Filter performance evaluation of Karangpilang III drinking water treatment plant PDAM Surya Sembada Surabaya

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Abstract. Due to uprating, decreasing the quality of the effluent filter and unstable backwash frequency on its unit filter per day result in the volatility of Karangpilang III water production quantity and quality. Two evaluations were conducted to determine the performance of the unit filter and its backwash process. The parameter used in the evaluation is turbidity. The first evaluation showed that (1) the turbidity of all units has complied with the national regulation. However, five units were found to not comply with the criteria from PDAM; (2) the ratio of backwash volume and water production indicated that the performance of filter number 5-10 was normal with a percentage between 3-7%; (3) only five units have fulfilled UFRV criteria being within the range of 300-500 m$^3$/m$^2$. Further assessment on filter numbers 2 and 10 was conducted using filter coring method. The loss of media, unstratified media, cracking, and air binging were seen on filter numbers 2 and 10. Based on the post-backwash turbidity value profile, removal and effluent turbidity of filter number 2 were better than filter number 10. Floc retention filter profile of filter number 10 showed different conditions in each sampling depth from 3 sampling points.

1. Introduction
Local water company Surya Sembada—hereinafter referred to as Perusahaan Daerah Air Minum Surya Sembada (PDAM)—aims to improve its services by achieving 100% in the provision of drinking water in Surabaya. PDAM attempts to do so by updating several of its water treatment plant (WTP). Karangpilang III WTP is one of the plants which capacity has been increased by 400 L/sec, from 2,000 L/sec to 2,400 L/sec. In order to maintain the quality of treatment, however, it is actually suggested that the capacity should remain to be 2,000 L/sec [1]. Due to the uprating, there was a decrease in water production. Both the quality and quantity of the water produced became unstable. Although the capacity improvement was intended to increase the water production, the objective has not been able to be achieved as it resulted in the increasing frequency of backwash filter to become irregular up to two backwashes per day.

Based on the secondary data obtained from PDAM in December 2019, the filter’s average turbidity still complied with the regulation from Indonesia’s Ministry of Health No. 492 in 2010 about Drinking Water Quality Requirement, which is below 5 NTU [2]. Exceptions were found only on two days; December 20th and 21st. However, the majority of the effluent turbidity value was unable to achieve PDAM’s target stipulated in its key performance indicator (KPI), where turbidity value should be lower than 1 NTU. KPI was set in an attempt to maintain the turbidity distributed on the farthest point to
remain within the regulated value. Therefore, to achieve PDAM's target in both the quantity and quality of the water produced, the unit filter evaluation needs to be conducted. The evaluation would be focused on determining filter unit performance and backwash performance.

2. Methodology

The equipments used in this research are as follows:
1. Turbidimeter
2. Analytic scale
3. Core sampling tool: AW type PVC based pipe with 1,5-inch or 3,81cm diameter and 5 feet or 152,4 cm length.
4. Containers for water and media sample
5. Glasswares: 3 pieces 100 mL erlenmeyer glass, 3 pieces 500 mL beaker glass, 3 glass funnel, and 1 piece 100 mL measuring glass.

Initially, the evaluation was conducted on 14 unit filters to determine all of their performance as general and backwash performance for 3 units selected from the first evaluation. Data consists of secondary and primary data was collected. Primary data was obtained from the field measurements, while secondary data was obtained from data gathered by Karangpilang III WTP.

2.1. Filter performance evaluation

Initially, an evaluation was conducted to 14 unit filters to determine the three filters that will be further evaluated using the filter coring method. The evaluation consists of 3 steps.

2.1.1. Turbidity value measurement. Measurements were made by collecting a total of 28 samples for both the influent and effluent filter, followed by measuring them with a turbidimeter. Based on the measurement results, filter removal efficiency is calculated.

2.1.2. The ratio of backwash water used. The calculation used secondary data to determine the ratio of backwash water volume used per unit in percentage. The results are then compared to the filter performance criteria. The following formula is used to calculate the ratio:

\[
Ratio \ (\%) = \frac{Backwash \ water \ volume \ (m^3)}{Production \ water \ volume \ (m^3)} \times 100\%
\]  

(1)

2.1.3. UFRV calculation. The calculation used secondary data to determine the filter production based on the operating unit filter's size, where the results are then compared to the filter performance criteria. The following formula is used to calculate the UFRV:

\[
UFRV \ \left(\frac{m^3}{m^2}\right) = \text{Filtration rate} \ \left(\frac{m^3}{m^2 \cdot \text{hour}}\right) \times \text{operating duration} \ (\text{hour})
\]  

(2)

2.2. Backwash performance evaluation

Using the evaluation result, an assessment was conducted to determine 3 filter units to be evaluated specifically using filter coring method and 2 other evaluation. Three filter units were 1 filter unit with the best performance, 1 filter unit with moderate performance, and 1 filter unit with the worst performance.

2.2.1. Filter unit visual inspection. The procedure is to drain and isolate the filter, then visually inspect it to see signs of cracking on the surface of the media, mud balls' formation, and media mounds by entering the filter with a ladder and plywood as a base to surround the media without directly stepping on the media.
2.2.2. Core sampling. Core sampling was conducted on 3 selected points in the filter media. The procedure is to drain and isolate the filter, take the samples based on the different depths—which is 0-15.24 cm, 15.24-45.72 cm, and 45.72-76.2 cm for each sampling point using a core sampling tool. The results are analyzed using a floc retention analysis. The analysis was done on the filter media as the core sampling sample. The following steps are conducted for the analysis:
1) Obtain 50 gram of filter media sample
2) Mix it with 100 mL water, then shake it for 30 seconds
3) Separate the water from media, then repeat step number 2
4) Repeat step number 2 and 3 until the water volume reaches 500 mL
5) Measure the turbidity value with turbidimeter, then multiply it with 2 to obtain a measurement for 100-gram samples. Record the result
6) Repeat steps 1-5 for each core sampling sample, then compare it with turbidity value range criteria to determine filter media condition. After the analysis is finished, a profile representing the relation between turbidity value and core sampling's depth variation is created.

![Figure 1. Core sampling tools.](image)

2.2.3. Turbidity value measurement after backwash. The measurement is conducted by taking samples every 5 minutes during the first 30 minutes on the effluent after the filter is operating again. From the measurement result of effluent, a profile is created for each of them that represents the relation between effluent turbidity value and time of sample taken.

3. Results and discussion

3.1. Filter performance evaluation

3.1.1. Turbidity value measurement. Measurement is conducted one time on both influent and effluent unit filters. The measurement tool used is Turb WTW 430 IR turbidimeter. The measurement result shows that all filter unit effluent turbidity values already comply with the national regulation, less than or equal to 5 NTU [2]. But 5 units did not meet the criteria based on Key Performance Indicator (KPI), which is set less than 1 NTU. A complete measurement result can be seen in table 1.

| Filter Number | Influent (NTU) | Effluent (NTU) | Efficiency (%) |
|---------------|---------------|----------------|----------------|
| 1             | 13.2          | 1.3            | 90             |
| 2             | 11.9          | 0.37           | 97             |
| 3             | 12.4          | 0.73           | 94             |
| 4             | 10.9          | 1.29           | 88             |
| 5             | 10.7          | 0.88           | 92             |
| 6             | 7.6           | 1.4            | 82             |
| 7             | 11.7          | 0.77           | 93             |
| 8             | 11.5          | 0.93           | 92             |
| 9             | 12.4          | 0.66           | 95             |
| 10            | 13            | 2.1            | 84             |
| 11            | 14.6          | 0.66           | 95             |
| 12            | 15.1          | 1.25           | 92             |
| 13            | 13.4          | 0.81           | 94             |
| 14            | 14.5          | 0.61           | 96             |
3.1.2. The ratio of backwash water used. Based on the calculation result in table 2, it is found that only filter numbers 5 to 10 that comply with the criteria being 3-7%. Based on the calculation result in table 2, it is found that only filter numbers 5 to 10 that comply with the criteria being 3-7%. The required backwash water volume is between 3-7% from the total produced water [3]. As the percentage ratio is lower than the criteria, it indicates that the implemented backwash duration does not conform with filter operation duration.

| Filter Number | Influent (NTU) | Effluent (NTU) | Efficiency (%) |
|---------------|----------------|----------------|----------------|
| Average       | 12.35          | 0.98           | 92             |

3.1.3. UFRV calculation. UFRV was calculated based on the secondary data obtained by PDAM. Figure 2 shows the result of the UFRV calculation.

Table 2. The ratio of backwash water used.

| Number Filter | Backwash Water Volume (m³) | Production Water Volume (m³) | The Ratio of Backwash Used in Percentage |
|---------------|-----------------------------|------------------------------|------------------------------------------|
| 1             | 486                         | 35.729,06                    | 1.36                                     |
| 2             | 486                         | 24.320,65                    | 2.00                                     |
| 3             | 486                         | 24.631,79                    | 1.97                                     |
| 4             | 486                         | 20.584,92                    | 2.36                                     |
| 5             | 486                         | 11.873,04                    | 4.09                                     |
| 6             | 486                         | 10.578,71                    | 4.59                                     |
| 7             | 486                         | 10.319,42                    | 4.71                                     |
| 8             | 486                         | 14.984,43                    | 3.24                                     |
| 9             | 486                         | 13.739,87                    | 3.54                                     |
| 10            | 486                         | 9.334,15                     | 5.21                                     |
| 11            | 486                         | 21.829,47                    | 2.23                                     |
| 12            | 486                         | 27.276,47                    | 1.78                                     |
| 13            | 486                         | 62.899,74                    | 0.77                                     |
| 14            | 486                         | 33.551,09                    | 1.45                                     |

Figure 2. Unit filter run volume (UFRV).
The calculation result shows that only filter numbers 2, 3, 4, 11, and 12 that comply with the criteria being 300-500 m\(^3\)/m\(^2\) [4]. From the measurement and calculation that have been conducted, a complete assessment was conducted. Table 3 shows the result of the assessment.

### Table 3. Filter performance’s score.

| Filter Number | Turbidity Value | Unit Filter Run Volume | The Ratio of Backwash Used in Percentage | Total Score |
|---------------|-----------------|------------------------|------------------------------------------|-------------|
| 1             | 2               | 4                      | 1                                        | 7           |
| 2             | 4               | 4                      | 2                                        | 9           |
| 3             | 3               | 4                      | 2                                        | 3           |
| 4             | 2               | 3                      | 2                                        | 7           |
| 5             | 3               | 2                      | 3                                        | 8           |
| 6             | 2               | 1                      | 4                                        | 7           |
| 7             | 3               | 1                      | 4                                        | 8           |
| 8             | 3               | 2                      | 3                                        | 8           |
| 9             | 3               | 2                      | 3                                        | 8           |
| 10            | 1               | 1                      | 4                                        | 6           |
| 11            | 3               | 4                      | 2                                        | 9           |
| 12            | 2               | 4                      | 2                                        | 8           |
| 13            | 3               | 4                      | 1                                        | 8           |
| 14            | 3               | 4                      | 1                                        | 8           |

Note: The value range for each criteria is 1-4.

Based on table 3, unit numbers 2, 14, and 10 were chosen to represent each of the three performance categories: good performance, medium performance, and poor performance. The chosen units were then specifically evaluated to determine backwash performance.

#### 3.2. Backwash performance evaluation

**3.2.1. Filter unit visual inspection.** Based on the result of visual analysis, filter channelling was found on filter unit numbers 2 and 10. The number of filter media on filter number 10 decreased, which was indicated by the height marking that was previously above the media on the filter wall and irregular media surface. During the backwash on filter numbers 2 and 10, there were irregular backwash distribution and dead zones. Thus, it could be confirmed that there was clogging on the orifice and the issues happening on the filter may not be due to the media's age. Air binding was also found during the backwash on filter unit numbers 2 and 10. Mud balls were not found on the media surface and the media samples taken from the core sampling filter result on filter unit number 10. The result of visual inspection on filter media on filter unit number 10 can be seen in figure 3 and figure 4.

![Figure 3. Filter channelling on filter media](image1)

![Figure 4. Air binding on filter media.](image2)
3.2.2. Core sampling. It was conducted before backwash being performed. The result of the floc retention profile could be seen in figure 5. 

![Figure 5](image_url)

**Figure 5.** Floc retention profile for sampling points 1, 2, and 3.

| Depth (cm) | Turbidity Value Point 1 (NTU) | Turbidity Value Point 2 (NTU) | Turbidity Value Point 3 (NTU) |
|------------|-------------------------------|-------------------------------|-------------------------------|
| 0-15,24    | 1.100                         | 704                           | 682                           |
| 15,24-45,72 | 900                           | 800                           | 522                           |
| 45,72-76,2 | 900                           | 492                           | 526                           |
| Average    | 967                           | 665                           | 577                           |

Floc retention profile on figure 5 indicated that point 1 and point 3 has a lot of floc retention on 0 – 15,24 cm depth, while point 2 had floc retention on 15,24 – 45,72 cm depth. It showed that the maximal filtration process occurs on various different points. The accumulated floc on the top of sand media may result from anthracite media loss, which causes air binding. Based on McGlohorn (2003), the media condition on various points are as follows [5]:

- Point 1 = Media is very dirty with lots of mud balls formed (600 – 1.200 NTU)
- Point 2 = Media is very dirty with lots of mud balls formed (600 – 1.200 NTU)
- Point 3 = Media is very dirty with the possibility of mud balls being formed and well-ripened (300 – 600 NTU)

3.2.3. Turbidity value measurement after backwash. Based on measurement result data, the effluent turbidity value profile was obtained after the backwash process on filter unit numbers 2 and 10, as shown in figure 6.

![Figure 6](image_url)

**Figure 6.** Effluent’s turbidity profile for filter number 2 and 10.
Table 5. Effluent’s turbidity value for filter number 2 and 10.

| Minute | Turbidity Value Filter Number 2 (NTU) | Turbidity Value Filter Number 10 (NTU) |
|--------|--------------------------------------|----------------------------------------|
| 5      | 2.49                                 | 3.25                                   |
| 10     | 1.72                                 | 2.74                                   |
| 15     | 1.71                                 | 1.76                                   |
| 20     | 1.76                                 | 1.74                                   |
| 25     | 1.32                                 | 1.64                                   |
| 35     | 1.23                                 | 1.4                                    |

The measurement result showed that the highest decrease in turbidity occurred during the fifth minute to the tenth minute on unit number 2 with 0.77 NTU. The highest decrease in turbidity occurred during the tenth minute to the fifteenth minute on unit number 10 with 0.51 NTU. After 30 minutes, effluent quality produced by filter number 2 was better than filter number 10. However, both effluents did not meet PDAM’s KPI being lower than 1 NTU in the thirtieth minute.

4. Conclusion
All filters did not meet three performance criteria: turbidity value, the ratio of backwash water used in percentage, and UFRV value. All of the criteria connect to each other. The operational parameter that affects filter performance is backwash operation, including backwash duration and backwash water rate control. Marking based on measurements results and calculation of filter performance evaluation based on these 3 criteria shows that filter unit number 2 has the best filter performance with a score of 10, filter unit number 14 has a moderate filter performance with a score of 8, and filter unit number 10 has the worst filter performance with a score of 6. There are 10 units filters with scores above the average score, while 4 units filters are under the average score.

Backwash performance evaluation showed that both unit filter number 2 and number 10 should change their backwash procedure by specifying and setting a new backwash duration and adding a filter-to-waste step in the filtering process. There was filter channeling in filter media numbers 2 and 10, while media shrinking and media loss were found in filter number 10. Core sampling results showed that each sampling point had different media conditions in accumulating floc particles. The turbidity value profile represents that the reduction of turbidity value on filter number 2 is better than filter number 10.

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