# Optimization of Powdered Activated Carbon Treatment with Intermediate Chlorination, Modifying Channels as Mixing Basins

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**Abstract:** At the Ozaku WTP, the concentration of 2-MIB, a causative agent of musty odor, increased from 2011, and the amount of activated carbon used for removal increased with it. When activated carbon contacts with chlorine, a part of the adsorbed 2-MIB is re-released. To counteract this, we planned the installation of an intermediate chlorination. When introducing this process, we compared the method of injecting into the sedimentation water channel with the method of installing partition wall at right angle to the flow of the sedimentation water channel, and installing equipment with the aim of introducing an intermediate chlorination that makes use of existing facilities.

**Keywords:** 2-MIB, Intermediate Chlorination, Activated Carbon, Effective Use of Existing Facility, Partition Wall, Model Experiment

## 1. Overview of the Ozaku WTP and details of the intermediate chlorination introduction

The Ozaku Water Treatment Plant (Ozaku WTP) is located on the upper reaches of the Tama River, and is capable of purifying up to 280,000 cubic meters of water per day, injected with chlorine and subject to a rapid filtration process. Raw water source is the surface water from the Tama River, which is taken in from Hamura intake barrage located 3 kilometers southeast of the WTP, then pressurized with pumps. Raw water flows into the receiving well, and is then diverted into two lines, then divided into four groups in the flocculation and sedimentation basin. Next, after passing through the sedimentation water channel, the water is again divided into four groups in the filter basin, and flows into the four filter basins in each group. The ground of the Ozaku WTP is narrow, so there is no space to install new equipment. (Fig.1)

The water quality has been good because there are no sources of pollution on the upper reaches of the rivers, except when it rains heavily or the dam releases water. However, 2-Methylisoborneol (2-MIB) generating cyanophyceae suddenly started to increase in 2011. In response, we have injected activated carbon to reduce 2-MIB. In the summer of 2012 and 2013, the concentration of 2-MIB reached 200ng/L in raw water, which is 20 times the water quality standard. (Fig.2) As a result, the amount of activated carbon used as increased to 1,778 tons in 2013, in order to keep level of 2-MIB below 3ng/L, a unique 2-MIB management goal set by the Tokyo Metropolitan Government.

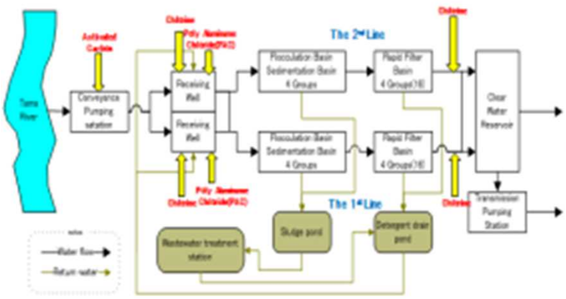

Figure 1 Process flow of Ozaku WTP


Figure 2 Change of 2-MIB concentration of the raw water

The Ozaku WTP was developed as a preparatory chlorination. In the current flow, after injecting activated carbon, chlorine is injected in a rapid mixing basin before the flocculation and sedimentation process. Subsequen activated carbon is re-released by the chlorine. So, it was necessary to inject a large amount of activated carbon in advance. (Fig.3) Activated carbon has a high unit cost and increases the volume of sludge treated, which greatly increases the cost of purified water. Therefore, after sedimentation with 2-MIB adsorbed, intermediate chlorine injection was introduced before the filtration, with the aim of making activated carbon removal more efficient.

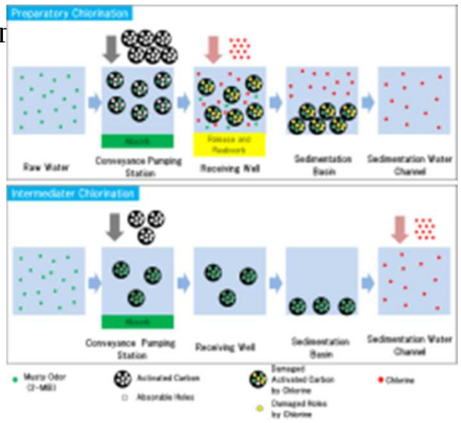


Figure 3 Image of releasing 2-MIB chlorine

## 2. Demonstration experiment

In the demonstration experiment, two methods are compared for mixing chlorine in the existing sedimentation water channel. (Fig.4)

### 2.1 Intermediate chlorine injection experiment using temporary equipment

Comparisons were made by using the current flow of the sedimentation water as it is, setting different injection sites and mixing the substances, and by setting one or two injection points in each group of sedimentation. (Referred to below as "Method A")

### 2.2. Verification experiment using a model test

Based on the experimental result of "Method A" and studying of the operation, maintenance and economic factors, it can be considered effective to set up partition wall in the sedimentation water channel and set one chlorine injection point per line. Therefore, a hydraulic model was made to conduct verification experiment. (Referred to below as "Method B")

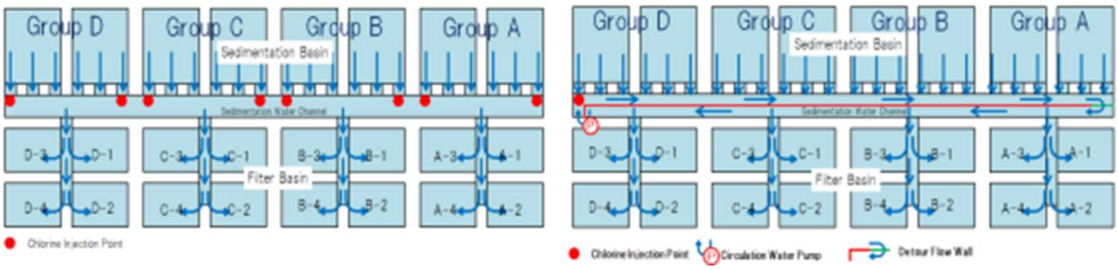


Figure 4 Image of "Method A" and "Method B"

## 3. Method A

### 3.1 Experiment methods

The experiment was carried out in the first line of the WTP. Considering experiences so far, treated water was set to 2,000m$^3$/h or 5,500m$^3$/h in a range from time minimum to time maximum flow, and the following three points were compared in order to find the optimal injection method.

① In order to study the condition of mixture caused by differences in chlorine injection sites, one was set in the collecting trough on the sedimentation basin and the other was set in the sedimentation water channel.

② In order to study the condition of mixture caused by the difference in the number of injection points, as well as find the maintenance costs, each group was tested with one injection point and with two injection points.

③ In order to confirm whether or not it is effective for homogeneous mixing to increase the injection amount using dilution water when the injection amount is smaller, the difference was compared between two types of injection fluids: the stock solution and the dilution water.

These experiments were conducted by changing the amount of treated water, injection sites, number of injection points, and liquid conditions. Thus, 16 experiments in total were carried out, as shown in Table 1 below. (Fig.5)

Table 1 Experiment contents of “Method A”

| terms conditions | Amount of treated water | Injection sites | Types of fluid | Number of injection |
|---|---|---|---|---|
| 1～4 | 2,000$m^3$/h | Sedimentation water channel | Stock solution/ Dilution solution | 4 points/8points |
| 5～8 | 2,000$m^3$/h | Sedimentation basin collecting trough | Stock solution/ Dilution solution | 4 points/8points |
| 9～12 | 5,500$m^3$/h | Sedimentation water channel | Stock solution/ Dilution solution | 4 points/8points |
| 13～16 | 5,500$m^3$/h | Sedimentation basin collecting trough | Stock solution/ Dilution solution | 4 points/8points |
| Filter basin washing | 2,000$m^3$/h, 5,500$m^3$/h | Sedimentation water channel | Stock solution/ Dilution solution | 4 points |

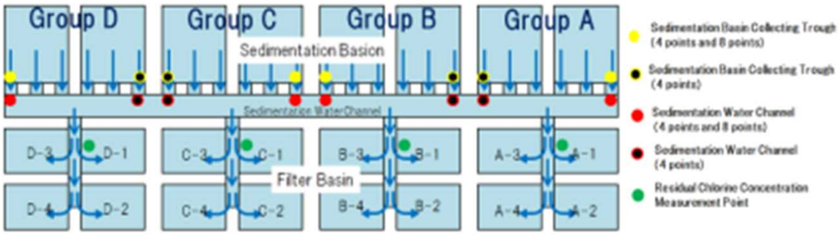


Figure 5 Chlorine injection sites and chlorine measurement points

To measure the residual chlorine concentration, four automatic measuring instruments were prepared and measurements were made at the points where it flowed into A-1, B-1, C-1, D–1. The concentrations of each group were compared. In addition to the designated experimental conditions, changes to the mixing condition during filter washing were also studied. In this experiment, the injection volume in each group was set to be the same.

### 3.2 Experiment results

Figure 6 shows the average value of the residual chlorine concentration of the filter basin for each of groups A to D at a throughput of 2,000$m^3$/h and 5,500$m^3$/h.

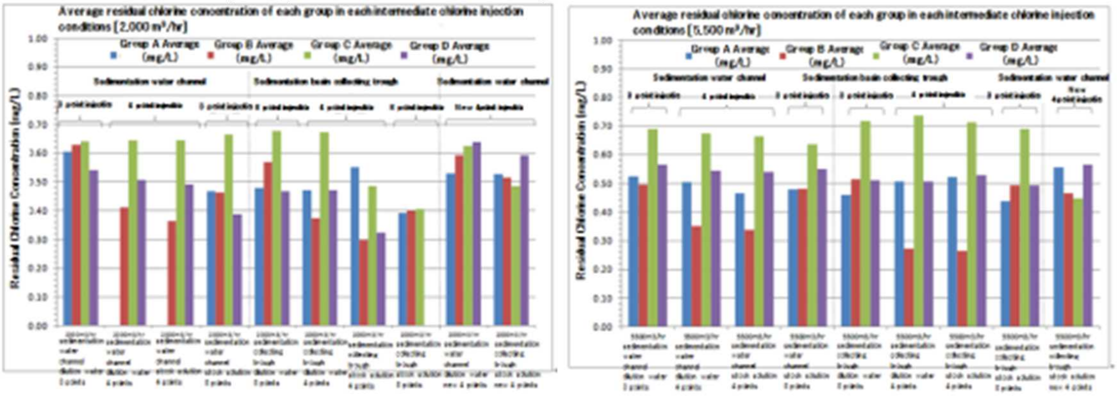

Figure 6 Residual chlorine concentration of each group in each injection conditions

The results obtained from experiments with “Method A” are summarized below.

① In the sedimentation collecting trough, when the amount of treated water was 2,000$m^3$/h, residual chlorine concentration in each group varied. This is believed to be caused by the difference in the amount of water flowing into the collecting trough.

② In sedimentation water channel injection, when the treated water volume was 5,500$m^3$/h, the residual chlorine concentration in each group varied. In 4-point injection, injection sites of group B and C are close to each other, so most of the chlorine injected into group B flows down to group C. For this reason, variations decreased at the new conditions where injection sites of group B and C were changed.

③ There was no clear difference caused by injection of stock solution or dilution water in the residual chlorine concentration of each group.

## 4. “Method B”

### 4.1 Experiment methods

Since "Method B" involves structural changes to the sedimentation water channel, it is difficult to verify at the existing facility. Therefore, to guarantee of the experiment accuracy and control costs, it was decided to conduct a 1/5 scale model, which satisfies a Reynolds Number on the flow velocity scale greater than or equal to $10^4$ degrees as an empirical indicator. In addition, the range of reproduction in the model experiment was set to the sedimentation basin collecting trough, sedimentation water channel and filter basin inlet for the first line. (Fig.7, Fig.8)

Figure 7 Water purification model experiment


Figure 8 Hydraulic model experiment recreation range

First, the model experiments were started by reproducing the experimental conditions of "Method A" 4-point injection, in order to verify the consistency between the field experiment and the model experiment. Next, the influence of the partition wall installed in the 1-point injection and improvement proposals were examined, and the final plan for the shape of the partition wall and detour flow wall were evaluated. The examination of the shapes of the partition wall and the detour flow wall were conducted as follows.

① The partition wall shape was set as shown in Figure 9, in order to verify the difference in stirring, water level, and flow distribution depending caused by the shape of the folded back portion of the partition wall. (Table 2)

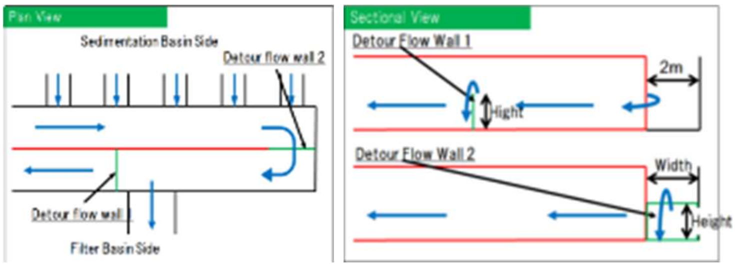


Figure 9 Partition shape in model experiments

Table 2 Verification cases

| Case | Detour Flow Wall | Width (m) | Hight(m) | Circulation flow |
|---|---|---|---|---|
| B-1 | - | 2.0 | — | 10% |
| B-2 | - | 2.0 | — | 2% |
| B-3 | - | 5.6 | — | 2% |
| B-4 | - | 3.4 | — | 2% |
| B-5 | Wall 1 | 2.0 | 0.3 | 2% |
| B-6 | Wall 1 | 2.0 | 0.6 | 2% |
| B-7 | Wall 2 | 2.0 | 1.2 | 2% |
| B-8 | Wall 2 | 2.0 | 0.8 | 2% |
| B-9 | Wall 2 | 2.0 | 0.6 | 2% |
| B-10 | Wall 2 | 2.0 | 0.3 | 2% |

Circulation flow：Corresponding to maximum filtration flow

② The water level margin is only 40cm in the sedimentation water channel (trough floor height minus (—) overflow level at filter basin inflow), the channel width narrows due to the installation of the partition wall, and the flow makes a 180 degree U-turn, so it is assumed that there will be an imbalance in the flow rate of each group of filter basins. Therefore, the water level in the channel and the flow ratio to the filter basin were checked.

### 4.2 Experiment results

First, in order to verify the reproducibility of these experiments, the distribution of residual chlorine when injecting chlorine with 4-point injection in "Method A" was compared between the model and the actual facility. Differences in concentration were observed at each measuring position, but similar results were obtained in the filter basin. (Fig.10)

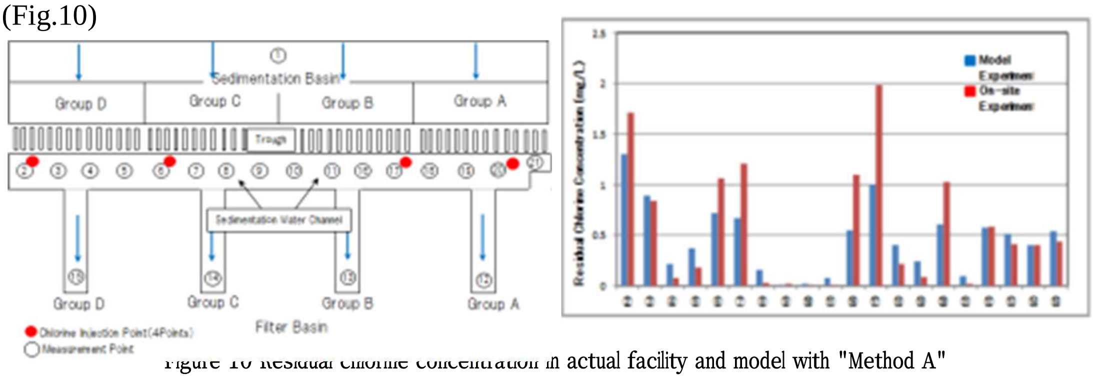


Figure 10 Residual chlorine concentration in actual facility and model with "Method A"

Figure 11 shows the measurement results for the water level in the sedimentation water channel for each partition wall shape.

In case B-7, water level exceeded the outflow trough floor height of the sedimentation water channel, which makes it difficult to adopt. In the other eight cases, although water level exceeded the current H.W.L., it was judged that it could be used because water level did not reach the trough floor height.

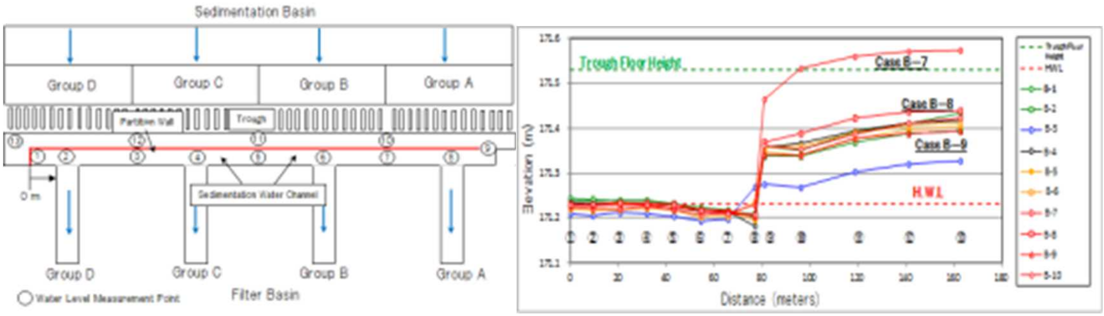


Figure 11 Water level measurement positions and measurement results in the model experiment

Measurement results for the rate of flow distribution to each group filter basin in each study case, as well as the difference between the maximum and minimum flow ratio, are shown in Figure12. Table 3 shows an evaluation based on the results of examining loss and flow distribution. The flow ratio was calculated by dividing the flow amount into each group by the flow amount when it flows equally into the four groups.

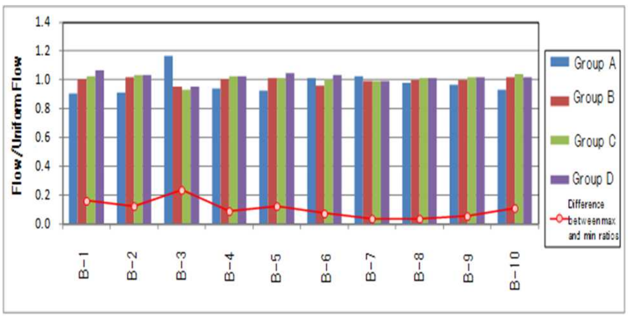


Figure 12 Flow ratio to filter basins of each group

Table 3
Evaluation based on results of studying loss and flow distribution

| Case | Detour flow wall | Width(m) | Height(m) | Loss (Water level) | Flow distribution | Final evaluation |
|---|---|---|---|---|---|---|
| B-1 | - | 2.0 | — | ○ | × | × |
| B-2 | - | 2.0 | — | ○ | × | × |
| B-3 | - | 5.6 | — | ○ | × | × |
| B-4 | - | 3.4 | — | ○ | × | × |
| B-5 | Wall1 | 2.0 | 0.3 | ○ | × | × |
| B-6 | Wall1 | 2.0 | 0.6 | ○ | × | × |
| B-7 | Wall2 | 2.0 | 1.2 | × | ○ | × |
| B-8 | Wall2 | 2.0 | 0.8 | ○ | ○ | ○ |
| B-9 | Wall2 | 2.0 | 0.6 | ○ | ○ | ○ |
| B-10 | Wall2 | 2.0 | 0.3 | ○ | × | × |

In case B-5, B-6 with detour flow wall 1 installed and cases B-7 to B-9 (excluding case B-10) with detour wall 2 installed, the latter case was confirmed to be more effective for flow distribution. When detour flow wall 2 was installed, with the weir height set to 0.6m, 0.8m or 1.2m, the balance of flow distribution was good. On the other hand, at 0.3m in case B-10, it was confirmed that the balance of flow distribution deteriorated. Therefore, considering the loss results along with this, it was evaluated that the structure of the weir height 0.6m in case B-9 is hydraulically most effective.

In case the partition wall and the detour flow wall are put in the final plan, the necessity of a circulation pump was also studied, because residual chlorine concentration needs to be maintained in each filter basin even when the group D sedimentation basin is stopped.

When the amount of circulating water is 0% and the group A filter basin is stopped, the rise of the sedimentation water channel level is maximized. As such, the water level was checked when the amount of circulating water was changed from 2% to 5%. The results confirmed that when the amount of circulating water was 3% or more, the water level rises higher than the trough lower end height, so it was confirmed that the circulating water amount needs to be 2% or less. (Fig.13)

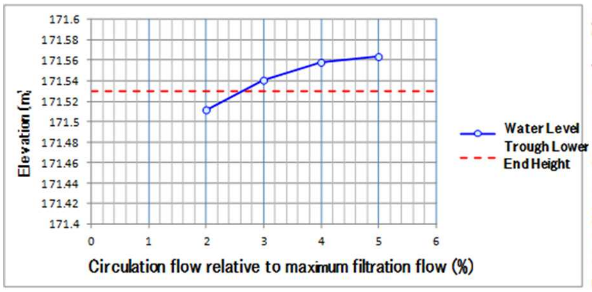


Figure 13 Relationship between circulation flow and maximum water level in the sedimentation water channel

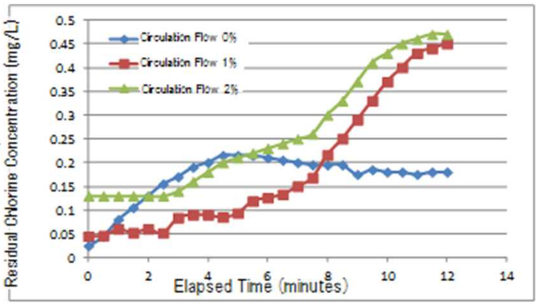


Figure 14 Circulation flow and time for residual chlorine to reach Group D filter basin

Also, when the amount of circulating water was changed to 0%, 1% and 2%, the length of time was confirmed from the start of the chlorine injection until a stable concentration was reached in the group D filter basin. (Fig.14)

From the experiment results, it was found that when the amount of circulating water was set to 0%, even when the time until arrival was confirmed with the amount of circulating water at 1% and 2%, the group D filter basin did not have a stable concentration. Therefore, there is no major difference between when the amount of circulating water is 1% and 2%, and power consumption can be reduced by making the pump capacity smaller because a circulation pump is necessary in order to stabilize the concentration of the group D filter basin as quickly as possible. Thus, 1% was chosen.

The mixture condition of chlorine was confirmed to have little variation with respect to changes in the amount of water treated, from the minimum to the maximum in B-9, with an error of approximately ± 10% in the concentration at the inflow point of each filter basin (0.44–0.56 compared to a target of 0.5mg/L). Therefore, the plan for "Method B" uses the shape of B-9 and the circulating water volume is set to 1%. The overflow weir is raised to the trough lower end height (altitude 171.53m).

**5. Final plan shape from verification experiments of "Method A", "Method B"**

From verifications conducted thus far, it was confirmed that intermediate chlorine injection is possible in the water treatment process of the Ozaku WTP by setting the final shape to that in Figure 15.

① It is possible to eliminate variations in residual chlorine concentration in each group of filter basins by installing a partition wall in the sedimentation water channel, installing a detour flow wall, and a circulation pump.

② It can be structured to be superior in terms of maintenance and in terms of control because this plan uses the minimum necessary equipment such as pumps.

③ Although it exceeds the H.W.L. of the initial sedimentation water channel in the Ozaku WTP, this can be supported by raising the weir height of the overflow basin.

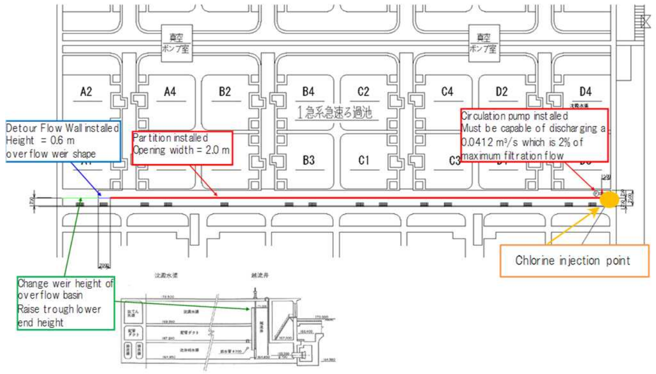


Figure 15 Shape in final plan

## 6. Construction and operation results

In the period from 2015 to 2016, it took about 9 months to complete construction and implement the plan of "Method B" in the actual facility. Figures 16 and 17 show the completed photographs in the sedimentation water channel and the flow conditions after construction.

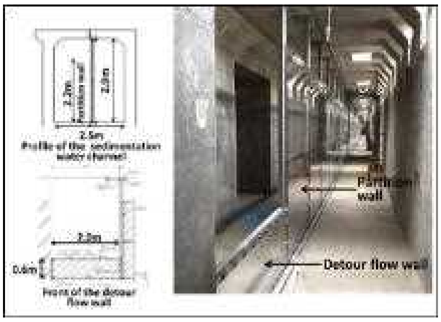


Figure 16 Partition wall and detour flow wall installed

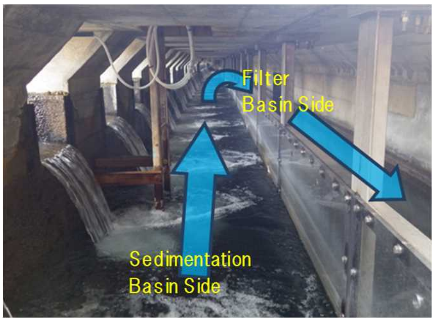


Figure 17 Partition wall installed in sedimentation water channel

Residual chlorine concentration in intermediate chlorine injection is managed with feed-back and feed-forward control similar to current preparatory chlorination. There was no major bias in chlorine concentration in each filter basin. As for the water level, looking at a given certain month, throughput is operated in the range of 1,900 to 5,000$m^3$/h, and the water level fluctuates in the range of 171.01 to 171.12m in elevation. This was lower than the result of the model experiment and it was confirmed that there were no problems in operation. In addition, the amount of activated carbon used after construction can be reduced by approximately half, so it can be operated with this fact reflected in the activated carbon injection manual.

Table 4 shows the activated carbon injection coefficients for preparatory and intermediate chlorination. Especially when the concentration of 2-MIB is high, injection volume can be reduced to just half.

Table 4 Comparison of activated carbon injection ratio for preparatory and intermediate chlorination

| 2－MIB Concemtration (ng/L) | ～1.5 | ～8 | ～15 | ～60 | ～100 | ～200 | 200～ |
|---|---|---|---|---|---|---|---|
| Preparatory chlorination (mg/L) | 0 | 16 | 27 | 96 | 150 | 300 | 300 |
| Intermediate chlorination (mg/L) | 0 | 6 | 12 | 48 | 70 | 120 | 150 |

Benefits of introducing the intermediate chlorination include the suppression of chlorine consumption. The injection amount can especially be reduced at high turbidity because chlorine is injected after sedimentation and removing chlorine-consuming substances such as turbidity. In this respect, in addition to cost control, the fluctuation range of the injection rate is also smaller, making it possible to do more stable injection control.

## 7. Conclusion

To introduce intermediate chlorination as a countermeasure against musty odor at the Ozaku WTP, the findings obtained by experiments using the 1/5 scale model of "Method A" and “Method B" and introduction to actual facilities are summarized below.

① Results of verification of "Method A"

Considering the flow of the sedimentation water channel, a certain degree of mixing could be achieved with the new 4-point injection. Further studies are necessary to control the injection amount for each injection point corresponding to the operating conditions of the sedimentation basin and filter basin.

② Evaluation of effectiveness of the 1/5 scale model when studying "Method B"

Through model experiments, it was possible to establish specifications for effective partition walls, detour flow walls, and circulation pumps. It was also found that it can respond on an adequate level to the operating conditions of sedimentation basin and filter basin. Also, because the sedimentation water channel level increased slightly, it was necessary to raise the overflow weir.

③ Evaluation of application in actual facilities

“Method B” was selected after comparing the results of the experiment in the actual facility of "Method A" and the result of the model experiment of "Method B”. When this was built in the actual facility, it operated without problems, confirming the effectiveness of the model experiment.

④ Evaluation of intermediate chlorination after starting of operation

Activated carbon removal efficiency has been greatly improved, making it possible to process musty odor with an injection rate of approximately half. As a result, it is possible to reduce the purchase cost of activated carbon and sludge generated. In addition, it was possible to confirm improvements to operational performance and cost reduction benefits accompanying the drastic decrease of chlorine usage at high turbidity.

⑤ Cost Effectiveness

With evaluating introduction costs, the purchase cost of activated carbon was 390 million yen in June to September 2013 when the musty odor reached its maximum. In case of conducting intermediate chlorination during this period, the purchase cost of activated carbon was about 200 million yen, so there was a cost reduction benefit.

In actual operation of this water treatment plant in the winter season, preparatory chlorination with consideration for the dissolved Manganese countermeasures for raw water is necessary. We intend to conduct optimal operations according to the conditions of the raw water and make full use of the benefits of the newly developed intermediate chlorination to provide safe, high quality and delicious water.

**Reference**

1) Akiyama Masashige, Bureau of Waterworks, Tokyo Metropolitan Government, *4-66 Ozaku Water Purification Plan Intermediate Chlorine Injection Equipment Verification*, Japan Waterworks Association FY2016 National Conference (Waterworks Research Presentations),