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Development of Methods to Efficiently Remove Disinfection By-product Precursors in Slow Filtration

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Abstract
In slow filtration, it is difficult to remove natural organic matter with high levels of color which reacts with chlorine forming disinfection by-products (DBPs). In order to suppress the formation of DBPs, it was attempted to remove color in water by laying granular activated carbon (GAC) on the upper sand layer of filter basins. The formation of trichloroacetic acid, one of DBPs, has a high correlation with the filtered water color before chlorine dose and it is possible to suppress trichloroacetic acid formation by using the filtered water color as indicator. Additionally, the total amount of color in raw water through the GAC layer (cumulative water color) is correlated with the water color removal efficiency and it is thus possible to estimate the useful life of the GAC.

Keywords
Slow filtration; trichloroacetic acid; granular activated carbon; water color removal

Introduction

The drinking water quality standards value of trichloroacetic acid (TCAA) was tightened from 0.2mg/L to 0.03mg/L since April 2015 in Japan. Whereas, the concentration of TCAA in tap water supplied by Ogouchi Purification Plant (PP) has reached 0.051 mg/L in August 2011, and that's the highest value which we have measured. Although Ogouchi PP is currently a membrane filtration facility with a granular activated carbon (GAC) absorption basin, it had been a slow filtration facility during 2015, and that was why we were required to remove TCAA precursors with slow filtration. It is considered major TCAA precursors are natural organic matter with high levels of color in raw water, which are difficult to remove with slow filtration. In this study, the possibility of suppressing TCAA formation was investigated by laying GAC on upper sand layer of slow filter basins.

Materials and Methods

The purification flow in Ogouchi PP is shown in **Figure 1**. The GAC 20 centimeters in thickness was laid on filter basins, and the capacity to remove color of raw water was evaluated. The properties of GAC are summarized in **Table 1.** The hourly indication of a colorimeter at the inlet of the sedimentation basin was used as the color of raw water. The filtered water color was obtained by absorptiometry from absorbance of 390nm. The unfiltered water color was also measured by absorptiometry, and a correlation equation between the unfiltered water color (colorimeter) and the unfiltered water color (absorptiometry) was leaded. Additionally, the water color removal efficiency by GAC was calculated with the formula (1).

$$Z = 100 \times (Ca - X) / Ca \quad \cdots\cdots\cdots (1)$$

Z: Water color removal efficiency (%)
Ca: Unfiltered water color measured by absorptiometry (degrees)
X: Filtered water color measured by absorptiometry (degrees)

The total amount of color in raw water through the GAC layer (cumulative water color) was calculated as follows:

$$D_i = X_i Q_i / N \quad \cdot\cdot\cdot\cdot\cdot\cdot\cdot\cdot \quad (2)$$

D_i: Water color per day (degrees・m^3/day)
X_i: Average of color per day indicated in colorimeter (degrees)
Q_i: Daily amount of water distribution (m^3/day)
N: The number of slow filter basins

$$L_n = \Sigma D_i \quad \cdot\cdot\cdot\cdot\cdot\cdot\cdot\cdot \quad (3)$$

L_n: Cumulative water color (degrees・m^3)

Furthermore, TCAA formation potential (TCAA-FP) was measured in order to investigate the correlation between water color and TCAA formation.

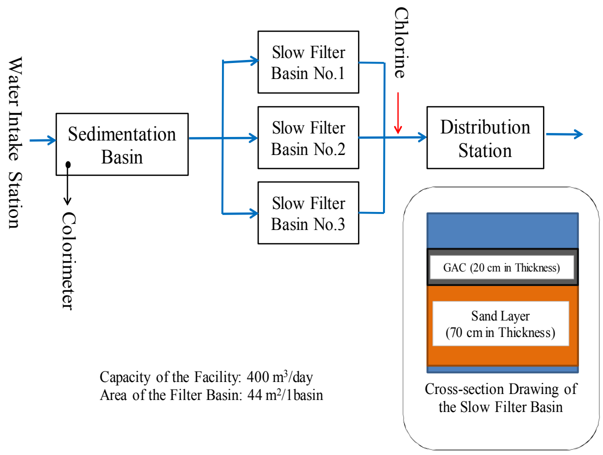

Figure 1 Purification Flow in Ogouchi PP

Table 1 Properties of the GAC

Items	Data
Effective Size	0.89 mm
Uniformity Coefficient	1.25
Hardness Number	96.8 %
Apparent Density	0.494 g/mL
Iodine Number	1130 mg/g
Methylene Blue Number	219 mL/g
Ash Content	2.5 %

Results and Discussion

The Relation between Water Color and TCAA-FP

The relation between water color and TCAA-FP was analyzed. There is a strong positive correlation between color of the filtered water before chlorine dose and TCAA-FP (**Figure 2**), and the relationship is approximated by the formula (4).

$$Y = 0.0166X - 0.0052 \quad \cdot\cdot\cdot\cdot\cdot\cdot \quad (4)$$

Y : TCAA-FP (mg/L)

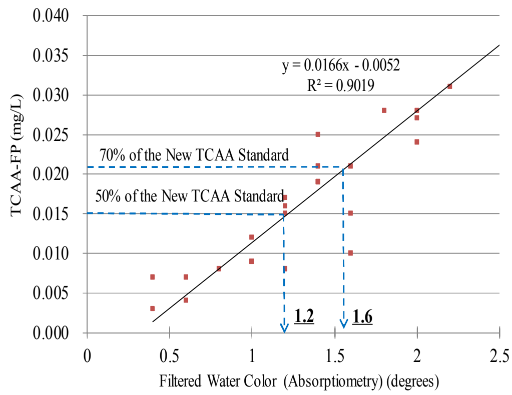

Figure 2 Filtered Water Color and TCAA-FP

The filtered water color required in suppressing TCAA formation was calculated by the formula (4). In order to keep the concentration of TCAA in the filtered water within 50% of the new TCAA standard, it was necessary to hold the filtered water color below 1.2 degrees. Additionally, it has turned out that the filtered water color must be held below 1.6 degrees in order to keep the TCAA within 70% of the new standard, during low temperature season. Consequently, the concentration of TCAA in tap water was successfully controlled within 3% of the new standard.

The factors Determining the Water Color Removal Efficiency

The water color removal efficiency was correlated with cumulative water color (**Figure 3**) and estimated as follows:

$$Z = -0.0095L + 97.57 \quad \cdots\cdots\cdots (5)$$

L: Cumulative water color until the previous day (degrees・100 m^3)

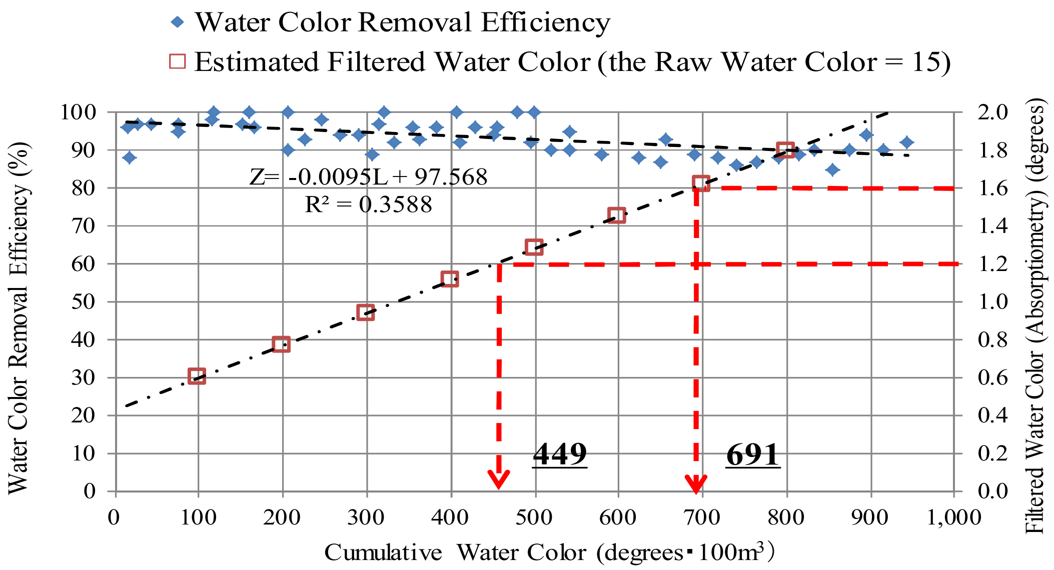

Figure 3 Cumulative Water Color and the Water Color Removal Efficiency

How long is the GAC available?

In order to reduce the load to filter basins, the unfiltered water color (colorimeter) was controlled with 15 degrees as the upper limit. Furthermore, the upper limit of the unfiltered water color (absorptiometry) was calculated from a correlation equation between the unfiltered water color (colorimeter) and the unfiltered water color (absorptiometry). Moreover, the target values of filtered water color were set as 1.2 or 1.6 degrees and the upper limit of cumulative water color was obtained by assigning the water color removal efficiency calculated from the formula (1) into the formula (5). The cumulative water color divided by the water color per day should bring about the useful life of the GAC.

The research periods were divided into two according to the temperatures of raw water. The calculation results during the two periods are shown in **Table 2**. In this table, it is clear that the useful life of the GAC is approximately 125 days if the target value of TCAA in the filtered water is set within 50% of the new standard. Similarly, it is approximately 200 days if the target is set within 70% during low temperature season.

Table 2 Calculation Results during Each Period

	【Research period A】 4/1/2015 - 10/21/2015	【Research period B】 10/22/2015 - 1/19/2016
Upper limit of the unfiltered water color (colorimeter) (degrees)	15	15
Upper limit of the unfiltered water color (absorptiometry) (degrees)	17.8	17.8
Upper limit of the target values of filtered water color (degrees)	1.2	1.6
Water color removal efficiency (%)	93.3	91.0
Upper limit of cumulative water color (degrees・$100m^3$)	449	691
Water color per day (degrees・$100m^3$/day)	3.60	3.53
Useful life of the granular activated carbon (days)	125	196

Conclusions

TCAA-FP has a high correlation with the filtered water color before chlorine dose and it is possible to suppress TCAA formation by using the filtered water color as indicator.

The cumulative water color is correlated with the water color removal efficiency and it is thus possible to estimate the useful life of the GAC.

As a result of operating the facility, the concentration of TCAA in tap water could be controlled within 3 % of the new standard. The useful life of the GAC is approximately 125 days when the target value of TCAA in the filtered water is set within 50% of the new standard, and approximately 200 days when it is set within 70% during low temperature season.

References

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