Optimization of Cipageran water treatment plant, Cimahi, West Java, Indonesia

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Abstract. The Cipageran Water Treatment Plant (WTP) is one of water treatment plants managed by PDAM Tirta Raharja, Bandung Regency, which supply drinking water for Cimahi District and Central Cimahi Subdistricts with an average production capacity of 169 L/sec. This research aims to evaluate the performance of the operating unit and process in Cipageran WTP and provide optimization recommendations based on evaluation results. The steps in this research include evaluated the existing conditions of Cipageran WTP, providing recommendations on the results of evaluations and analyzing the quality of the production of Cipageran WTP. From the results of Cipageran WTP evaluation, there were several parameters that did not fulfill the design criteria which were Gt on coagulation, Nfr values on sedimentation and backwash rate on filtration. The evaluation result of maximum discharge in intake was 400 L/second, coagulation of 210 L/second, flocculation of 210 L/second, sedimentation of 270 L/second and filtration of 250 L/second, with the result the optimum discharge can operated in Cipageran WTP is 210 L/second. The quality water production has met the quality standard according to the Minister of Health Regulation No. 492 of 2010 concerning drinking water quality requirement, that turbidity limit is 5 NTU with very high removal efficiency, which was more than 90%. From the result, it can be said that Cipageran water treatment plant in this study had met the drinking water quality standard to be applied as drinking water treatment plant.

Keyword : Water Treatment Plant, Cipageran WTP, Optimizing WTP, Drinking Water

1. Introduction

Water plays an important role in the development of any activity in the world. Due to the growth of population, consumption of water resources is more and availability is less. So the demand for water is increasing [1]. With the rapid growth of industrialization and population, the earth has faced over the last one hundred years has considerably increased environmental pollution, and is affecting water resources, air and soil qualities. In the last decade, wastewater treatment modeling has become a standard engineering tool for wastewater treatment plant design, process optimization, operator training, and developing control strategies, and attracted extensive attention by many researchers [2].

The global water management situation is alarming and requires urgent and innovative technologies to ensure a proper treatment of raw, process and sewage waters. In the coming decades, problems with accessing good quality water are expected to worsen. Water scarcity is predicted to occur globally,
even in regions currently considered water rich. Addressing these problems has triggered a tremendous amount of research to identify robust methods of purifying water at lower cost and with less energy, while at the same time minimizing the total impact on the environment [3].

The increase in population growth is increasing every year, with increasing population will cause an increase in water needs to meet the daily needs of the community. However, the increase in population also causes a decrease in water quality in raw water sources because of human activities and land use around the source [4]. Water that can be consumed by the Indonesian people fulfill the requirements of the Minister of Health Regulation of the Republic of Indonesia No.492 of 2010 [5] concerning requirements for the quality of drinking water, which includes physical, chemical, and biological requirements [6]. Nowadays, research been done on how to treat water effectively and improved water treatment process continuously in order to cater human needs competently [7]. The most commonly used processes are filtering, coagulation, flocculation, sedimentation and disinfection for surface water [8].

PDAM Tirta Raharja, Bandung Regency as one of the drinking water service providers for Cimahi City and Bandung Regency which has several drinking water treatment installation units, one of which is Cipageran WTP serving Cimahi City. Cipageran WTP has a design capacity of 200 L/sec with an average production capacity of 169 L/sec in 2018 with process units, i.e. intake, coagulation, flocculation, sedimentation, filtration and reservoirs. The objective of this work are (1) evaluate the performance of the operating unit and process in Cipageran WTP and provide optimization recommendations based on evaluation results; (2) comparing the quality of production water produced by Cipageran WTP with drinking water quality standards.

2. Analysis Method

2.1. Data Collection

Data collection was done by collecting primary data in the form of processing discharge and processing unit design criteria and secondary data in the form of processing capacity and water quality.

2.2. Data Analysis

2.2.1. Calculation and Evaluation of Existing Conditions of Installation

Analysis of the operational system of the building units installation can be seen from the comparison between the results of calculations in accordance with the existing WTP conditions regarding parameters which are important factors in building operational systems and building design planning criteria [9]. Evaluations for WTP can be calculated by the equation below [10]:

Velocity
\[ v = \frac{Q}{A} \]  
(1)

Detention time
\[ t_d = \frac{V}{Q} \]  
(2)

Gradien
\[ G = \sqrt{\frac{p}{\mu \times V}} \]  
(3)

Hydraulic Gradien
\[ G_{td} = G \times t_d \]  
(4)

Reynolds number
\[ N_{Re} = \frac{v p x R}{\mu} \]  
(5)

Froude number
\[ N_{Fr} = \frac{v p^2}{g x R} \]  
(6)

Whereby,
\( Q \) = discharge (m³/second)
\( V \) = volume (m³)
\( \mu \) = absolute viscosity (kg/m.second)
\( \rho \) = density (kg/m³)
P = power (kg m²/second³)

ν_p = velocity on plate/tube settler (m/s)

R = hydraulic radius (m)

υ = kinematic viscosity (m²/s)

g = gravity (m/s²)

2.2.2. Analysis of the quality water
Analysis of the quality of water produces for drinking water quality standards contained in Minister of Health Regulation No. 492 of 2010 [5].

3. Results and Discussion
The evaluation of the existing WTP was conducted at the Cipageran WTP of PDAM Tirta Raharja, Bandung Regency with a production capacity of 169 L/s. The source of treated raw water comes from the Cijanggel River that flow down gravity toward the drinking water treatment unit. The distance of the intake building to the water treatment plant is 11 km. Cipageran WTP processing flow chart is shown in Figure 1.

![Figure 1. Cipageran WTP Unit Scheme](image)

3.1. Intake
Intake is a building to collect raw water that will be distributed to drinking water treatment plants [11]. Intake of Cipageran WTP uses the river intake type equipped with sluicegate, bar screens, carrier channels and collecting wells. Raw water that is tapped flows into the collecting well then goes to a gravity water treatment plant with a 300 mm diameter transmission pipe. The distance of the intake to the WTP is as far as 11 km which is equipped with a press release tank to reduce the pressure so that the pipe does not break due to the difference in elevation between the intake and WTP is 597.5 m. River intake of Cipageran WTP can be seen in Figure 2, while evaluation results of intake in
Cipageran WTP is shown in Table 1. From Table 1, it can be seen that all parameters fulfil the design criteria.

**Table 1. Evaluation Results of Intake in Cipageran WTP**

| Unit          | Design Criteria | Source               | Result  | Remarks     |
|---------------|-----------------|----------------------|---------|-------------|
| Velocity (v)  | >0,6 m/sec      | Al-Layla, 1977       | 0,83 m/sec | Appropriate |

**Figure 2. River Intake of Cipageran WTP (a) Real Picture and (b) Elongated Pieces**

3.2. **Coagulation**

Coagulation defined as “The addition of certain chemicals into the raw water causes particles to destabilize and allows agglomeration and floc formation to occur”. In this process, it consists of two chemicals which are coagulant and flocculant, but Cipageran WTP just uses coagulant. Chemical coagulants are commonly positive charge and it function to neutralize the negative charge of particles in the raw water to bind them together. Then, flocculation process can assist the messing and joining of the binding particles together to form a larger particles called ‘floc’ that are large enough to settle out. This settling process is called sedimentation. Hence, this settling time will take shorter time if the floc is larger and heavier [7].

Coagulation unit of Cipageran WTP uses a type of hydraulic stirring. In the coagulation process, there is one receiving tub to collect raw water before entering the stirring tank and given the coagulant material. The raw water inlet pipe in the receiving bath is 300 mm. The coagulant material used in Cipageran WTP is aluminum sulfate with dose of 20 mg/l. In the coagulation tank, the process of formation of stable colloids becomes unstable colloids and stimulates the formation of flocs from colloid combinations. Hydraulic coagulation in Cipageran WTP can be seen in Figure 3, while evaluation results of coagulation tank is shown in Table 2. From Table 2, it can be seen that there was one parameter that did not fulfil the design criteria, which was $G_t_d$.

**Table 2. Evaluation results of Coagulation in Cipageran WTP**

| No  | Unit      | Design Criteria | Source               | Result          | Remarks  |
|-----|-----------|-----------------|----------------------|-----------------|----------|
| $t_d$ | < 60 second | Reynolds, 1996  | 9,05 second         | Appropriate     |
| $G$  | 100-1000/second | Qasim, 2000 [14] | 745,48/second       | Appropriate     |
| $G_t_d$ | 30000-60000 | Qasim, 2000 [14] | 6746,6              | Inappropriate   |
|     | $10^2-10^6$ | Reynolds & Richards, 1982 [13] | 6746,6              | Inappropriate   |
3.3. Flocculation
Flocculation unit of Cipageran WTP uses a type of hydraulic flocculation with vertical flow and consists of 6 hexagonal compartments. In the flocculation bath, the process of combining several particles into large-sized floc is intended to accelerate the number of collisions that cause the grouping of unstable colloidal electrolyte particles into a size that can be deposited. Hydraulic flocculation in Cipageran WTP can be seen in Figure 4, while evaluation results of flocculation tank is shown in Table 3. From Table 3, it can be seen that all parameters fulfil the design criteria.

Table 3. Evaluation results of Flocculation in Cipageran WTP

| No  | Unit     | Design Criteria   | Source                      | Result     | Remarks  |
|-----|----------|-------------------|-----------------------------|------------|----------|
| t_d | total    | 10 - 60 minute    | Droste, 1997 [15]           | 12.88 minute | Appropriate |
| G1  |         | 10-100 / second   |                             | 76.89 / second | Appropriate |
| G2  |         | 10-100 / second   |                             | 77.34 / second | Appropriate |
| G3  |         | 10-100 / second   | Darmasetiawan, 2000 [16]    | 65.76 / second | Appropriate |
| G4  |         | 10-100 / second   |                             | 78.14 / second | Appropriate |
| G5  |         | 10-100 / second   |                             | 59.43 / second | Appropriate |
| G6  |         | 10-100 / second   |                             | 41.32 / second | Appropriate |
| G_{t_d} | total   | $10^4$-$10^6$    | Reynolds dan Richards, 1982 [13] | 51535 | Appropriate |

3.3. Flocculation

Figure 3. Hydraulic Coagulation in Cipageran WTP (a) Real Picture and (b) Elongated Pieces

Figure 4. Hydraulic Flocculation in Cipageran WTP (a) Real Picture and (b) Elongated Pieces
3.4. Sedimentation

Sedimentation unit of Cipageran WTP is divided into two tanks. Each sedimentation tank is equipped with a tube settler with a slope of 60° and there are two sludge spaces per sedimentation tank. In the sedimentation basin, the process of settling or separating particles contained in water is deposited by gravity. Sedimentation tank in Cipageran WTP is shown in Figure 5, while evaluation results of sedimentation tank can be shown in Table 4. From Table 4, it can be seen that there was one parameter that did not fulfill the design criteria, which is $N_{Fr}$.

Table 4. Evaluation Results of Sedimentation in Cipageran WTP

| No | Unit | Design Criteria | Source             | Result         | Remarks      |
|----|------|-----------------|--------------------|----------------|--------------|
| 1  | Td   | 1 – 3 hour      | Montgomery, 1985 [17] | 1,07 hour     | Appropriate  |
|    |      | **Surface Loading** | 2.5-6.25 m³/m².hour | 3,875 m³/m².hour | Appropriate  |
|    |      |                 | Montgomery, 1985 [17] |               |              |
|    | $N_{Re}$ | < 2000         | Kawamura, 2000 [18]    | 35.44 m³/m².hour | Appropriate  |
|    | $N_{Fr}$ | $> 10^{-5}$    |                     | 6,26 x $10^{-6}$ | Inappropriate |

Figure 5. Sedimentation with Tube Settler in Cipageran WTP (a) Real Picture and (b) Elongated Pieces

3.5. Filtration

Once the floc settled to the bottom of water supply, the clear water on the top will pass to the filter of varying composition (sand, gravel, charcoal) and pore sizes to remove dissolved particles such as dust, parasites, bacteria, virus, and chemicals [19]. The filtration unit in Cipageran WTP consists of eight tanks with a rectangular shape. The type of filtration used is rapid sand filter. Filter medias used are sand and anthracite while the supporting media is gravel. After filtration process, there is a calming tank or clear well before the treated water enters the reservoir. In the clear well tank, chemical or disinfectants are added. The disinfectant used is chlorine gas with dose is 1.6 mg/l. Filtration tank in Cipageran WTP is shown in Figure 6, while evaluation results of filtration tank can be seen in Table 5. From Table 5, it can be seen that all parameters fulfill the design criteria.

Table 5. Evaluation Results of Filtration in Cipageran WTP

| No   | Unit       | Design Criteria | Source          | Result         | Remarks     |
|------|------------|-----------------|-----------------|----------------|-------------|
|      | Filtration rate | 6 – 11 m/hour   | SNI 6774-2008   | 7,92 m/hour    | Appropriate |

[Image 74x362 to 218x506]
[Image 244x362 to 521x490]
3.6. Optimization of Cipageran WTP

Cipageran WTP optimization is carried out by making a maximum discharge simulation that can be processed by each water treatment unit. The calculation results of maximum discharge in the Cipageran WTP evaluation unit compared to the design criteria can be seen in Table 6.

Table 6. Evaluation Maximum Discharge in Cipageran WTP

| Parameter | Maximum Discharge | Design Criteria | Evaluate Of Existing WTP | Result | Remarks |
|-----------|-------------------|----------------|--------------------------|--------|---------|
| Intake    |                   |                |                          |        |         |
| \( v \)   | 400 L/sec         | >0.6 m/sec     | 0.83 m/sec               | 1.67 m/sec | Appropriate |
| Hydraulic Coagulation |             |                |                          |        |         |
| \( t_d \) | 210 L/sec         | <60 sec        | 9.05 sec                 | 11.25 sec | Appropriate |
| \( G \)   | 700 - 1000 /sec   | 745.48/sec     | 996.9 /sec               |         |         |
| \( G_{10} \)| 10000 - 1000000  | 6746.6         | 11215.3                  |         |         |
| Hydraulic Flocculation |             |                |                          |        |         |
| \( t_d \) | 210 L/sec         | 10 - 60 minute | 12.88 minute             | 10.42 minute | Appropriate |
| \( G \)   | 76.89 /sec        | 85.57 /sec     | 77.34 /sec               | 79.69 /sec | Appropriate |
| \( G \)   | 65.76 /sec        | 76.68 /sec     | 59.43 /sec               | 69.99 /sec | Appropriate |

Figure 6. Filtration Tank in Cipageran WTP (a) Real Picture and (b) Elongated Pieces
| Parameter   | Maximum Discharge | Design Criteria | Evaluate Of Existing WTP | Result     | Remarks   |
|-------------|-------------------|-----------------|--------------------------|------------|-----------|
| G6          |                   |                 | 41,32 /sec               | 66,25 /sec | Appropriate |
| Gt[d]1      |                   |                 | 10178,82                 | 9146,39    |           |
| Gt[d]2      |                   |                 | 10119,06                 | 8418,37    |           |
| Gt[d]3      |                   |                 | 8501,37                  | 8019,09    |           |
| Gt[d]4      |                   |                 | 10015,81                 | 7610,00    |           |
| Gt[d]5      |                   |                 | 7525,33                  | 7188,38    |           |
| Gt[d]6      |                   |                 | 5195,44                  | 6750,76    |           |
| Gt[d] total | 10000 - 1000000   |                 | 51535,83                 | 47133,00   | Appropriate |

**Sedimentation (Tube Settler)**

| Parameter | Design Criteria | Evaluate Of Existing WTP | Result     | Remarks   |
|-----------|-----------------|--------------------------|------------|-----------|
| t[d]      | 1 - 3 hour      | 1,07 hour                | 1,03       | Appropriate |
| Surface Loading | 270 L/sec | 2.5 - 6.25 m/hour        | 3,875 m/hour       | 6.19  | Appropriate |
| N[Re]    | <2000           | 35,44                    | 56,77      | Appropriate |
| N[Fr]    | >10^-5          | 6,26 x 10^-6             | 0,000011   | Appropriate |

**Filtration (Rapid Sand Filter)**

| Parameter | Design Criteria | Evaluate Of Existing WTP | Result     | Remarks   |
|-----------|-----------------|--------------------------|------------|-----------|
| Filtration rate | 250 L/sec | 4 - 12.5 m/hour        | 7,92 m/hour       | 12,02  | Appropriate |

Table 6 shows that the results of the maximum discharge in Cipageran WTP is 210 L/second. Table 7 shows that the result of the maximum discharge of 210 L/second that still fulfil design criteria.

### Table 7. The Optimization Maximum Discharge of 210 L/sec in Cipageran WTP

| Parameter | Design Criteria | Evaluate Of Existing WTP | Result | Remarks   |
|-----------|-----------------|--------------------------|--------|-----------|
| Intake    |                 |                          |        |           |
| v         | >0 m/sec        | 0,83 m/sec               | 0,88   | Appropriate |
| Hydraulic Coagulation | | | | |
| t[d]      | <60 sec         | 9,05 second              | 11,25  | Appropriate |
| G         | 700 - 1000 /second | 745,48/second           | 996,9  | Appropriate |
| Gt[d]     | 10000 - 1000000 | 6746,6                  | 11215,3 | Appropriate |
| Hydraulic Flocculation | | | | |
| t[d]1     |                 | 132,38 sec              | 106,89  |           |
| t[d]2     |                 | 130,83 sec              | 105,64  |           |
| t[d]3     |                 | 129,28 sec              | 104,57  |           |
| t[d]4     |                 | 128,18 sec              | 103,59  |           |
| t[d]5     |                 | 126,63 sec              | 102,70  |           |
| t[d]6     |                 | 125,74 sec              | 101,90  |           |
| t[d] total | 10 - 60 minute | 12,88 minute             | 10,42   | Appropriate |
| G1        |                 | 76,89                    | 85,57   | Appropriate |
| G2        |                 | 77,34                    | 79,69   | Appropriate |
| G3        |                 | 65,76                    | 76,68   | Appropriate |
| G4        |                 | 78,14                    | 73,46   | Appropriate |
| G5        |                 | 59,43                    | 69,99   | Appropriate |
### Parameter Design Criteria Evaluate of Existing WTP Result Remarks

| G6  | Design Criteria | Evaluate of Existing WTP | Result | Remarks |
|-----|------------------|---------------------------|--------|---------|
| Gtd1|                  | 10178,82                  | 9146,39|         |
| Gtd2|                  | 10119,06                  | 8418,37|         |
| Gtd3|                  | 8501,37                   | 8019,09|         |
| Gtd4|                  | 10015,81                  | 7610,00|         |
| Gtd5|                  | 7525,33                   | 7188,38|         |
| Gtd6|                  | 5195,44                   | 6750,76|         |
| Gtd total | 10000 - 100000 | 51535,83                  | 47133,00| Appropriate |

### Sedimentation (Tube Settler)

| Parameter | Value |
|-----------|-------|
| t_d       | 1-3 hour |
| Surface Loading | 2.5 - 6.25 m/hour |
| N_Re      | <2000 |
| N_Fr      | >10^-5 |

### Filtration (Rapid Sand Filter)

| Parameter | Value |
|-----------|-------|
| Filtration Rate | 4 - 12.5 m/hour |

#### 3.7 Quality of Water Production in Cipageran WTP

A study of water quality was carried out within one month (March 2019) to see the quality of water produced of Cipageran WTP. The results of the water quality production measurement of the Cipageran WTP can be seen in Table 8.

**Table 8. Removal Efficiency of Turbidity on March 2019 in Cipageran WTP**

| Description | Turbidity (NTU) | Removal Efficiency (%) |
|-------------|-----------------|------------------------|
|             | Raw Water       | Treated Water          |
| Minimum     | 20              | 0.45                   | 93.65 |
| Maximum     | 54.4            | 1.93                   | 98.84 |
| Average     | 39.9            | 1.1                    | 97.01 |

Table 7 shows that the results of quality of production at Cipageran WTP, from the results obtained by the quality water production has met the quality standard according to the Minister of Health Regulation No. 492 of 2010 [5] concerning drinking water quality requirement, that turbidity limit is 5 NTU. From Table 7, it can be seen that removal efficiency of the water treatment plant was very high, which was more than 90%. From the result it can be said that Cipageran water treatment plant in this study deserved to be applied as drinking water treatment plant.

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