Optimisation of degreemont water treatment package on Kedung Halang water treatment plant, Bogor, West Java

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Abstract. To provide drinking water in Bogor Regency, PDAM Tirta Kahuripan has several Water Treatment Plants (WTP) Kedung Halang WTP. Kedung Halang WTP consists of two water treatment packages, Indisi and Degreemont, with an average production of 37.3 L/s and 83.9 L/s, respectively. The purposes of this research are to evaluate the performance of the operating unit and process on the Degreemont Package and to provide optimisation recommendations based on the evaluation result. Steps in this research include evaluating the existing condition, providing recommendations, and analysing the quality of water produced.

The evaluation found that one of the parameters did not fulfil the design criteria: the G.Td value on coagulation. The evaluation result of maximum flow rate is 125 L/s on intake, 150 L/s on coagulation, 130 L/s on flocculation and sedimentation, and 200 L/s on filtration. Thus, the optimum flow rate that can be operated is 125 L/s. The turbidity of the water produced has met the drinking water standard according to Minister of Health Regulation No. 492 of 2010, with removal efficiency above 95%. According to the result, it can be said that Degreemont Package is qualified to be applied as a drinking water treatment.

1. Introduction

Water is the fundamental of human, and all other creatures, life. However, with the increasing number of populations, the water demand is also increasing. Population growth will limit the amount of water available per person [1]. The United Nations World Water Development Report 2021 stated that the global population experiencing water scarcity increased from 32 million people in 1900 to a projected 3.1 billion people by 2050 [2]. Besides the water quantity, but population growth also decreases water quality in natural water sources due to human activities and land use around the water sources [3]. Many of the world's major urban areas are withdrawing water from rivers recharged with wastewater from all the cities located upstream or even from the urban area itself [1].

The Water Treatment Plant (WTP) aims to ensure that the water distributed in society is safe for health. In general, the water treatment process consists of coagulation, flocculation, sedimentation, filtration, and disinfection [4]. In Indonesia, the water distributed should fulfil the drinking water requirements in quality, which is regulated in Minister of Health Regulation No. 492 of 2010 [5]. One way to fulfil the increasing water demand is optimising the drinking water supply system, including the WTP [6].

In recent studies, optimisation consists of measures to decrease the managing and monitoring expenses and improve the quality of produced water [4]. A study done by Sani et al. showed that
optimisation of Cipageran WTP could increase the processing capacity to 210 L/s from the initial design capacity of 200 L/s [7]. In contrast, a study done by Ramadhan et al. showed that optimisation of Solar WTP could increase the processing capacity of 130 L/s from the initial design capacity of 100 L/s [6].

Like any other city or regency across Indonesia, the population in Bogor Regency is increasing, with a population growth rate of 2.45%. The drinking water supply in Bogor Regency is managed by PDAM Tirta Kahuripan. To fulfil the drinking water demand, PDAM Tirta Kahuripan has several WTP. One of them is WTP Kedung Halang, with a design capacity of 130 L/s. WTP Kedung Halang consists of two water treatment packages, Indisi and Degreemont, with a design capacity of 40 L/s and 90 L/s. However, the average processing flow rate is only 37.3 L/s for the Indisi Package and 83.9 L/s for Degreemont Package. Both packages have processing units consist of intake, coagulation, flocculation, sedimentation, filtration, and disinfection.

Though many studies have discussed WTP optimisation, there have not been any studies mentioning Kedung Halang WTP yet. Thus, this research would propose an optimisation to maximise the processing capacity of Kedung Halang WTP, particularly the Degreemont Package, without compromising the quality of water produced.

The purposes of this research are (1) to evaluate the performance of operating unit and process on Degreemont Package, and to provide optimisation recommendations based on the evaluation result; and (2) to compare the quality of water produced with drinking water quality standards.

2. Methodology

2.1. Research stages

Stages on this research include literature review, data collection, and data analysis. The outcomes of this research consist of evaluation results of existing conditions, optimum processing flow rate, and existing performance based on turbidity and removal efficiency. The research flow chart can be seen in Figure 1.

![Figure 1. Research flow chart.](image)

2.2. Location and time

This research was conducted on Kedung Halang WTP, which is located at Jl. Perumahan PPKN, Kedung Halang Ward, Bogor Regencies, throughout March 2021.

2.3. Data collection

There were two types of data used in this research, primary data and secondary data. Primary data includes the dimensions of each unit, which are measured directly on the installation. Secondary data consist of the average processing flow rate and the quality of raw water and water produced in turbidity. The secondary data was obtained from Kedung Halang WTP’s archives for March 2021. Kedung Halang
WTP used a water meter to measure the processing flow rate, while turbidity was measured using a turbidimeter.

2.4. Data analysis
The dimensions of each unit and average processing flow rate data were used to calculate the value of design parameters important to the operational system. There are 8 design parameters calculated with the following equations [13]:

Pipe velocity:

\[ v = \frac{Q}{A_{\text{pipe}}} \]  

(2.1)

Gradient velocity:

\[ G = \sqrt{\frac{P}{\mu \times \text{Vol}}} \]  

(2.2)

Detention time:

\[ T_d = \frac{\text{Vol}}{Q} \]  

(2.3)

G.Td value:

\[ G \times T_d = G \times T_d \]  

(2.4)

Surface loading:

\[ S_o = \frac{Q}{A_{\text{sedimentation}}} \]  

(2.5)

Reynolds number:

\[ N_{Re} = \frac{v_o \times R}{\nu} \]  

(2.6)

Froude number:

\[ N_{Fr} = \frac{v_o^2}{g \times R} \]  

(2.7)

Filtration rate:

\[ v_f = \frac{Q}{A_{\text{filtration}}} \]  

(2.8)

Whereby,

- \( Q \) = flow rate (m³/s)
- \( A \) = area (m²)
- \( P \) = power (kg.m²/s³)
- \( \mu \) = absolute viscosity (kg/m.s)
- \( \text{Vol} \) = volume (m³)
- \( v_o \) = settling velocity on settler (m/s)
- \( R \) = hydraulic radius (m)
- \( \nu \) = kinematic viscosity (m/s²)

Analysis of operational system was carried out by comparing the critical design parameters value between results of calculations by the actual condition and the design criteria obtained from the literature review. Analysis of the quality of water produced by comparing the turbidity parameter of water produced with drinking water quality standard contained in Minister of Health Regulation No. 492 of 2010. The removal efficiency was calculated with equations below:
Removal efficiency: \( \frac{\text{Raw water turbidity - treated water turbidity}}{\text{raw water turbidity}} \times 100\% \) (2.9)

3. Results and discussion

Treatment processes of Degreemont Package on Kedung Halang WTP consist of intake, coagulation, flocculation, sedimentation, filtration, disinfection, and reservoir, with an average production of 83.9 L/s as the raw water source is the Ciliwung River, which is pumped to Kedung Halang WTP. The Degreemont Package processing flow chart is shown in Figure 2.

3.1. Intake

Intake is a building made on the side of a water source, with the intention that some water from the source can be deflected used as desired [8]. On Kedung Halang WTP, the intake is equipped with a bar screen, sluice gate, intake well, and intake pump. There are four pumps with a maximum capacity of 50 L/s each. The water collected will be brought to WTP with a 300 mm diameter transmission pipe. The length of the transmission pipe is 120 m. The evaluation result of intake on Kedung Halang WTP can be seen in Table 1.

| Parameter                        | Design Criteria | Source                  | Result | Remarks  |
|----------------------------------|-----------------|-------------------------|--------|----------|
| Velocity in transmission pipe    | 0.9 – 1.8 m/s   | Fair et al., 1968 [9]   | 1.51 m/s | appropriate |

The evaluation result showed that the velocity in the transmission pipe had met the design criteria. This parameter was evaluated because the velocity that is too slow could cause deposition inside the transmission pipe, while velocity that is too fast could damage the pipe.

3.2. Coagulation

Coagulation, or rapid mixing, aims to disperse the added coagulant uniformly and trigger the collisions between coagulant and turbidity-causing particles [10]. The coagulant usually is a positively charged metal ion. Thus, it can neutralise the negative charges of colloidal particles, which are the cause of turbidity. Coagulants that are usually used are aluminium sulphate and Poly Aluminium Chloride (PAC) [11]. The type of coagulation used on the Degreemont Package is hydraulic mixing, where the water is dropped from a certain height so that it causes mixing power. The water is collected first in the receiving
tank before being dropped to the coagulation tank. The coagulant used is aluminium sulphate, with an average dose of 29.10 mg/L. There are three coagulation tanks on Degreemont Package. The evaluation results of the coagulation process are shown in Table 2.

Table 2. Evaluation results of coagulation.

| Parameter     | Design Criteria | Source                      | Result  | Remarks    |
|---------------|-----------------|-----------------------------|---------|------------|
| Detention time| 1 – 60 s        | Schulz & Okun, 1984 [12]    | 10.69 s | appropriate|
| Gradient velocity | 100 – 1000 /s  | Qasim, 2000 [13]            | 594.06 /s | appropriate|
| G.Td value    | $10^4$ – $10^6$ | Reynolds & Richards, 1996   | 6350.79 | inappropriate|

Gradient velocity and G.Td value should be calculated in coagulation and flocculation units because these numbers represent the mixing intensity. The evaluation results found that G.Td value on coagulation did not fulfil the design criteria. Theoretically, the G.Td value that is too low may cause the coagulant not to be wholly dispersed and eventually affect the flocculation process on flocculation. However, it did not cause any problem on the installation, as the flocs formed after flocculation are already large and dense.

3.3. Flocculation

The flocculation process is the aggregation of destabilising particles in the micro-flocs and larger particles called flocs. There are two types of flocculation, hydraulic and mechanical. The hydraulic flocculator is preferred in developing countries because of the ease of operation and maintenance [15]. There are six hydraulic flocculation units on Degreemont Package, with six rectangular-shaped compartments on each unit. The agitation occurs because of the opening between compartments. The evaluation results of the flocculation process are shown in Table 3.

Table 3. Evaluation results of flocculation.

| Parameter     | Design Criteria | Source                      | Result     | Remarks    |
|---------------|-----------------|-----------------------------|------------|------------|
| Detention time| 10 - 60 min     | Droste, 1977 [16]           | 15.85 min  | appropriate|
| Gradient velocity | 10 - 100 /s  | Schulz & Okun, 1984 [12]    | 74.29 – 27.15/s | appropriate|
| G.Td value    | $10^4$ – $10^6$ | Reynolds & Richards, 1996   | 44997.99    | appropriate|

The evaluation results showed that all the parameters on flocculation had fulfilled the design criteria. It indicates that the agitation on flocculation is slow enough to give the destabilised particle a chance to coalesce, but not too slow that it may cause sedimentation on the flocculation unit. The gradient velocity is gradually decreasing from one compartment to the next compartment, creating tapered flocculation. It intended to keep the flocs formed from breaking.

3.4. Sedimentation

Sedimentation is one of the most common particle separations. In water treatment, sedimentation aims to remove impurities, turbidity, and colour produced by the floc formed in the coagulation and flocculation process [17]. Plate or tube settlers could be installed in the sedimentation tank with a particular slope to increase the settling efficiency in the sedimentation tank [18].

There are six sedimentation units equipped with 60° slope tube settlers on Degreemont Package. Each unit has two sludge spaces at the bottom of the tank. The water is flowing out from the sedimentation tank using two gutters. The evaluation results of sedimentation are shown in Table 4.
Table 4. Evaluation results of sedimentation.

| Parameter          | Design Criteria | Source                          | Result  | Remarks |
|--------------------|-----------------|---------------------------------|---------|---------|
| Detention time     | 15 - 60 min     | Darmasetiawan, 2004 [19]        | 24.08 min | appropriate |
| Surface loading    | 5.8 – 9.6 m³/m²h| Schulz & Okun, 1984 [12]        | 6.18 m³/m²h | appropriate |
| Reynolds Number    | > 10⁻⁵          | Kawamura, 2000 [20]             | 2 x 10⁻⁵ | appropriate |
| Froude Number      | ≤ 0.15          | Kawamura, 2000 [20]             | 0.12    | appropriate |

The evaluation results showed that all the parameters on sedimentation had fulfilled the design criteria, creating an ideal situation for particles to settle. Surface loading is one of the essential parameters because when the value is too high, the particles would not settle ultimately and could burden the following unit. Detention time is calculated because its value is proportional to the number of particles that settle. Reynolds and Froude number that has fulfilled design criteria signify that the flow is calm and laminar so that the particles may settle.

3.5. Filtration
Filtration removes suspended and colloidal particles in an aqueous suspension that drains through a porous medium [21]. On Degreemont Package, six filtration units with dual media filters consist of anthracite and sand, with gravel below them as supporting media. The disinfection process is applied to the connecting pipe between the filtration unit and reservoir as a disinfectant is calcium hypochlorite, with an average dose of 1.48 mg/L. The evaluation results of filtration can be seen in Table 5.

Table 5. Evaluation results of filtration.

| Parameter        | Design Criteria | Source                          | Result  | Remarks |
|------------------|-----------------|---------------------------------|---------|---------|
| Filtration rate  | 7.3 – 19.5 m/h  | Reynolds & Richards, 1996 [14]  | 8.18 m/h | appropriate |

The evaluation results showed that the filtration rate had fulfilled the design criteria. The filtration rate is the only parameter calculated infiltration because a filtration rate that is too high could reduce the quality of the water produced, while a filtration rate that is too low could decrease the effectiveness of the filtration process.

3.6. Optimisation of degreemont package
To optimise the Degreemont Package’s production capacity, the maximum flow rate that each unit could process should be found. The optimisation is done by simulating various flow rates until the maximum value is found. The evaluation results on the maximum flow rate of each unit are shown in Table 6.

Table 6. Evaluation results on maximum flow rate on each unit.

| Parameter        | Maximum Flow Rate | Design Criteria | Existing Condition | Result  | Remarks |
|------------------|-------------------|-----------------|--------------------|---------|---------|
| Intake Pipe velocity | 125 L/s          | 0.9 – 1.8 m/s   | 1.51 m/s           | 1.77 m/s | appropriate |
| Detention time   | 1 - 60 s          | 10.69 s         | 9.2 s              |         | appropriate |
| Gradient Velocity| 150 L/s           | 100 - 1000 /s   | 594.06 /s          | 705.03 /s | appropriate |
| G.Td value       | 10⁴ - 10⁶         | 6350.79         | 6486.3             |         | appropriate |
| Detention time   | 130 L/s           | 10 - 60 min     | 15.85 min          | 10.23 min | appropriate |
Parameter | Maximum Flow Rate | Design Criteria | Existing Condition | Result | Remarks |
---|---|---|---|---|---|
Gradient Velocity | 10 - 100 /s | 74.29 – 27.15/s | 92.47 – 33.85/s | | appropriate |
G.Td value | 10⁴ - 10⁶ | 44997.99 | 36496.49 | | appropriate |
Detention time | 15 - 60 min | 24.08 min | 15.54 min | | appropriate |
Surface loading | 130 L/s | 5.8 – 9.6 m³/m²/h | 6.18 m³/m²/h | | appropriate |
Reynolds Number | > 10⁵ | 2 x 10⁵ | 71.64 | | appropriate |
Froude Number | ≤ 0.15 | 0.12 | 4.8 x 10⁻⁵ | | appropriate |
Filtration rate | 200 L/s | 7.3 – 19.5 m/h | 8.18 m/h | 19.49 m/h | appropriate |

From Table 6, it was shown that one of the parameters, which is the G.Td value of coagulation, did not fulfill the design criteria. It could happen because the G.Td value on the existing condition did not fulfill the design criteria from the beginning. However, because this does not cause any problem in the existing condition, the lowest G.Td value limiting the maximum flow rate is set on the G.Td value on the existing condition, 6350.79. Based on Table 6, the maximum flow rate on Degreemont Package is 125 L/s. The evaluation result with a maximum flow rate of 125 L/s can be seen in Table 7.

**Table 7.** Evaluation results on 125 l/s flow rate.

Parameter | Design Criteria | Existing Condition | Result | Remarks |
---|---|---|---|---|
Intake | | | |
Pipe velocity | 0.9 – 1.8 m/s | 1.51 m/s | 1.77 m/s | appropriate |
Detention time | 1 – 60 s | 10.69 s | 11.04 s | appropriate |
Gradient Velocity | 100 – 1000 /s | 594.06 /s | 996.54 /s | appropriate |
G.Td value | 10⁴ - 10⁶ | 6350.79 | 7105.39 | appropriate |
Flocculation | | | |
Detention time | 10 – 60 min | 15.85 min | 10.64 min | appropriate |
Gradient Velocity | 10 – 100 /s | 74.29 – 27.15 /s | 90.68 – 33.13 /s | appropriate |
G.Td value | 10⁴ - 10⁶ | 44997.99 | 36866.9 | appropriate |
Sedimentation | | | |
Detention time | 15 – 60 min | 24.08 min | 16.16 | appropriate |
Surface loading | 5.8 – 9.6 m³/m²/h | 6.18 m³/m²/h | 9.21 m³/m²/h | appropriate |
Reynolds Number | > 10⁵ | 2 x 10⁵ | 68.88 | appropriate |
Froude Number | ≤ 0.15 | 0.12 | 4.5 x 10⁻⁵ | appropriate |
Filtration rate | 7.3 – 19.5 m/h | 8.18 m/h | 12.18 m/h | appropriate |

From Table 7, it was obtained that the evaluation results of all parameters are appropriate. This show that the flow rate of 125 L/s is possible to be applied on the Degreemont Package.
3.7. Quality of water produced
The quality of the water produced and efficiency removal based on turbidity parameter on Degreemont Package can be seen in Table 8. Water turbidity measurements were carried out throughout March 2021. Table 8 show that the water produced has fulfilled drinking water standard according to Minister of Health Regulation No. 492 of 2010 [5] based on turbidity parameter, which is below 5 NTU.

Table 8. Turbidity and removal efficiency of degreemont package.

| Description      | Turbidity (NTU) | Removal Efficiency |
|------------------|-----------------|--------------------|
|                  | Raw Water       | Treated Water      |                  |
| Minimum          | 21.92           | 0.33               | 96.95%           |
| Maximum          | 470.67          | 0.93               | 99.86%           |
| Average          | 95.58           | 0.54               | 98.81%           |

4. Conclusion
Degreemont Treatment Package on Kedung Halang WTP has an average production of 83.9 L/s, with treatment processes consist of intake, coagulation, flocculation, sedimentation, filtration, disinfection, and reservoir. On existing conditions, the value of G.Td on coagulation did not fulfil the design criteria. However, this did not cause any problem on installation since the flocs formed were already large and dense enough. The maximum flow rate that can be operated on each unit is 125 L/s on intake, 150 L/s on coagulation, 130 L/s on flocculation and sedimentation, and 200 L/s on filtration. This show that the optimisation of the Degreemont Package could increase the processing capacity to 125 L/s from the initial design capacity of 90 L/s. The quality of water produced has fulfilled drinking water standards based on Minister of Health Regulation No. 492 of 2010, with turbidity on treated water ranged from 0.33 to 0.93 NTU and average removal efficiency of 98.81%. Therefore, it can be said that the Degreemont Package is qualified as a drinking water treatment.

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