Development of an Energy-saving Membrane Filtration System Utilizing Geographical Conditions of Mountainous Area

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INTRODUCTION

As the membrane filtration facilitates a stable drinking water treatment and the reduction of maintenance burdens, it has been introduced to various purification plants. In general, membrane filtration requires installation of pumps to put a certain pressure upon the source water. Therefore, a membrane filtration consumes more energy than a slow sand filtration. As the drinking water supply requires a lot of energy, water utilities are large CO2 emitters in their regions. In Tokyo, the Bureau of Waterworks consumed more than 0.8 billion kWh in FY 2013 which is equal to about 1% of total energy consumption in the Tokyo metropolitan area [1]. Water utilities need to reduce further energy consumption.

The old-Hikawa purification plant (p.p.) was in the mountainous area of the western part of Tokyo where the population density is low (23 people/km^2 as of 2017). Because the quality of the source water is relatively good, slow sand filters had been used. However, various problems had occurred such as a sudden shutdown of its operation due to a high turbidity in the source water, difficulties in maintenance works in the mountainous area and the lack of seismic resistance due to aging. Therefore, immediate renewal was required.

To solve these problems, it was decided that the p.p. needed to be renewed and introduce membrane filters instead of slow sand filters. In addition, a new filtration method, which uses the gravity as a filtration pressure was introduced aiming to reduce the energy consumption.

METHODS

The old-Hikawa p.p was constructed in 1979 with a capacity of 1,645 m^3/d. As shown in Figure 1, the source water is taken from a river and introduced into a receiving tank which adjusts the water level. Slow sand filters treated the source water. As shown in Figure 2, the quality of the source water is normally good. However, its turbidity surges when it rains. In such cases, contamination by pathogenic organisms such as Cryptosporidium was of particular concern. Furthermore, filtration could stop due to a clogging. Therefore, the operation of sand filters was often suspended.

The new-Hikawa p.p. was designed to have a capacity of 2,470 m^3/d by integrating the capacity of a neighboring p.p. To solve above-mentioned problems, membrane filters were introduced instead of slow sand filters as shown in Figure 1. Ceramic membranes having an average pore diameter of 0.1 μm filter whole amount of the source water. Designed flow rate is 1.5 m/d. Results of plant-scale experiments showed that when operated at flow rates of 2.0 m/d and 3.0 m/d, transmembrane pressures (TMPs) are about 8 kPa and 21 kPa, respectively. In addition, no surge of TMP was observed even when the turbidity of the source water hits 180 mg/l as shown in Figure 3.

Generally, a membrane filtration requires more energy than slow sand filtration because the source water needs to be pressurized. However, as intake facilities of the p.p. are located at higher elevation than the p.p., the gravity was utilized as a pressure source to reduce energy consumption. The pressure required for the filtration was approximately 26 m as an effective water head, which was composed of the maximum allowable TMP (approximately 20 m) and losses by pipes and attached equipment (6 m). On the other hand, the elevation difference between the p.p. and the sand settling basin is 110 m. Therefore, the gravity can produce enough pressure required for filtration. For further utilization of the gravity, a small hydraulic generator (7 kW) was installed to the source water transmission pipe.

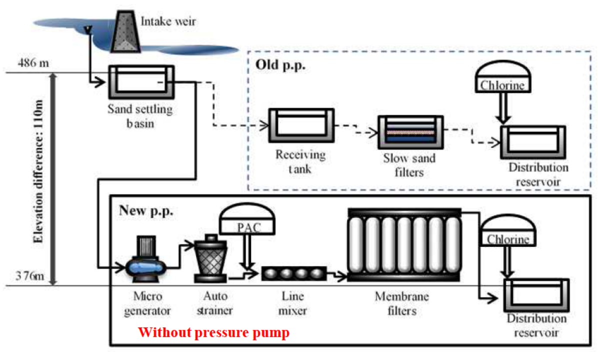

Figure 1 - Treatment process of Hikawa purification plant (Before and after the renewal)

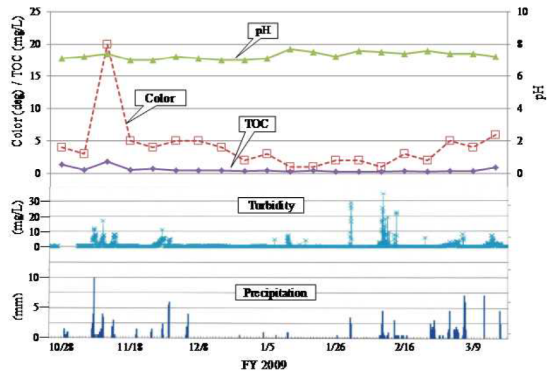

Figure 2 - Records of precipitation and changes of turbidity, pH, color and TOC in the source water

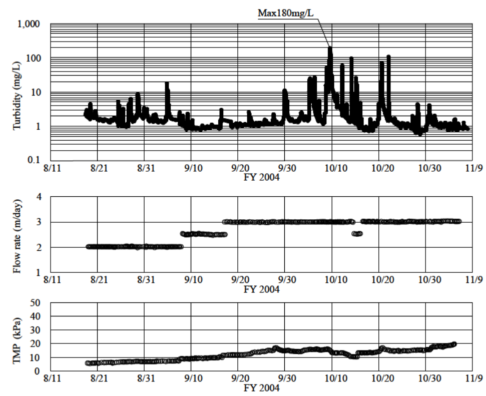

Figure 3 - Changes of turbidity in the source water, flow rate and TMP during the plant-scale experiment

Other issues that relate to this new filtration method were studied. In general, coagulants are added before filtration to remove organic substances [2]. However, this method does not have any receiving tank where coagulants are usually added. Therefore, a line-mixer was installed to the source water transmission pipe, which disperses the coagulant without releasing water pressure. In addition, as the source water is introduced directly from the sand settling basin to filtration units, effects of suspended materials were concerned. To remove these materials, a stainless auto-strainer was installed to the source water transmission pipe.

RESULTS AND CONCLUSIONS

The new-Hikawa p.p started its operation in March 2015. Figure 3 shows changes of turbidity, colour and TMP during the summer in 2016. Though 15 months have passed without chemical cleaning, TMPs were kept below 150 kPa. Even when turbidity increased rapidly after precipitation, TMP was kept stable. After the first chemical cleaning using H_2SO_4 and NaClO in October 2016, TMP dropped to 4 kPa. As a stable filtration had been kept for 17 months, the effectiveness and practicality of this method including line-mixer and auto-strainer has been demonstrated.

If pressure pumps with a rated capacity of 11 kW were used instead of the gravity to treat the same amount of the source water, estimated electricity consumption would be 95,000 kWh/year, which is equal to about 36 tons of CO_2 emission in Japan as shown in Table 1. In addition to energy conservation, the small hydraulic generator produced 10,665 kWh of electricity in FY 2016 which was sold to a power company and yielded 391,615 JPY (approximately 3,500 US$). Following the new-Hikawa p.p., Tokyo Waterworks plans to install this new filtration method at two aging p.p. waiting for complete renewal and will start their operations in FY 2018.

In conclusion, the new filtration method developed in this study achieves energy conservation and power generation by utilizing geographical condition in the mountainous area. It is applicable to other p.p with similar geographical conditions.

Table 1- Advantages of the new filtration method developed in this study

Energy conservation	95,000 kWh/year
CO2 emission reduction	36 t/year
Electricity generated	10,665 kWh/year
Revenue from sales of electricity	3,500 US$/year

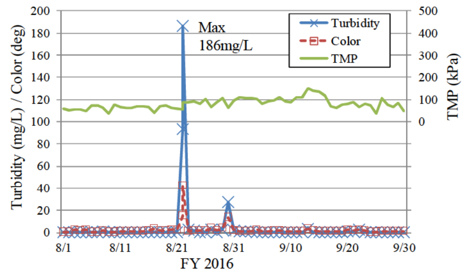

Figure 4 - Changes of turbidity and color in the source water and TMP at the new-Hikawa p.p.

References:
[1] Tokyo Waterworks Bureau (2015), Five-year environmental plan (2015 – 2019)
[2] Moon, J., Moon, S.K., Jae, L.L., Choong, H.K., & Hee, D.P., (2009), Evaluation of a low-pressure membrane filtration for drinking water treatment: pretreatment by coagulation/sedimentation for the MF membrane, Desalination, 247, 271-284