrastruktur's Water Treatment Plant (WTP) 2 is a water treatment facility that aims to serve clean water needs. WTP 2 uses raw water sources from the West Tarum Main Channel, class I water that can be used for hygiene and sanitation. However, over time the condition of raw water, which is influenced by the environment, climate, and weather, its quality will change due to the presence of pollutants that may enter the river flow. This happened several years ago at WTP 2 PT Jababeka Infrastruktur, where there was a problem with the water treatment system. The water distributed to consumers and the water in the plant is different, the water in the plant is clean and clear. At the same time, the water received by consumers changes color to cloudy, black, and smelly. This is possible because the pollutant load in raw water, such as organic substances, iron, and manganese, has yet to oxidize completely, even though the laboratory results for the content of reducing agents and organics are low. According to the Regulation of the Minister of Public Works and Housing, Number 26/PRT/M/2014 concerning Standard Operating Procedures Standard Operating Procedures for Processing Systems Drinking Water Supply System regulates the treatment of water polluted with organic substances or high iron and manganese using pre-chlorination which serves to oxidize raw water contaminants [1]. Therefore, WTP 2 provides a pre-chlorination unit at the beginning of the process at the intake to overcome this problem.

Pre-chlorination injection at WTP 2 PT Jababeka Infrastruktur still uses an open system where chlorine is injected directly into the raw water intake, this allows for waste of chlorine which is wasted due to evaporation and also the lack of homogeneity of chlorine applied to water. The dose of chlorine injected in the pre-chlorination process is 7 - 7.5 mg/l with a residual chlorine of 0.7 mg/l. The residual chlor is outside the standard criteria where the recommended residual chlor, according to the World Health Organization Guidelines on water quality, limits the concentration of residual chlorine in drinking water to the range of 0.2 - 0.5 mg/l [2].

The pre-chlorination dose may not be 7 mg/L - 7.5 mg/L because the residual chlorine produced is higher than the standard criteria. In this case, it is supported by the secondary data of WTP 2 for the past year, where the ammonia, nitrate, nitrite, and iron content in water is less than (1 mg/L and 10 mg/L), this means that chlorine will experience direct contact with organic substances. These parameters are part of the parameters that react with chlorine, especially in treating drinking water, where chlorine reacts with ammonia, iron, manganese, sulfide, and some organic substances [3]. Thus, the injected dose at pre-chlorination should be more optimized than the current dose, as the chlorine load on the reduction parameters is less due to the low reducing agent.

Breakpoint Chlorination is the concentration of active chlorine required to oxidize organic matter (ammonia) and other oxidizable materials. The relationship between chlorine addition dose and residual active chlorine forms a breakpoint chlorination graph. This condition describes the optimum point on the chlorination graph because the residual threshold point occurs when the chlorine dosage rate exceeds the demand caused by reducing agents, ammonia, and organic matter [4]. According to the chlorination breakpoint graph type theory, the graph pattern will be linear because the water conditions containing reducing agents are no/low [4]. So, it is predicted that the graph type in this study is linear.

Determination of the optimum dose in the pre-chlorination process is important. If the injected chlorination dose has residual chlorine less than 0.2 mg/L, the risk of microbial contamination can still occur. Bacteria can proliferate in the water and cause waterborne diseases in the community. However, if the chlorination dose has residual chlorine higher than 0.5 mg/L, excessive residual chlorine compounds can form, which can cause a strong chlorine odor and harm human health if ingested. One of the side effects of the chlorination process is Trihalomethane (THM), which is a residual chlorination product that is carcinogenic [5]. The optimal chlorine dosage is not only related to the safety of water consumption but also has implications on production process efficiency, operational costs, and environmental impact.

This study aims to analyze and determine the optimum dose of chlorine used in clean water treatment to maintain a balance between the effectiveness of infection and environmental health and safety. Then, the recommended pre-chlorination unit at WTP 2 PT Jababeka Infrastruktur with a closed design to homogenize chlorine and chlorine is not wasted so that it has a good effect on the chlorine injection process.

2 Method

2.1 Location and Time of the Study

Data collection was carried out at Water Treatment Plant 2 PT Jababeka Infrastruktur. Located on Jl. Highway Irrigation, Jayamukti, Central Cikarang, Bekasi Regency, West Java 17550 with a coordinate point of 6°18'.27"S 107°10'06"E. This study will take place in the raw water intake taken from the West Tarum Main Canal located in BTB 29. The study was conducted from April 16, 2023 – June 24, 2023.

2.2 Research Variable

This study used independent and dependent variables. The independent variable is the variation of sodium hypochlorite ($NaOCl^-$) dosage. The concentration of sodium hypochlorite used is 10% of chlorine. The dependent variable is the amount of pH, turbidity, nitrite, nitrate, total iron, and ammonia concentration in the sample.

2.2.1 Sodium Hypochlorite 10% Dose Variations

In this study using sodium hypochlorite solution which has a concentration of purity 10%. Then diluted as much as 200 dilution. The calculation:

- Sodium Hypochlorite solution 10% = 1.11 g/cm^3 = 110.000 mg/L
  Work diluted until 200 = 550 mg/L
  Working solution 1 : 200 x dilution , the result is 0.05 % Wt. or 550 mg/L

$$(V_1 \times N_1) + (V_2 \times N_2) = V_3 \times N_3$$

$$0 \quad + V_2 \times 500 \; = (550 + V_3) \times 1$$

$$499 \times V_2 = 550$$

$$V_2 = 1\,ml \;\rightarrow \frac{1}{1.1} = 0.9\,mg/l$$

Table 1. NaOCl 0.05% dose variations

Raw Water Sample (500 mL)	1	2	3	4	5	6
$NaOCl^-$ dose 0.05% (mL)	1	2	3	4	5	6
$NaOCl^-$ dose 0.05% (mg/L)	0.9	1.8	2.7	3.6	4.5	5.4

Then the dose was added to 6 beaker glasses with a volume of 500 mL. The treatment process in the beaker glass is covered with aluminum foil to prevent the release of Cl_2 and the oxidization process is perfect [6], the stirring process uses a jar test with a maximum stirring speed of 100 rpm [7] around 2 minutes. For effective disinfection, wait for the reaction of water with chlorine around 30 minutes of contact time [2]. This treatment was conducted triple every dose variation (with two replications).

2.3 Laboratory Analysis Method

This study used the laboratory analysis method with the references shown below:

Table 2. The laboratory analysis method

No.	Parameter Analysis	Sources
1.	Turbidity	SNI 06-6989.25-2005 [8]
2.	pH	SNI 6989.11:2019 [9]
3.	Residual Chlorine	Standard Methods For The Examination of Water and Wastewater [3]
4.	Ammonia	SNI 06-6989.30-2005 [10]
5.	Nitrite	SNI 06-6989.9:2004 [11]
6.	Nitrate	Standard Methods For The Examination of Water and Wastewater [3]
7.	Total Iron	Standard Methods For The Examination of Water and Wastewater [3]

2.4 Data Calculation Method

2.4.1 Residual Chlorine Calculation

$$mg\ Cl\ as\ Cl_2/L = \frac{(A \pm B) \times N \times 35.45 \times 1000}{ml\ sample} \tag{1}$$

Information:

A = ml sample titration

B = ml blank titration (positive or negative), and
N = normality of $Na_2S_2O_3$

2.4.2 Linear Regression Test

Linearity testing is carried out to show a linear relationship between analyte concentration and device response. Linearity is depicted graphically, a plot of the concentration standard solution with the absorbance value of the measurement results, called a calibration curve. In this case, the linearity gives the linear regression value (R), Slope (b), and intercept (α). The following formula can be used to calculate simple linear regression.

$$y' = a + bx \quad (1)$$

Information:

y' = dependent variable
a = intercept
b = slope of the regression line
x = independent variable

3 Results and Discussion

3.1 Characteristic of Raw Water

Observations of raw water quality clean water at WTP 2 PT Jababeka Infrastruktur were observed three times. The quality of raw water originating from the West Tarum Canal is still within the allowable range. According to Government Regulation No. 82 of 2001. The following are the results of laboratory analysis of raw water at the intake of Water Treatment Plant 2 PT Jababeka Infrastruktur.

Table 3. Laboratory Analysis of Raw Water Quality

Parameter	Unit	Standard	Sample 1 16/04/2023	Sample 2 05/05/2023	Sample 3 24/06/2023
Physics					
Turbidity	NTU	-	82	41	30.5
Chemical					
pH	pH unit	6.5 – 9	7.53	7.28	7.62
Ammonia	mg/L	-	-	0.072	-
Nitrite	mg/L	1	-	0.018	-
Nitrate	mg/L	10	-	0.706	-
Total Iron	mg/L	-	-	1.720	-

3.2 Residual Chlor Result

This experiment was conducted 3 times with 2 replications for each experiment. In this experiment is not bound by time so that samples can be taken at any time, but still consider the quality of turbidity that is not to different. This experiment on April 16th, 2023 – June 24th, 2023 because in this period I see the fluctuating conditions.

3.2.1 Experiment 1

Experiment 1 used a dose range based on the WTP 2 PT Jababeka Infrastruktur dose, which was 7 mg/L – 7.5 mg/L. Then, determine the optimal point of chlorine dosage with less than 7 mg/L and more than 7 mg/L. So, the dose of chlorine injected in experiment 1 was 2.5 mg/L – 15 mg/L. The following is a graph of residual chlorine obtained from the results of the laboratory analysis.

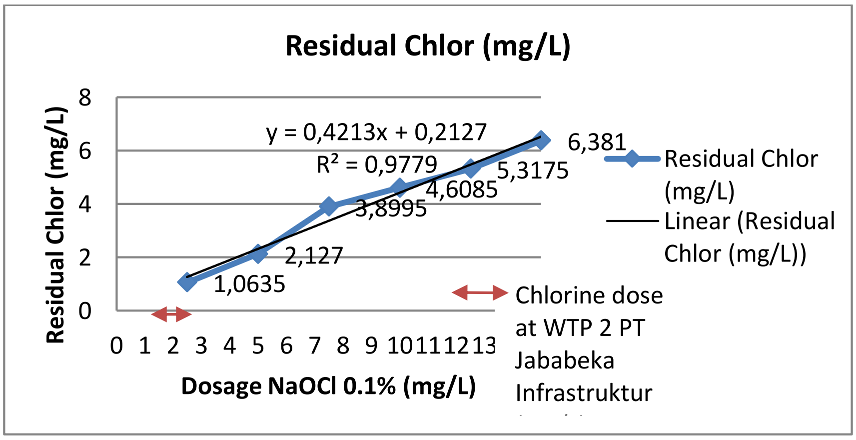

Fig. 1. Graph of residual chlorine in the experiment 1

From the graph, it can also be concluded that the pattern formed is directly linear, where this type of graph represents water without interference from reducing substances referring to the reference [4]. This is approved by the statistically significant test from the p-value <0.05, which confirms that the graph is linear, the following table can be seen below.

Table 4. Statistical significance from experiment 1

	Coefficients	Standard Error	t Stat	P-value
Intercept	0.2127	0.308076225	0.69041355	0.527906104
NaOCl (mg/L)	0.421348571	0.031642669	13.31583551	0.000183875

3.2.2 Experiment 2

Experiment 2 used a dose range lower than 7 mg/L. Because the results of experiment 1 show that the residual chlorine graph with a dose above 7 mg/L is straight because the chlorine dose has become free chlorine. So, in experiment 2, the chlorine dose injected is in the range of 0.9 mg/L – 5.45 mg/L. The following is a graph of residual chlorine obtained from the results of the laboratory analysis.

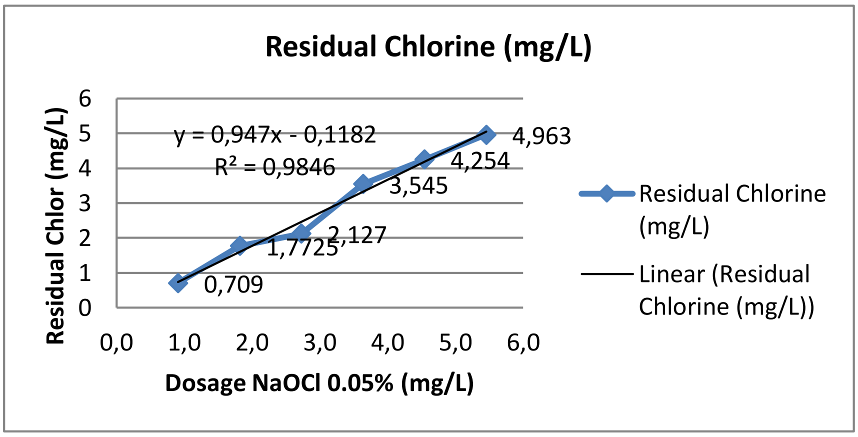

Fig. 2. Graph of residual chlorine in the experiment 2

From the graph, it can also be concluded that the pattern formed is directly linear, where this type of graph represents water without interference from reducing substances referring to the reference [4]. This is approved by the statistically significant test from the p-value <0.05, which confirms that the graph is linear, the following table can be seen below.

Table 5. Statistical significance from experiment 2

	Coefficients	Standard Error	t Stat	P-value
Intercept	-0.11816667	0.209962677	-0.56279843	0.60361987
NaOCl (mg/L)	0.947021429	0.059304782	15.96871942	0.000089908

In the second experiment, checking was carried out to confirm breakpoint graphs supported by data on total iron, nitrate, nitrite, and ammonia test parameters for the analysis results can be seen below.

- *Ammonia Concentration*

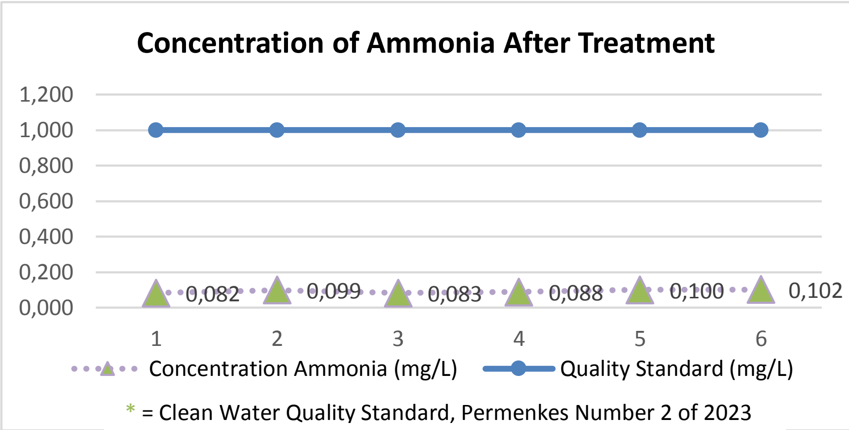

Fig. 3. Graphic plot for ammonia concentration after treatment

From the results of the ammonia test on raw water that has been treated with 0.05% NaOCl, there is an increase in the ammonia content, this is because the water contains organic substances, one of which is ammonia, which is bound to organic substances. Because the analysis used initially is dissolved ammonia where the substance in it is still bound, it is not detected by the analysis method. But after the chlorine is injected, the ammonia decomposes so that it increases. The ammonia content is still by the applicable standard criteria because there is no standard limit [12].

- *Nitrite Concentration*

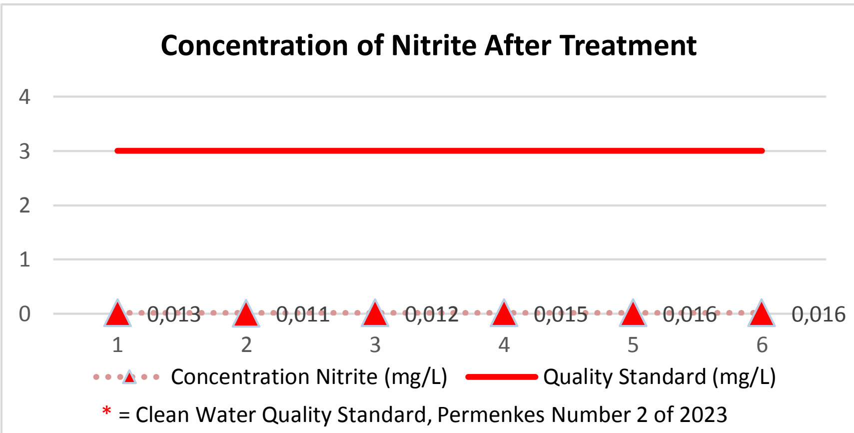

Fig. 4. Graphic plot for nitrite concentration after treatment

From the nitrite analysis test results in raw water that has been treated with 0.05% NaOCl for nitrite content has decreased. This means that chlorine functions as an oxidizer in reducing nitrite content. The nitrite content is still in accordance with the applicable standard criteria which is below 3 mg/L [12].

- *Nitrate Concentration*

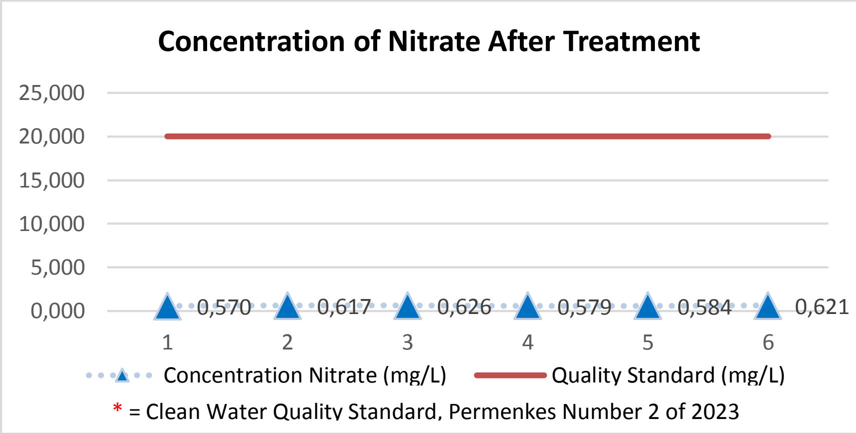

Fig. 5. Graphic plot for nitrate concentration after treatment

From the nitrate analysis test results in raw water that has been treated with 0.05% NaOCl nitrate content has decreased. This means that chlorine functions as an oxidizer in reducing nitrate content. The nitrate content is still by the applicable standard criteria, which is below 20 mg/L [12].

- *Total Iron Concentration*

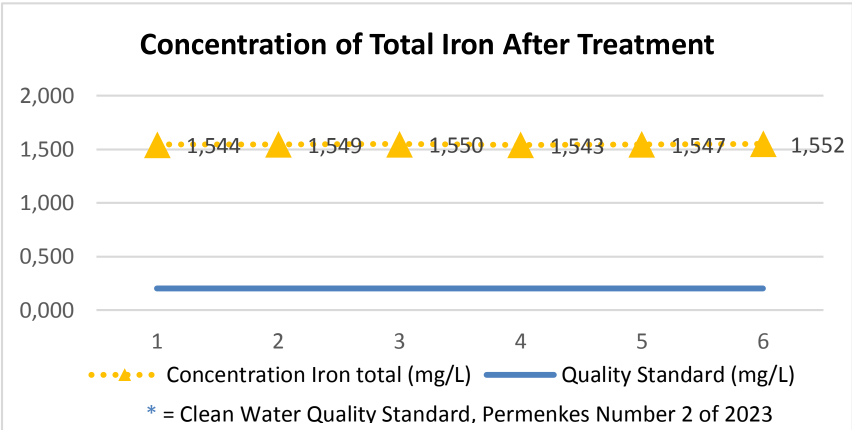

Fig. 6. Graphic plot for total Iron concentration after treatment

The total Iron content has decreased from the total Iron analysis test results in raw water treated with 0.05% NaOCl. This means that chlorine functions as an oxidizer in reducing total Iron content. However, the iron content is still outside the applicable criteria standards [12]. This is because Iron has not been entirely decreased in the pre-chlorination process; this Iron will be returned to the next process, namely coagulation, where PAC (Poly Aluminum Chloride) is given.

3.2.3 Experiment 3

Experiment 3 used a lower dose range than the experiment 2 results to find the optimum chlorine dose. So, in experiment 3, the dose of chlorine injected was in the range of 0 mg/L – 2.3 mg/L. The following is a graph of residual chlorine obtained from the results of the laboratory analysis.

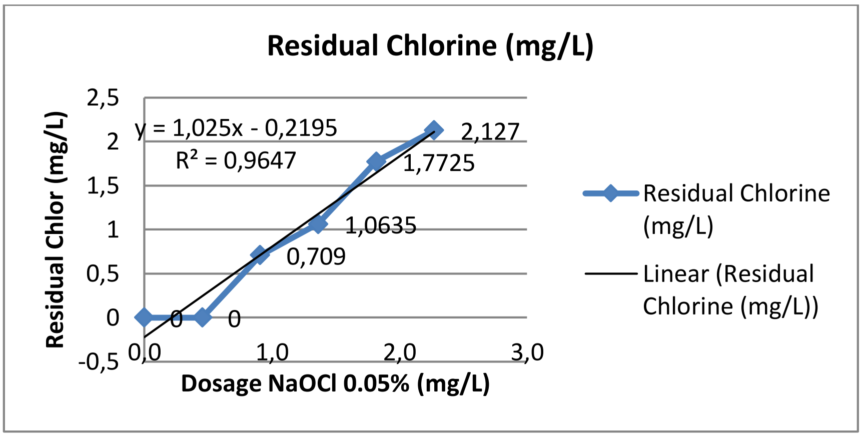

Fig. 7. Graph of residual chlorine in the experiment 3

From the graph, the breakpoint was obtained at a dose of 0.9 mg/L with residual chlorine of 0.709 mg/L. The pattern formed is directly linear, where this type of graph represents water without interference from reducing substances referring to the reference [4]. This is approved by the statistically significant test from the p-value <0.05, which confirms that the graph is linear; the following table can be seen below.

Table 6. Statistical significance from experiment 3

	Coefficients	Standard Error	t Stat	P-value
Intercept	-0.21945238	0.134836442	-1.62754503	0.178951046
NaOCl (mg/L)	1.025011429	0.097977024	10.461753	0.000471772

After getting the third data from residual chlorine analysis with different variations of 0.1% and 0.05% $NaOCl^-$ doses. The data for chlorine residual after the experimental test is shown below:

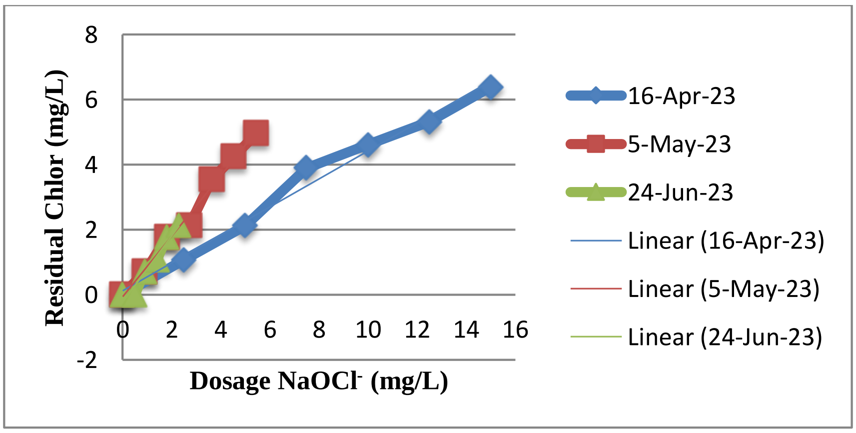

Fig. 8. Breakpoint Chlorination Graph

The optimum point occurs when 0.05% NaOCl is added to the sample at a dose of 0.9 mg/L, as seen in the graph above. Then, to determine the dose of chlorine, the sum of the chlorine dose with residual chlorine so that the dose result is 1.1 mg/L.

3.3 Pre-chlorination Unit Recommendation

From the analysis of the optimum dose of laboratory-scale, this dose cannot be applied directly to the pre-chlorination unit in WTP 2 PT Jababeka Infrastruktur because conditions of chlorine injection are now in the open. Therefore, it is recommended for WTP 2 PT Jababeka Infrastruktur two lines chlorination unit with a closed design with a mixer inside to homogenize the chlorine and chlorine not wasted when injected. The following is a schematic illustration of the current water treatment process at WTP 2 PT Jababeka Infrastruktur.

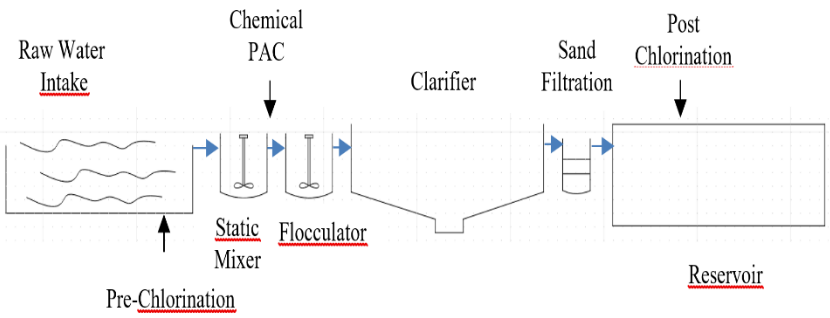

Fig. 9. Diagram of the current water treatment process in WTP 2 PT Jababeka Infrastruktur

The following is a schematic illustration of the recommended process for WTP 2 PT Jababeka Infrastruktur.

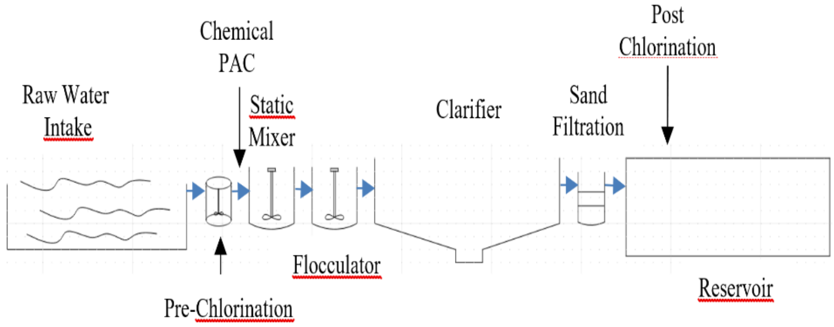

Fig. 10. Diagram of the water treatment process recommended in WTP 2 PT Jababeka Infrastruktur (side view)

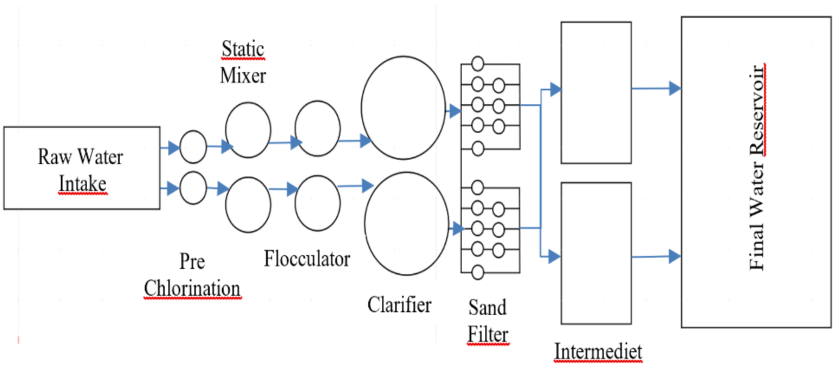

Fig. 11. Diagram of the water treatment process recommended in WTP 2 PT Jababeka Infrastruktur (top view)

The calculation of the pre-chlorination unit design can be seen below.

Flow rate at WTP 2 PT Jababeka Infrastruktur is 270 l/s.

Volume for pre-chlorination unit $= 270\ l/s \times 60\ \text{s} = 16.2\ \text{m}^3$

We assumption the depth

Depth = 2.5 m

so the equation is,

$$V = \pi r^2 h \quad (1)$$

$$r = \left[\frac{V}{\pi . h}\right]^{\frac{1}{2}}$$

$$r = \left[\frac{16.2}{3.14 \times 2.5}\right]^{\frac{1}{2}}$$

$$r = 1.4\ m$$

The design of the pre-chlorination unit follows the principle of coagulation in the jar test. But the difference is only in the detention time. This pre-chlorination unit plan used a detention time of 2 minutes. The following are the criteria for designing a coagulation unit (rapid stirrer) [13]. The power requirement for the pre-chlorination unit that follows the coagulation design criteria is calculated with the following formula.

$$\boldsymbol{P = G^2 \times \mu \times V} \quad (1)$$

Temperature = 25°C, $\mu = 0.890 \times 10^{-3}\ Pa.s$

$P = 750^2\ s^{-2} \times (0.890 \times 10^{-3}\ Pa.s) \times 16.2\ m^3$

$P = 8{,}110\ watt$

The illustration of the pre-chlorination unit design can be seen below.

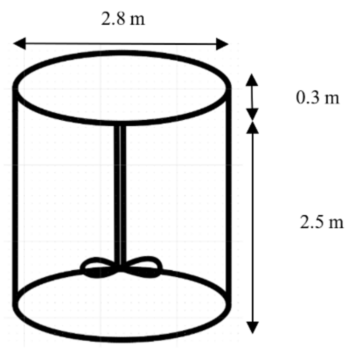

Fig. 12. The typical pre-chlorination unit design recommended in WTP 2 PT Jababeka Infrastruktur

The recommendation of a closed pre-chlorination unit will positively affect the chlorine injection process. The benefit is to homogenize chlorine further entering the water and save wasted chlorine costs. The other health benefit is to prevent excess residual chlorine, which can cause odor and is an irritant (irritates the mucous membranes of the eyes, the nose, the throat, the vocal cords, and the lungs). If chlorine gas enters the lung tissue and reacts with hydrogen ions, it can form hydrochloric acid, which is very corrosive [14]. Chlorine exposure in the body is associated with male infertility, congenital disabilities, mental retardation, and cancer [15].

4 Conclusions

The chlorination breakpoint the graph pattern formed is a linear pattern. This is due to the low reducing agent present in the raw water sample. The residual chlorine vs chlorination dose graph showed that the breakpoint was achieved at 0.9 mg/L of chlorination dose for raw water turbidity 30.5 NTU. The recommended optimum dose at WTP 2 PT Jababeka Infrastruktur is in the breakpoint dose range of 1.1 mg/L. With this optimum dose, it will provide benefits in terms of cost as well as health and the environment where the residual chlorine is by the standards that have been set, it can minimize one of the side effects of the chlorination process is Trihalomethane (THM) which is a residual chlorination product that is carcinogenic. Then, the recommended pre-chlorination unit in WTP 2 of PT Jababeka Infrastruktur is a two lines chlorination unit with a closed design with a mixer inside to homogenize chlorine, and chlorine is not wasted when injected, so it has a good effect on the chlorine injection process. In addition, it minimizes the occurrence of excessive chlorine residue that can cause odor and irritation.

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