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Process control system of granular media filter considering daily flow-rate fluctuation

Seong-Su Kim[a,*], No-Suk Park[b], Woo-Chang Jeong[c], Chang-Keun Wang[d]

[a]*K-water Institute, Korea Water Resources Corporation, 462-1 Jeonmin-dong, Yuseong-gu, Daejeon 305-730, Republic of Korea*
Tel. +82 42 870 7527; Fax: +82 42 870 7549; email: kssman@kwater.or.kr
[b]*Department of Civil Engineering, Gyeongsang National University, Jinju, Republic of Korea*
[c]*Department of Civil Engineering, Kyungnam University, Changwon, Republic of Korea*
[d]*Department of Environmental Engineering, Chungnam National University, Daejeon, Republic of Korea*

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ABSTRACT

In this study, to investigate the influence of fluctuation in hydraulic loads on both the operation of filtration process and the quality of filtered water for a domestic water treatment plant, two different control methods were analyzed and compared with each other: (1) constant-rate filtration using a flow meter and a flow modulation valve (rate control method; RC method), (2) constant-level filtration using equal-flow splitting inlet weirs, water level sensors, and a flow modulator valve (level control method; LC method). From the results of experiments, it could be showed that a sudden flow surge may cause significant particle detachment in terms of particle count in filtered water under conditions of LC method. In addition, this method can lead to difficulty in maintaining residual chlorine at the outlet of clear well. On the other hand, the RC method, in two aspects – the process operation and the quality, is evaluated to be more appropriate than the LC method with seriously large fluctuation in inlet flow.

Keywords: Influence of fluctuation; Rate control method; Level control method; Filtration process

1. Introduction

Granular media filtration is the major process that removes fine particles from the water treated by conventional solid/liquid separation. The most common rapid filtration process uses sand, which has a unique media size and media depth or granular layers, in combination with anthracite. The design and construction of a rapid filtration system are more difficult than those of other water treatment facilities. Several design parameters such as the evenness of inflow distribution, selection of a method for controlling the filtration rate, the collection and transportation of effluent flow, and the underdrain system should consider accurate hydraulic issues. In particular, when designing the filter, achieving a unique distribution for the effluent flow rate in each site from the entire filtration system consisting of several filters is very important for enhancing the quality of filtered water; however, in fact, the design process of the filter is very difficult and the operation periods are undesirable.

*Corresponding author.

Generally, pretreated water is distributed to each filter through a distribution channel; however, it is difficult to evenly distribute pretreated water into each zone owing to differences in design flow conditions and operation flows in this type of hydraulic distribution method. That is, the increase in flow as the velocity head changes to the pressure head at the end of a channel in most waterway structures cannot be prevented. Further, even if the slope of the channel is adjusted upward, minor differences occur, and a more even distribution is harder to achieve if the inlet flow changes. Thus, the installation of equipment that controls inlet flow using a valve at the inlet of the filter and other relevant units is recommended.

Depending on changes in effluent flow rate, two filtration modes exist: constant-rate filtration and declining-rate filtration. The constant-rate filtration mode is generally used. There are three types of methods for constant-rate filtration: (1) constant-rate filtration using a flow meter and a flow modulation valve (rate control method; RC method); (2) constant-level filtration using equal-flow splitting inlet weirs, water level sensors, and a flow modulator valve (level control method; LC method); and (3) constant-rate filtration using equal-flow splitting inlet weirs and a weir to control the common effluent level (naturally balance method; NB method). The RC method involves the installation of a flow meter and a flow modulation valve at the outlet of the filter to maintain uniform effluent flow rate by opening the valve in case of clogging of the filter bed during filtration. The advantage of the RC method is that it can reduce the height difference between the surface of the filter bed and the water level; however, the equipment is relatively complex, and the water quality may deteriorate owing to negative pressure in the case of high head loss. The LC method involves the installation of a water level meter, an inlet weir for uniform flow distribution, and a flow modulation valve. As the filtration process proceeds, water level increases. If the water level reaches the target height fixed at a certain level, a signal is transmitted to the outlet valve and the flow modulation valve is opened to maintain a constant water level. The NB method (constant-rate filtration using equal-flow splitting inlet weirs and a weir to control the common effluent level) uses a weir that controls the outflow level of each site and an inlet weir that ensures uniform flow distribution; the outlet weir is installed at a position above the filter bed. As filtration proceeds, the outlet weir overcomes the resistance depending on blocking of the filter bed by increasing the filtration water level to maintain the effluent flow rate. If the water level above the filter bed reaches the setup value, filtration ceases and backwash is carried out; therefore, the water depth increases with the duration of filtration. The pressure in the upper position of the filter bed may be reduced to below atmospheric pressure owing to the creation of negative pressure during the latter stages of filtration.

The declining mode (declining-rate filtration using a submerged inlet that may or may not be fitted with a weir to control the effluent level) has no modulation valve on the filter outlet side. Generally, this method involves fixing the upper limit of filtration rate by installing a control part such as an orifice in the filtration outlet; the design and construction of a declining-rate filter is very simple and has the advantage of yielding high-quality filtered water. However, if the number of filters is small, it is difficult to manage the flow depending on the reduction of filtration rate, and filtration rate or water level varies largely in accordance with beginning and end of the operation. Therefore, the declining-rate filtration method is not selected in developing countries.

Studies on hydraulic shock loads in the filtration process have been conducted so far. Cleasby et al., 1989, recommended exercising caution when the filtration rate is increased and during the ripening period for optimal water quality [1]. Also, Cleasby et al. suggested in AWWARF's research report that the valve should be controlled slowly and in a step-by-step manner because a rapid increase in the filtration loading rate could deteriorate the water quality in the case of the RC method [2]. Detachment of an attached particle is related to the size of the particle, media size, flow and velocity conditions, and head loss; studies on various filtration models in terms of these factors have progressed. Practically, it is difficult to prevent hydraulic shock loads if backwash is carried out in the filtration process using multiple filters. However, if this hydraulic impact occurs, it causes detachment of particles, and the detached particles penetrate the filter bed, which may lead to the deterioration of water quality. Bai et al. revealed the relationships of particle diameter, head loss gradient, and particle detachment when flow impact load occurs [3]. Further, Kim and Tobiason investigated that attached particles are detached when hydraulic impact occurs in the filtration process [4,5]. They suggested that a relatively larger particle is detached more easily because it is influenced by shear forces. A study, conducted by Park et al. on the media composition considering the changes of daily flow rate, suggested that media depth should be sufficient to handle the changes in hydraulic loads [6]. Furthermore, several previous researchers have recently reported that deep-bed filter can be used as a pretreatment to a membrane filter [7,8].

Conventional water treatment for solid/liquid separation has a series of treatment processes such as flash mixing/flocculation, sedimentation, and filtration processes from an intake well. Moreover, flow of raw water from an intake well changes depending on the time of day. In this situation, follow-up processes are suitably carried out depending on the flow of the water, which results in changes in coagulant dose and mixing intensity, and changes in hydraulic behavior in the collecting well, and the number of running filters and filtration rate. However, according to Park et al.'s research, time taken for the follow-up processes by the fluctuation in open channel can be estimated by the propagation velocity of surface waves; the study suggests that rapid inlet flow fluctuation should be minimized because it spreads to the end process in a short time [6]. Also, they reported that variation in water production rate changes product water quality according to the characteristics of unit processes, especially sand filtration [9].

In this study, we investigate the influence of fluctuation in hydraulic load on the filtration process in filtration plants, which have large fluctuations in inlet flow. In this study, we evaluate the differences in the operation and treatment efficiencies of the LC method and the RC method.

2. Materials and methods

The plant, wherein Nakdong river water flows, evaluated in this study is the "G" water treatment plant (G-WTP) at which the following conventional water treatment processes are carried out: flash mixing/flocculation, sedimentation, and filtration. G-WTP has a capacity of 200,000 m^3/day and contains 10 rapid filters designed with a filtration rate of 203 m/day. The filtration area for each bed is 103.7 m^2, and the filter beds were made of dual media: anthracite and sand. The effective size of anthracite and sand is 1.1 mm (uniformity coefficient 1.4) and 0.6 mm (uniformity coefficient 1.5), respectively. The ratio of length to effective diameter of media (L/de) is 1,409. Filter bed is composed with anthracite 100 cm and sand 30 cm, and the underdrain system is operated with plastic underdrain blocks with a porous plate that replaced the wheeler block in 2008.

Figs. 1 and 2 shows the structure and the layout of filters of the G-WTP filter bed, respectively. The filter beds in the G-WTP are operated with filter control logic by the LC method (constant-level filtration using equal-flow splitting inlet weirs, water level sensors, and a flow modulator valve). The control logic indicates that the opening rate of the discharge valve changes in accordance with the signal of water level for each zone. The logic ensures that the flow values are measured after 120 s of adjusting the flow modulator valve (2 s) of the filter discharge valve on receiving the input signal, which is the water level. This method is generally applied to the WTP wherein treatment flow does not change, and if it can be controlled with less discharge valve control, it has numerous advantages. However, in the case of the G-WTP, as shown in Fig. 2, the structure is such that sedimented water flows to the filter bed inlet, which is affected by the water level if flow changes.

For Filter #8 in the G-WTP, as shown in Fig. 3, discharge flow rate, particle count, and turbidity of filter bed operated with the current water level control type filtration method (the LC method) are analyzed for every minute. Furthermore, after changing the control method to the discharge flow-rate control method (the RC method), the valve opening control method to achieve the set discharge flow, particle count, and turbidity has been evaluated and compared. The equipment used in the particle count analysis is PAMAS-316 (PAMAS GmbH, Germany), and turbidity was analyzed by using the online turbidimeter (HACH company).

3. Results and discussion

3.1. Fluctuation in inlet flow during filtration

Fluctuation in inlet flow during the day in the WTP affects the follow-up process in a very short time. As shown in Fig. 4 (refer to gray thicker line), the variation in the width of fluctuation in inlet flow is approximately 200% in the G-WTP, and instant fluctuation width is also very large. For such high fluctuation in inlet flow, the average value of the filtration rate should be maintained by changing the number of operational filters receiving inlet flow. Thus, the G-WTP is operated by changing the number of operational filters receiving inlet flow.

However, as shown in Fig. 4, total filtered water in the entire filter bed has a larger fluctuation width than that of inlet flow of the G-WTP, which is attributed to the current control method that controls the valve opening in the discharge side on the basis of the water level signals received from the filter bed. That is, depending on the sudden change in water level due to fluctuation in inlet flow and the rapid change in discharge valve opening ratio, flow of filtered water tends to change more than the fluctuation width of inlet flow in the G-WTP. Further, fluctuation in discharge flow in each filter bed has similar tendencies to the daily patterns of flow received by the WTP, and

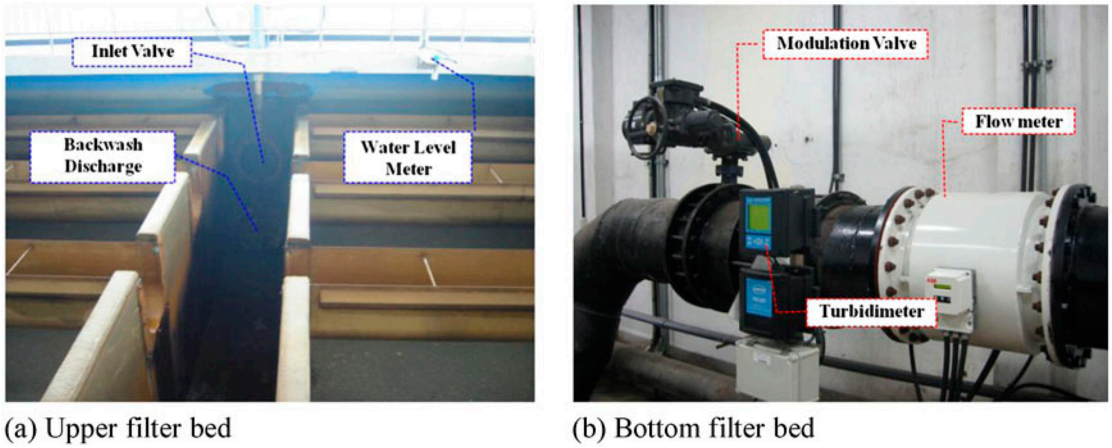

Fig. 1. Filterstructure of G-WTP.

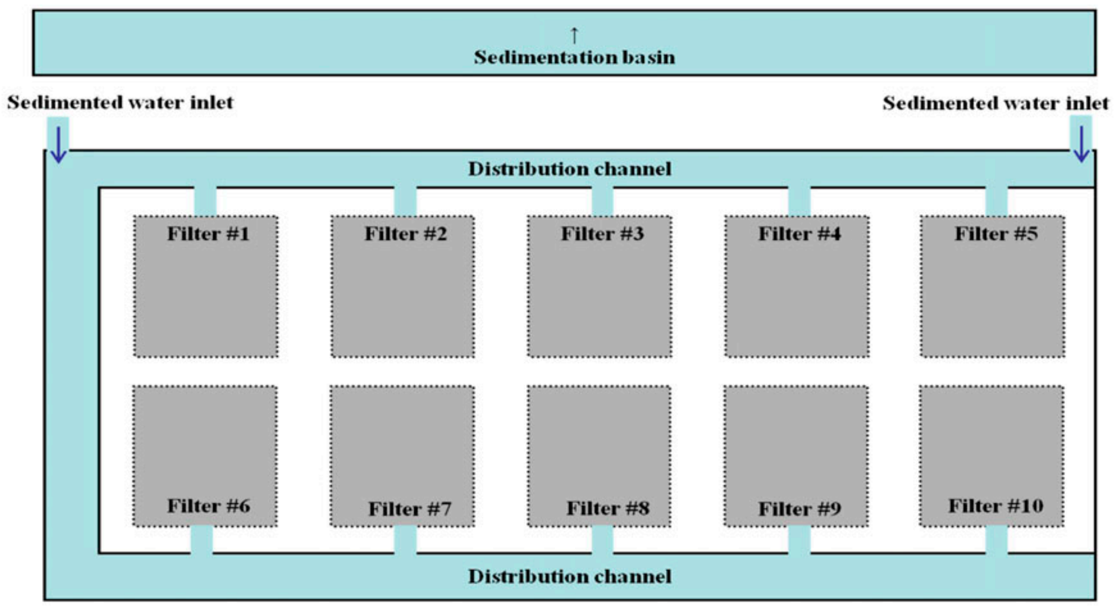

Fig. 2. Structure of filter inlet.

the time interval of fluctuation in inlet flow and flow fluctuation discharge at the filter bed is not very different. This result shows identical characteristics to those of a study wherein the influence of shock load due to increasing flow at the intake well affected the discharge flow of follow-up filtration process within several minutes.

As shown in Fig. 5 and Fig. 6, fluctuation in the instant filtration rate in the filter bed, operated by frequent opening rate changes in the discharge valve, is more than 203 m/day, which is the design filtration rate for each filter in the G-WTP, at many points. Numerous studies have suggested that shock load due to an instant increase in the filtration rate may deteriorate water quality because the particle attached to the media is detached.

However, in the case of the G-WTP, even if rapid increase or decrease in filtration rate according to changes in opening rate of the discharge valve at the filter bed and fluctuation in flow occurs, the turbidity of filtered water is within the range 0.04–0.06 NTU. Therefore, the deterioration in the quality of discharged water is relatively small. Because valve opening rate changes rapidly and frequently, the particle attached to the media does not detach instantly by shock load, but detaches continuously in normal time.

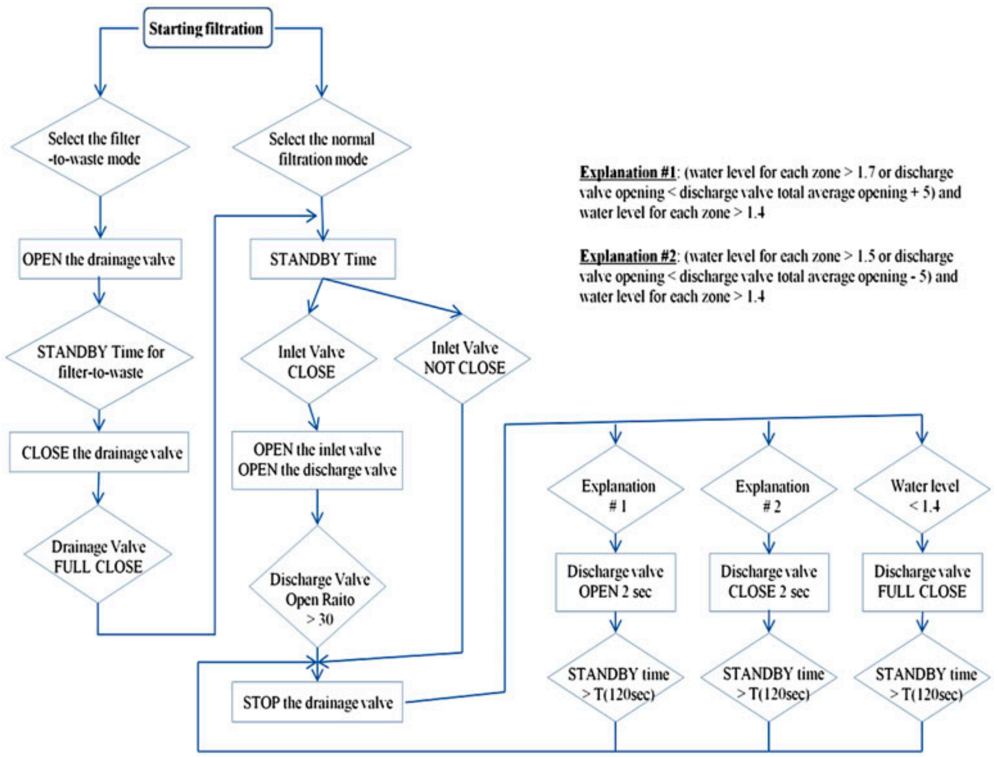

Fig. 3. Control logic of filtration for LC method in G-WTP.

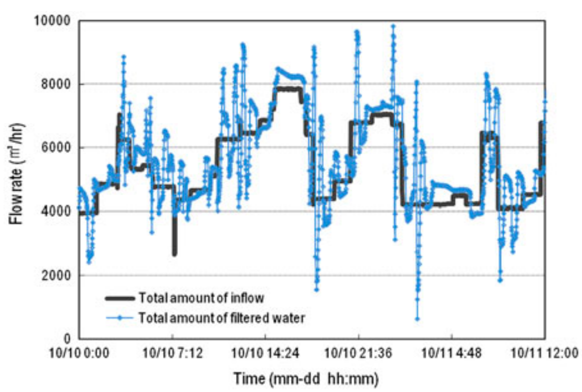

Fig. 4. Profile of inflow and filtered water flow in G-WTP.

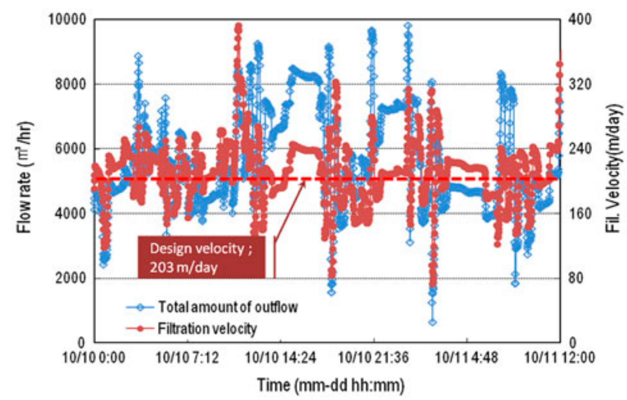

Fig. 5. Fluctuation in filtration rate according to the variation in flow.

3.2. Evaluation of efficiency of each treatment method

For large fluctuations in inlet flow in the water treatment plant, the valve opening rate was controlled by the LC method and the RC method to evaluate the influence of filter bed control logic on water quality of the filtration process in terms of turbidity and particle count.

Fig. 7 shows the turbidity and particle count of filter bed water discharged from the LC method in normal time. The turbidity of filtered water does not show any major differences within 0.03–0.04 NTU; however, in the case of particle count, small particles of sizes 2, 3, and 5 μm have changed in large proportion in the discharged water depending on fluctuation in flow.

Next, the RC method was applied, and the discharging flow was more uniform in the RC method than in the LC method. Also, the turbidity was kept less 0.03 NTU, which is lower than that in the LC method, as shown in Fig. 8. In the case of particle count, fluctuation was relatively lower than that in the

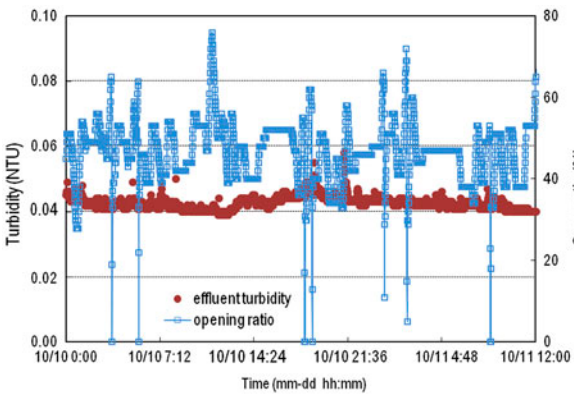

Fig. 6. Turbidity of filtered water according to valve opening ratio.

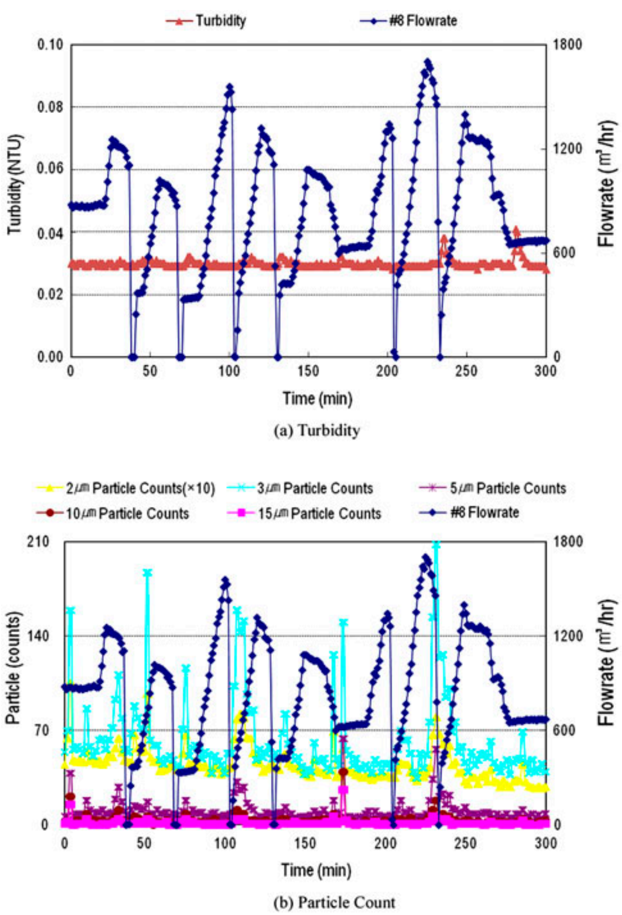

Fig. 7. Turbidity and particle count of filtered water in the LC method.

LC method. Since wider fluctuation of discharging flow might cause more serious detachment of the previously accumulated particles on sand media, fluctuation width of each sized particle count within

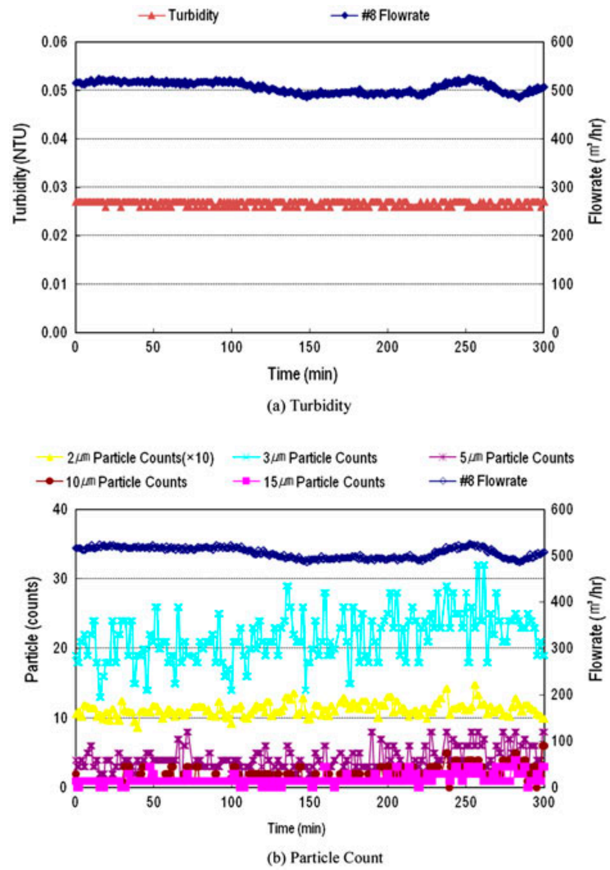

Fig. 8. Turbidity and particle count of filtered water in the RC method.

filtered water in the LC method is relatively higher than that in the RC method.

Depending on the control method, it is difficult to compare the advantages of water quality in terms of turbidity for each control method because of differences in raw water quality and pretreatment efficiency. However, rapid fluctuation in filtration rate can confirm the negative factors in water quality of filtered water, and the data of particle count and turbidity show this tendency more clearly.

Rapid fluctuation in discharging flow depending on fluctuation in inlet flow in the filtration process not only causes the deterioration of water quality but also affects the disinfection (chlorination) process of follow-up water treatment processes. In post-chlorination process, chlorine is injected after the filtration process to keep the residual chlorine from being contaminated by various types of micro-organisms. The chlorine dose should always be paced to the flow. Rapid fluctuation in inlet flow makes it difficult for the operator to add an adequate amount of chlorine, which is determined by considering the flow rate and water quality in the chlorine contactor. Thus, it is judged that instead of the LC method that is already employed in the G-WTP, the RC method is the optimal control method in the G-WTP.

4. Conclusions

In this study, the influence of fluctuation in hydraulic loads on the filtration processes has been investigated for the G-WTP, where the fluctuation in daily inlet flow is large. Further, the differences between the operation and treatment efficiency of the LC and RC methods, involving the operation logic of the filter bed, were evaluated in this study. The following conclusions are drawn.

(1) The method that controls the discharging valve opening rate to maintain the target water level in the LC method causes frequent fluctuations in the level if the fluctuations in inlet flows to the treatment plant are large. Therefore, rapid fluctuation in the filter bed discharging flow was indicated by rapid changes in discharging valve opening rates, and this led to an extremely high filtration rate.

(2) In the case of the LC method, the characteristics of the turbidity of discharging water changed within small scopes but particle count showed a large fluctuation according to the rapid fluctuation in filtration rate. On the other hand, the RC method has excellent quality filtered water because turbidity and particle count of discharging water have very small fluctuation as a uniform filtration rate is maintained in this method. Further, the LC method causes problems in administering optimal doses of chlorine in the chlorination process, so it leads to difficulty in maintaining residual chlorine at the end of the clear well.

(3) Thus, it is concluded that the RC method, which involves discharging flow interlocking, is more efficient than the LC method for the operation of water treatment processes and for better water quality at the water treatment plant, wherein large fluctuations in inlet flow occur.

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