Optimization of water treatment process performance of Duren Seribu Water Treatment Plant in Depok City: water quality and design parameters

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Abstract. Duren Seribu Water Treatment Plant (WTP) plays a role in fulfilling water needs due to the increase in population growth. This study aims to evaluate the performance of the WTP and the potential for capacity uprating from the aspect of conformity to water quality standards, removal efficiency, and design parameters. Data collection was carried out by observation, measurement, and sampling. The result showed that raw water quality complies with the quality standards and is influenced by seasons. Meanwhile, the quality of drinking water produced for the parameters of pH, turbidity, TDS, organic matter, iron, and total coliform has complied with the quality standards. The efficiency removal of turbidity, TDS, organic matter, and iron occurred in conventional processing units were 94.6%, 70.5%, and 90.9%, and the total coliform removal efficiency was 1.8-log (67.05%). Based on the assessment of the design criteria, there are design parameters of the unit that require technical improvement such as detention time of flocculation unit, velocity and detention time in tube settler sedimentation unit, and the capacity of Duren Seribu WTP could be increased by 10% or up to 110 liters/second.

1. Introduction
Humans use water for most aspects of life, such as drinking, washing, cooking, and fertilizing the soil for food [1]. This statement is embodied in Sustainable Development Goals (SDGs) number 6 (six), which focuses on clean water and sanitation and has a target of water infrastructure development to achieve drinking water services of 118.6 m³/second [2]. In 2030, the population of West Java Province is projected to be in second place in terms of population growth. In the last ten years, with an average growth rate of 1.48%. The percentage of the population in Depok City that has access to safe drinking water is 16% out of the 2.1 million inhabitants.

Meanwhile, 84% still chooses to use groundwater and other sources [3]. Referring to government regulation concerning in Drinking Water Supply System is an integral part of drinking water supply facilities and infrastructure. The sustainability of water supply programs in developing countries is influenced by interrelated and dynamic factors [4]. In addition, there are strategic issues and problems in the development of the Drinking Water Supply System in terms of increasing access to safe drinking water, developing funding, increasing institutional capacity, developing and implementing laws and regulations, meeting drinking water needs, and developing a Drinking Water Supply System through
application of technological innovation. The Drinking Water Supply System is designed to pay attention to sustainability in its operation. In addition, the treatment plant should be able to produce drinking water in distinct weather and environmental conditions [5]. Commonly water treatment units used include pre-sedimentation, conventional treatment (coagulation, flocculation, and sedimentation), filtration, and disinfection [6].

In fulfilling the need for clean water, the water treatment plant (WTP) management is not exempt from problems in the operation and process units. Duren Seribu WTP is currently dealing with problems with the disinfection process. The residual chlorine concentration is sometimes less than 2 mg/L. Moreover, based on water quality monitoring data conducted by PDAM Tirta Asasta, the raw water quality of the Angke River contains a high concentration of organic substances. The highest concentration was reached at 29.89 mg/L in September 2020, and with this concentration, it becomes an obstacle that causes the disinfection process to be not optimal [7].

Evaluation research is often used to determine whether water or wastewater treatment plants have been running well or not. In addition, evaluation research is conducted by seeking an explanation of a situation or problem using quantitative and qualitative data. Evaluation can be done by comparing the actual data with the literature. Research on WTP evaluation and optimization had been carried out by calculating and comparing the design parameters and criteria for each unit operation and process at Legong Water Treatment Plant in Depok City. The result showed that the drinking water produced showed compliance with quality standards, evaluation of each unit operation and process detected that the flocculation and sedimentation units did not meet the design criteria. The production capacity of the Legong Water Treatment Plant could be increased from 190 to 250 liters/second based on the results of the evaluation, the problem was analyzed, and a solution can be found and applied in WTP [8–10].

This study aims to evaluate the performance of the WTP and the potential for capacity uprating from the aspect of conformity to quality standards, removal efficiency, and design parameters. According to Permenkes No. 492/Menkes/Per/IV/2010 concerning Drinking Water Quality Requirements, technical evaluation of WTP performance is reviewed based on effluent quality and quality standards.

## 2. Methodology

This study is evaluation research through WTP observation, WTP operator interview, and sampling of raw and drinking water methods. Duren Seribu WTP is located at Sawangan Elok Street Block B6/10, Duren Seribu, Bojongsari, Depok City. The water sampling was carried out in March 2021, twice a week for three weeks in a row in the morning from 09.00 until 10.00 WIB. Sampling was carried out in raw water source, sedimentation unit outlet, filtration unit outlet, and disinfection unit outlet. Parameters observed were pH, turbidity, total dissolved solids (TDS), iron (Fe), organic matter, and total coliform. Secondary data in the form of technical drawings, technical reports, Standard Operating Procedures (SOP) for monitoring and maintenance, and data on the quality of raw water and drinking water for the last 24 months of 2018 – 2020 were processed and analyzed. The design parameters evaluation was carried out on the flocculation unit, sedimentation unit filtration unit, disinfection unit, and reservoir because there is still potential for increasing production capacity in each unit. The following table [table 1] is design parameters that are reviewed for each unit.

| Table 1. Design parameters. |
| --- |
| **Eq. No.** | **Design Parameters** | **Equation** | **Criteria** |
| (1) | Velocity through intake gate, (m/s) | \( v = \frac{Q}{A} \); Q=flow rate (m³/s), A=intake gate opening area (m²) | \( \leq 0.08 \) |
| (2) | Velocity through bar screen, (m/s) | \( v = \frac{Q}{A} \); Q=flow rate (m³/s), A=bar screen opening area (m²) | \( \leq 0.08 \) |
| (3) | Velocity through fine screen, (m/s) | \( v = \frac{Q}{A} \); Q=flow rate (m³/s), A=fine screen opening area (m²) | \( \leq 0.2 \) |
| Eq. No. | Design Parameters | Equation | Criteria |
|---------|-------------------|----------|----------|
| (1.4)   | Velocity through  | $v = \frac{Q}{A}$; $Q =$ flow rate (m$^3$/s), $A =$ transmission pipeline cross-section area (m$^2$) | 0.3-3 |
|         | (transmission     |           |          |
|         | pipeline, (m/s)   |           |          |
| (1.5)   | Major headloss,   | $h_f = 6.81 \left(\frac{V}{C}\right)^{1.85} \left(\frac{L}{D^{0.5}}\right)$; $v =$ water velocity (m/s), $C =$ pipeline roughness coefficient, $L =$ pipeline length (m), $D =$ pipeline diameter (m) |          |
|         | (m)               |           |          |
| (1.6)   | Minor headloss,   | $h_m = \frac{k V^2}{2g}$; $k =$ minor headloss coefficient, $v =$ water velocity (m/s) |          |
|         | (m)               |           |          |
| (1.7)   | Total head, (m)   | $TDH = H_s + h_f + h_m$; $H_s =$ head suction (m), $h_f =$ major headloss (m), $h_m =$ minor headloss (m) |          |
| (1.8)   | Pump power, (kW)  | $P = \frac{Q \times H \times \rho \times g}{1000 \times \eta_p \times \eta_m}$; $Q =$ flow rate (m$^3$/s), $H =$ total head (m), $\rho =$ water density (kg/m$^3$), $g =$ acceleration due to gravity (m/s$^2$), $\eta_p =$ pump efficiency, $\eta_m =$ motor efficiency |          |
| (2)     | Coagulation Unit  |           |          |
| (2.1)   | Detention time, (s) | $t_d = \frac{V}{Q}$; $V =$ unit volume (m$^3$), $Q =$ flow rate (m$^3$/s) | 10-300 |
| (2.2)   | Velocity gradient, (m/s) | $G = \sqrt{\frac{g \times h}{\mu}}$; $g =$ acceleration due to gravity (m/s$^2$), $h =$ headloss (m), $\mu =$ water kinematic viscosity (m$^2$/s), $t_d =$ detention time (s) | 100-1000 |
| (3)     | Flocculation Unit |           |          |
| (3.1)   | Detention time, (s) | $t_d = \frac{V}{Q}$; $V =$ unit volume (m$^3$), $Q =$ flow rate (m$^3$/s) | 30-45 |
| (3.2)   | Velocity gradient, (m/s) | $G = \sqrt{\frac{g \times h}{\mu}}$; $g =$ acceleration due to gravity (m/s$^2$), $h =$ headloss (m), $\mu =$ water kinematic viscosity (m$^2$/s), $t_d =$ detention time (s) | 60-5 |
| (3.3)   | Channel velocity, (m/s) | $v = \frac{Q}{A}$; $Q =$ flow rate (m$^3$/s), $A =$ compartment vertical cross-section area (m$^2$) | $\leq 0.9$ |
| (3.4)   | GT value          | $GT = G \times t_d$; $G =$ velocity gradient (m/s), $t_d =$ detention time (min) | 10,000-100,000 |
| (4)     | Sedimentation Unit |           |          |
| (4.1)   | Overflow rate, (m$^3$/m$^2$.h) | $S_o = \frac{Q}{(W \times (\cos \alpha + \cos \theta \cdot \sin \alpha))}$; $A =$ basin area (m$^2$), $Q =$ flow rate (m$^3$/s), $W =$ space between plate settler/tube settler diameter (m), $S_o =$ overflow rate (m$^3$/m$^2$.h), $H =$ length of plate/tube settler (m), $\alpha =$ angle of plate/tube settler from horizontal ($^\circ$) | 3.8-7.5 |
| (4.2)   | Weir loading, (m$^3$/m.h) | $WL = \frac{Q}{L}$; $Q =$ flow rate (m$^3$/s), $L =$ weir length (m) | $< 11$ |
| (4.3)   | Velocity through inlet pipe, (m/s) | $v = \frac{Q}{A}$; $Q =$ flow rate (m$^3$/s), $A =$ inlet pipe cross-section area (m$^2$) |          |
| (4.4)   | Velocity through tube settler, (m/min) | $v = \frac{Q}{A \sin \theta}$; $Q =$ flow rate (m$^3$/s), $A =$ compartment vertical cross-section area (m$^2$), $\alpha =$ angle of plate/tube settler from horizontal ($^\circ$) |          |
### Design Parameters

| Eq. No. | Design Parameters | Equation | Criteria |
|---------|-------------------|----------|----------|
| (4.5)  | Tube settler detention time, (jam) | \( t_d = \frac{d}{v \cos \theta} \); d=tube settler diameter (m), v=water velocity through tube settler (m/s), \( \theta \)= angle of plate/tube settler from horizontal (°) | |
| (4.6)  | Reynolds number | \( Re = \frac{vD}{\mu} \); v=velocity through tube settler (m/s), D=hydraulic radius (m), \( \mu \)=water kinematic viscosity (m²/s) | < 2,000 |
| (4.7)  | Fraude number | \( Fr = \frac{v}{\sqrt{gL}} \); v=water velocity through tube settler (m/s), g=acceleration due to gravity (m/s²), L=length of plate/tube settler (m) | > 10⁻⁵ |

### Filtration Unit

| (5) Number of filter units, (unit) | \( N = 12 Q^{0.5} \); N=number of filter units (unit), Q=flow rate (m³/s) | |
| (5.2) Filtration rate, (m/h) | \( v = \frac{Q}{A} \); Q=flow rate (m³/s), A=filter bed area (m²) | 6-11 |
| (5.3) Velocity through inlet pipe, (m/s) | \( v = \frac{Q}{A} \); Q=flow rate (m³/s), A=inlet pipe cross-section area (m²) | 0.3-0.6 |
| (5.4) Backwash rate, (m/h) | \( v_b = 10\% \times v_s \); \( v_b \)=backwash rate (m/h), \( v_s \)=terminal velocity, (m/h) | 36-50 |
| (5.5) Period between two backwashes, (hour) | | 18-24 |
| (5.6) Filter bed expansion, (%) | | 30-50 |

### Disinfection Unit and Reservoir

| (6.1) Chlorine dosage, (mg/L) | | 1-5 |
| (6.2) The free residual chlorine (mg/L) | | 0.25-0.35 |
| (6.3) Disinfection effectiveness (CT) | \( \frac{CT_{cal}}{CT_{tab}} \); \( CT_{cal} \)=free chlorine concentration multiply by \( t_{10} \) (mg.min/L), \( CT_{tab} \)=theoretical CT value based on literature (mg.min/L) | \( CT_{cal} > 1 \) |
| (6.4) Contact time, (\( t_{10} \)) | \( t_{10} = \frac{V}{Q} \cdot f \); V=unit volume (m³), Q=flow rate (m³/s), \( f \)=conversion factor depends on baffling condition | |

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### Results and discussion

**3.1. Raw water and drinking water quality**

Based on the processed data on monitoring the quality of raw water and drinking water by PDAM Tirta Asasta in 2018 – 2020 and tests conducted in March 2021, it shows that the pH value of raw water never exceeds 7. This indicates that raw water source tends to be acidic. The quality of drinking water produced and raw water is alike, which tends to be acidic. This is caused by uncontrolled coagulant chemicals that may affect the decrease in pH. The coagulant, aluminum sulfate, reacts with water to produce sulfuric acid compounds, which are acidic [10]. Jar test can be done to determine the optimum coagulant dose.

The highest turbidity removal efficiency is measured after the conventional treatment process [Fig. 1]. Water treatment with coagulation, flocculation, and sedimentation can significantly reduce turbidity in raw water from \( 63 \pm 32.03 \) NTU to \( 3.2 \pm 2.4 \) NTU with a removal efficiency of 94.6%.
Figure 1. Turbidity value at each sampling point.

The concentration of total dissolved solids at each sampling point showed increasing. That can be happened because of the interaction between water and steel material in WTP and water treatment. The process of adding a coagulant that is not by the optimum dose can increase the possibility of deflocculation.

The concentration of organic matter in raw water tends to fluctuate from 2018 – 2020. Meanwhile, a test in March 2021 showed that the concentration of organic matter in raw water sources was in the range of 5 – 7 mg/L [Fig. 2]. In order to overcome the presence of organic matter in raw water, all treatment units at Duren Seribu WTP need readjustment. The highest organic matter removal efficiency at Duren Seribu WTP only reached 70.5% in the conventional treatment process, from 5 ± 1.43 mg/L to 1.3 ± 0.35 mg/L. It is necessary to add another primary coagulant as a combination, such as adding polymer coagulants and using activated carbon so that the adsorption process of organic matter occurs to increase the efficiency of removing organic matter in raw water [8].

Figure 2. Organic matter concentration at each sampling point.

The amount of iron (Fe) concentration in raw water can be caused by river sediments that act as mineral traps, industrial waste disposal with corroded pipes, and domestic waste disposal without further treatment. The removal efficiency of iron (Fe) reaches 90.9% in the conventional treatment process [Fig. 3]. Furthermore, the removal efficiency decreases in the filtration unit. However, this does not significantly impact the iron (Fe) concentration that had reached 0.1 ± 0.06 mg/L.
Figure 3. Iron (Fe) concentration at each sampling point.

Total coliform in raw water is in the range of 70 – 1,600 MPN/100 mL sample. The presence of total coliform in raw water sources might be caused by the discharge of domestic wastewater without pre-treatment into the river stream and wastewater from cattle farms along the river. The number of total coliforms in drinking water was found 2 MPN/100 mL sample and 1.8 MPN/100 mL sample [Fig. 4]. This indicates that drinking water has not complied with the applicable quality standards for microbiological parameters. The total coliform removal from raw water reached 1.8-log (67.05%) but still did not reach 2-log or 99% [12,13]. The existence of total coliform can also be used as a reference that the disinfection process in the WTP has not been running properly.

Figure 4. Total coliform at each sampling point.

In this study, all drinking water quality parameters sampled and analyzed by the researchers had complied with the quality standards even before the WTP was optimized. So, it is expected that after the optimization is carried out, it will maintain or even improve the quality of drinking water produced.

3.2. Design parameters and potential uprating capacity of processing units

3.2.1. Intake unit. The intake unit of Duren Seribu WTP has a 6 mm thick steel gate with dimensions of 80 × 100 cm. The opening gate is equipped with a penstock to adjust the height of the opening gate. There is a bar or coarse screen made of iron material with dimensions of 360 × 100 cm. Evaluation of the first design parameter based on the actual flow rate of 70 liters/second, the maximum velocity of raw water does not meet the design criteria. Therefore the technical solution is to maximize the opening gate by 1 meter. Secondly, the exemplary screen should be added to the intake unit to maximize the filtering of raw water from waste and large materials.
3.2.2. **Coagulation unit.** Duren Seribu WTP uses coagulation with turbulent pipes. The pipe is located in one segment of the transmission line. The diameter of the turbulent pipe is 300 mm, which is equipped with bulkheads to achieve a certain gradient velocity. Evaluation and optimization cannot be carried out in this unit due to limited existing data.

3.2.3. **Flocculation unit.** The flocculation unit in Duren Seribu WTP is hydraulic flocculation with the vertical flow. The flocculation unit has six compartment basins in each. The six basins have the exact dimensions, both length and width of 2.52 meters and a depth of 3.3 meters, and steel. The detention time (49.89 minutes) does not comply with the design criteria for the flocculation unit, and the velocity gradient (15.71–25.34/second) met the design criteria. The longer detention time in the flocculation unit does not necessarily mean that the flocculation process has run optimally. The GT value indicates whether the mixing process has been going correctly or not in coagulation and flocculation units [14]. The GT value is measured at 47,033. Optimization can be done by reviewing the gradient velocity that is made to decrease constantly (60 s⁻¹, 50 s⁻¹, 40 s⁻¹, 30 s⁻¹, and 20 s⁻¹) with the height adjustment of the gate between basins gradually. Consequently, the optimum flow rate that the flocculation unit can process is 116 liters/second.

3.2.4. **Sedimentation unit.** Duren Seribu WTP uses a horizontal flow sedimentation unit equipped with a tube settler. The sedimentation unit consists of two basins in each with dimensions of length, with, and depth respectively 7.1 meters, 3 meters, and 5 meters equipped with a tube settler with a diameter of 50 mm and a height of 1.2 meters. The tube settler has been designed with a cut slope of 45°. The evaluation results of the velocity and detention time through tube settler at 0.18m/min and 0.005 hours, respectively, did not fulfill the quality standard. This can cause floc deposition not to settle optimally. Optimization can be done by reviewing the water velocity through tube settler to 0.14 m/min. In addition, it can be intervened from the dimensions by increasing the height/length by 30-80 cm, the diameter becomes 80 cm, and the slope is 60°. The optimum flow rate that the sedimentation unit can process is 141 liters/second.

3.2.5. **Filtration unit.** The filtration unit at Duren Seribu WTP is a rapid sand filter with the gravitational flow. The filtration unit consists of five filtration basins, each with the exact dimensions in length, width, and depth 1.2 meters, 3.35 meters, and 4.2 meters, respectively. The filtration unit uses three types of media filters, gravel, silica sand, and anthracite. Each media filter has a thickness of 40 cm. This unit is equipped with under-drain pipes below the filter bed. The evaluation results showed that the design parameters that did not meet the design criteria were the backwash velocity (15.48 m/hour) and the period between two backwashes (6 hours). Both can be influenced by the characteristics of the media filter used. According to SNI 6774:2018, the thickness of the silica sand media filter is 300-700 mm, while the anthracite is at the minimum limit of 400 mm from the range of 400-500 mm, so it will affect the terminal velocity of media filters. Optimization can be done by reviewing the design parameters of filtration rate to 11 m/hour. Filtration rate as an indicator of optimization also needs to be supported by the media used. The type and depth of each media are expected to comply with the applicable design criteria. Hence, the filtration unit can be optimized by 10 liters/second from design capacity to 110 liters/second.

3.2.6. **Disinfection unit and reservoir.** Duren Seribu WTP does not have a disinfection unit. The disinfection process is carried out in the flow rate measurement basin after the filtration unit. The type of disinfectant used is calcium hypochlorite. First, the result for evaluation of the disinfection unit is that the average dose of chlorine applied based on PDAM Tirta Asasta data records from 2018-2020 is still in compliance with the design criteria range. Meanwhile, the free residual chlorine based on data in 2020 averaged 0.8 mg/L. This concentration is less than 2 mg/L and may decrease during distribution pipelines. WTP can add a new unit to increase the contact time of the disinfectant with drinking water produced. The basin should be built with an average baffled so the coefficient of the baffle will be 0.5,
and the contact time will be doubled. In this case, the contact time, which was previously only 36 minutes, can also be increased to 60-65 minutes. Therefore, the optimum flow rate of the disinfection unit can increase to 98 liters/second from a design capacity of 100 liters/second. Meanwhile, the WTP reservoir is built circular with no baffle and on the ground level. There are two typical reservoirs next to the installation. Each reservoir has a storage capacity of 750 m³ made of fiber plastic material. The reservoir is 18 meters in diameter and 3 meters high. Reservoir evaluations are reviewed based on the volume of water needed for dissolving chemicals, filter backwashing, and distributing water to the consumer. The total reservoir requirement is 704.79 m³, and the WTP there is a total of 1,526.82 m³ so that the reservoir can still store water needs for the next few years.

4. Conclusion
Based on sampling and laboratory analysis, the investigated parameters such as pH, turbidity, TDS, organic matter, iron (Fe), and total coliform have already complied with Permenkes No. 492/Menkes/quality standard Per/IV/2010 regarding Drinking Water Quality Requirements. The highest efficiency removal of turbidity, organic matter, and iron (Fe) occurred in conventional treatment process units with 94.6%, 70.5%, and 90.9%, respectively. The total coliform removal efficiency was 1.8-log (67.05%) and had not yet reached 2-log or 99%. The addition of chemicals could explain the increase of TDS concentration. The assessment shows that several design parameters do not meet the design criteria, such as the water velocity (intake), the detention time (flocculation), surface loading (sedimentation), and backwash velocity (filter). Theoretical optimization steps based on the minimum requirement of design criteria indicated that the plant capacity could be increased up to 10% from 100 L/s to 110 L/s.

5. Acknowledgment
The authors would like to thank PDAM Tirta Asasta for providing a case study. The authors also thank the Laboratory of Sanitary and Environmental Engineering of Civil and Environmental Engineering Department, Universitas Indonesia, for assisting the measurement and analysis of samples.

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