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The optimal composition of the filter-media for coping with daily flow-rate fluctuation

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Abstract−The fluctuation of inlet flow in a water treatment plant can change the filtration rate abruptly and ultimately reduce the filtration performance by leaking the detained particles in filter media. The surface wave, occurring in the intake well by the fluctuation of inlet flow, reaches the filtration process in a very short time (about 10 minutes), which makes it impossible to control the filtration rate stably. In this study the authors evaluated the effect of daily flow-rate fluctuation on the performance of sand filtration process, and the dual media composition was proposed to improve the filtration performance. Comparative column tests were carried out for the various dual media, such as sand and anthracite compositions. From the results of column tests, dual media with the composition of sand 45 cm and anthracite 30 cm is more effective than the single media with sand in filtration process. In addition, irrespective of dual media composition, the managing ability to cope with that fluctuation tends to be weak at the end of allowable filtration duration time.

Key words: Filtration, Inlet Flow Fluctuation, Dual Media, Surface Wave

INTRODUCTION

The first tank, which forms the water level or head for the intake water from a water source within an arbitrary water treatment plant, is generally the 'intake well'. A water flow between the intake well and the latter processes, i.e., rapid mixing, distribution channel, flocculation, sedimentation and filtration and so on, is connected through a weir, orifice, open channel and closed pipes. Even though there might be a certain particularity for each water treatment plant, the water level within intake well could be occurring by the fluctuation of inlet flow rate and recycled flow with time. Several previous researches reported that this change of water level within the intake well can have a serious impact on the performance of each successive unit process as well as the efficiency of total system [1,2].

The fluctuation of inlet flow is an important operational parameter in a water treatment plant (WTP) that affects the optimization of the overall system composed of unit processes. Generally, the optimization of a rapid-mixing process can be achieved when the coagulant dose and mixing intensity are efficiently adjusted with the fluctuation of inlet flow to intake facilities. Also, the fluctuation of inlet flow can cause a change of G-value in the flocculation process, a difference of height in sedimentation basin, a variation of

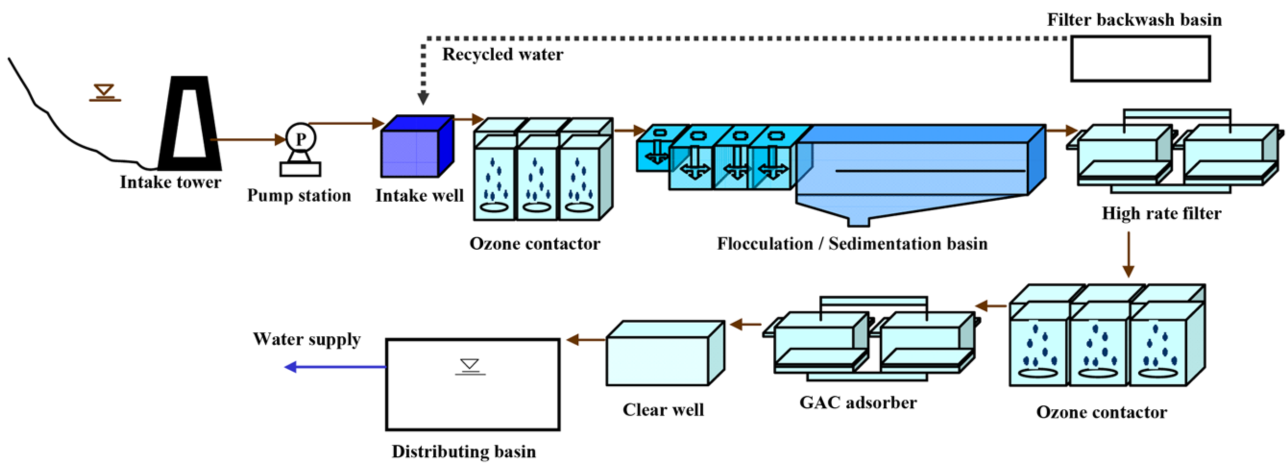

Fig. 1. Schematic of water treatment process.

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filtration rate, and consequently breakthrough of the particles inside the filter media. The optimization researches of water treatment systems have been carried out in the steady state [5]. But there is no place that the inlet flow of a water treatment plant is always constant in Korea [3].

The intake well is the first place that the inlet flow reaches in WTP and the water level and quantity are monitored on a daily basis (Fig. 1).

Until now, many researches have been conducted for optimization of a conventional water treatment process and system assuming that operation condition should be steady state. However, actually the water level within an equalization basin is changed several times all day long, and it is impossible to operate the treatment system at steady fixed condition. The reasons why a operator cannot cope with the fluctuation of the water level within the equalization basin are as follows: (1) The inflow rate into WTP changes depending on the daily usage pattern of residential consumers due to lack of storage tank (clear well) capacity. (2) The fluctuation of flow rate of recycled water into the equalization basin changes with time. (3) The rate of operation changes with time due to operation of WTP unconnected with water reservoir (the water reservoir is too small to keep a stable and steady water level). (4) The installation and operation of high capacity pumps without inverter causes a shock load and sudden change of water level at on and off for supplying raw water into WTP. Actually, there are few researches focusing on the investigation into the effect of the fluctuation of daily inflow rate on the performance of the water treatment process and system.

To predict the travel time of the flow rate fluctuation, the surface wave transfer velocity should be calculated. The Froude number is the ratio of the average velocity to the surface wave transfer velocity as well as the ratio of the inertia force to the gravity force. As shown in Eq. (1), the denominator term means physically the surface wave transfer velocity within a certain open channel or basin.

$$\text{Froude no.} = \frac{v}{\sqrt{g \times R}} \tag{1}$$

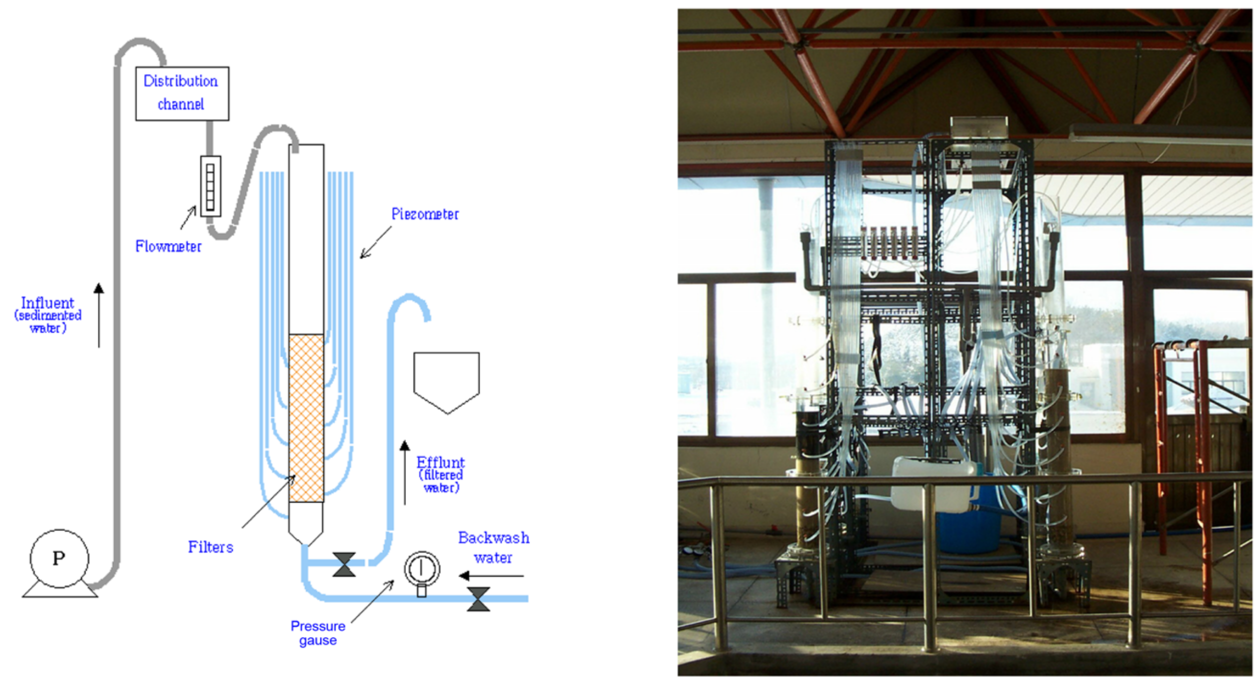
Where, v is average velocity (L/T), g is gravity acceleration (L/T^2) and R is hydraulic radius (L).

In the case of a two-dimensional open channel whose length and width are much longer than the depth from the surface to the bottom, the hydraulic radius in Eq. (1) can be replaced with depth. However, in the case of the open channels or basins used in WTP, the length, width and depth have the same order of magnitude. Also, the perimeter can be calculated directly from the measured geometrical information; it is reasonable to use the hydraulic radius. Accordingly, the surface wave transfer velocity within each process can derived with Eq. (2).

$$v_s = \sqrt{g \times R} \tag{2}$$

Where, v_s is the surface wave transfer velocity (L/T).

The surface wave transfer velocity and the travel time of the wave to each process can be calculated for the previous train in the water treatment plant. For example, the sum of the travel time of the surface wave within each process prior to filtration could be derived [4]. From the previous research, it has been revealed that the fluctuation of inlet flow to the water treatment plant makes a serious problem that can change the filtration rate abruptly, and ultimately the breakthrough will occur of the detained particles inside the filter media. The surface wave, occurring in the intake well by the fluctuation of inlet flow, reaches the filtration process in a very short time (about 10 minutes) [4]. Therefore, this study was conducted to evaluate the effect of daily flow-rate fluctuation on the performance of sand filtration process, and to suggest the optimal dual-media com-



(a) Schematic of the filter column (b) A photograph of the filter column

Fig. 2. Pilot plant used in this study.

Table 1. Media characteristics of each filter [unit: cm]

Filter type	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Anthracite	50	40	30	20	10	-
Sand	25	35	45	55	65	75
Total	75	75	75	75	75	75

※ Effective size of Anthracite 0.97 mm, Uniformity coefficient 1.36
Effective size of Sand 0.55 mm, Uniformity coefficient 1.58

Table 2. The water quality and coagulant condition used in experiment

	Parameters	Values
Raw water quality	Turbidity (as usual)	3-10 (NTU)
	Turbidity (as high-period)	20-800 (NTU)
	Temperature (°C)	6-25 (°C)
	pH	6.8-8.5
	Alkalinity (as $CaCO_3$)	Average 45 (mg/L)
Sedimentation basin	Turbidity (as usual)	0.5-1.0 (NTU)
	Turbidity (as high-period)	1.0-3.0 (NTU)
Condition of coagulant	PACs	8-14 (mg/L)
	PAC (as usual)	17-20 (mg/L)
	PAC (as high-period)	25-50 (mg/L)

position coping with the effects.

MATERIALS AND METHODS

The pilot plant was installed to analyze the filtration performance with different composition of medium simultaneously, which consisted of six acrylic column filters with 2.5 m height and 10 cm internal diameter (refer Fig. 2). The under-drain system was designed as a type of porous plate on the trumpet-shaped pipe to distribute the wash water uniformly. Each column was filled with 15 cm of gravel (grain size 5-10 mm) and filter bed given in Table 1. The manometer was set up to measure the rate of head loss during filtration on both sides of the column at intervals of 10 cm. Only water without air was used for backwashing every condition. Backwashing was continued until the turbidity form backwashed water was not changed.

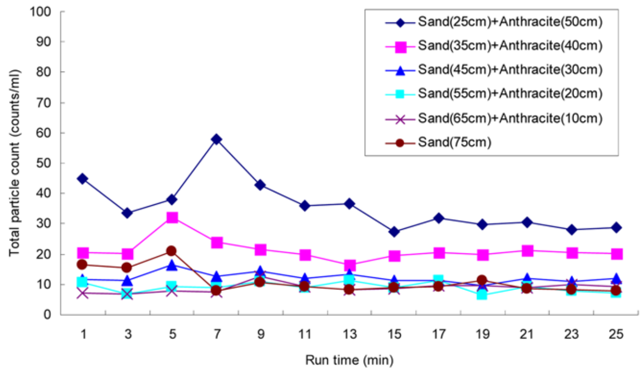
The water taken from sedimentation basin at the W-WTP was used as source water to the filtration column. The water quality of raw and sedimentation basin and coagulant condition are presented in Table 2. The online measurements of turbidity and particle counts were simultaneously carried out with a HACH 1720 Series Turbidimeter and US Filter WQA 2000 Particle counter.

To evaluate the ability for coping with the fluctuation of inlet flowrate, the filtration velocity was changed to 180 m/day after the filtration column was operating at 120 m/day for 24 hours, 48 hours and 65 hours.

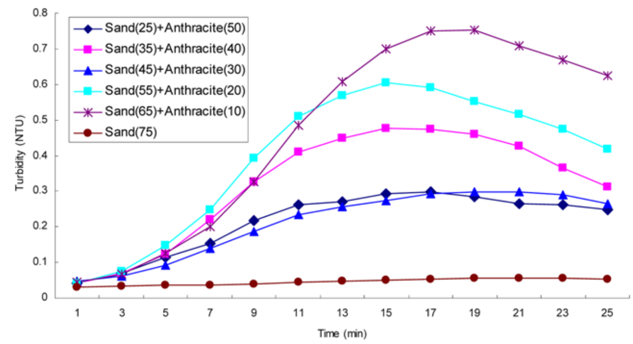
RESULTS AND DISCUSSION

1. Increase of Filtration Velocity After 24 hours Running

In the case that filtration velocity had been changed after filtration running for 24 hr, the value of turbidity and total count of the filtered water are presented in Fig. 3. As it can be seen, there are few alterations of water quality as a whole. Total particle count of Filter No. 1, composed of 25 cm sand and 50 cm anthracite, increased by 60 counts/mL at that moment and then decreased by 50 counts/mL after 2 minutes. The water quality of other filters was almost stable.



(a) Total particle count (counts/ml)



(b) Turbidity

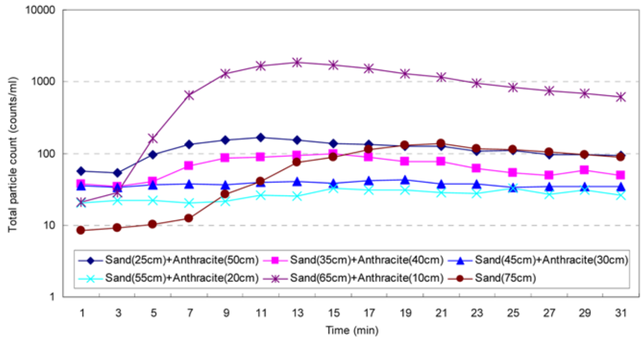
Fig. 3. The total particle counts and turbidities in effluent from each filter since increasing filtration velocity after 24 hours running.

2. Increase of Filtration Velocity After 48 hours Running

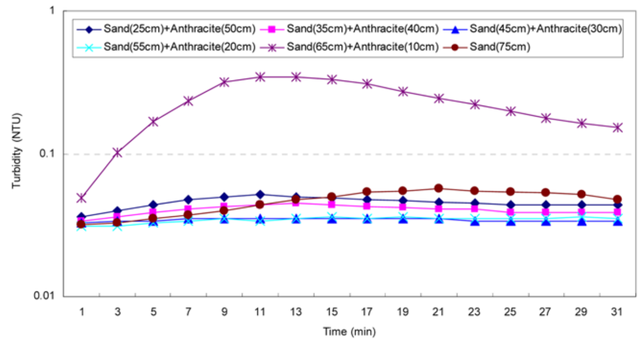
Fig. 4 shows the total counts and turbidity in the effluent from each filter since increasing filtration velocity to 180 m/day after running the filtration column at 120 m/day for 48 hours. Total particle count of Filter No. 8, composed of 65 cm sand and 10 cm anthracite, exceeded 1,800 counts/mL when the filtration velocity increased after operation of 48 hours. In addition, particle counter measurements, taken 1 hour after increasing velocity, were approximately 400 counts/mL, and by that could be judged the breakthrough of detained particles at which the average value was below 30 counts/mL considered at the steady state.

It is also observed that the particle count value of the other filters' effluent changed profoundly after the operation of 48 hours. Total counts decreased after increasing the filtration velocity up to 170 counts/mL at filter No. 1 (sand 25 cm+anthracite 50 cm), 140 counts/mL at filter No. 6 (sand 70 cm), 100 counts/mL at filter No. 2 (sand 35 cm+anthracite 40 cm), respectively. On the contrary, the effluent of filter No. 3 (sand 45 cm+anthracite 30 cm) and No. 4 (sand 35 cm+anthracite 40 cm) exhibited a continuously stable trend.

From the results of the experiment after running the filtration column for 48 hours, the reason why filter No. 5 showed a serious leak

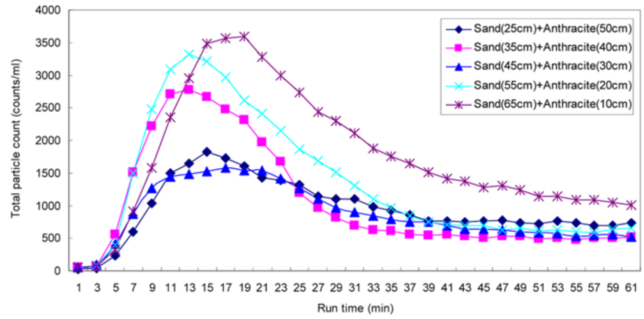


(a) Total particle count (counts/mL)

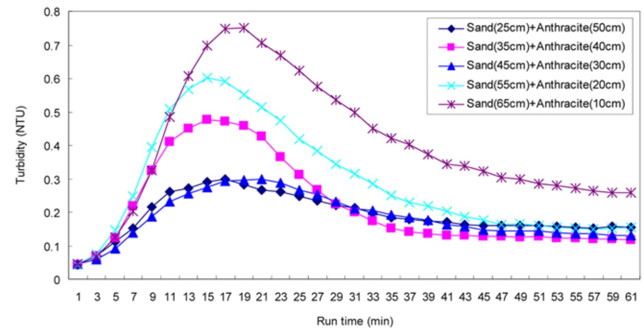


(b) Turbidity

Fig. 4. Total particle counts and turbidities in effluent from each filter since increasing filtration velocity after 48 hours running.



(a) Total particle count (counts/ml)



(b) Turbidity

Fig. 5. The total particle counts and turbidities in effluent from each filter since increasing filtration velocity after 65 hours operation.

of particles is that excessive matters attached to 10 cm layer of anthracite might have detached from the media surface due to abrupt shocking fluctuation. In the case of filter No. 6, since the cake on the sand surface had absorbed the effect of fluctuation by surface filtration mechanism, particulates might have escaped much less. Also, when the particulate matters attached on the layer of anthracite were leaked by inflow fluctuation, there was a limit to control leaking particle from No. 1 and No. 2 filters because of the thin sand layer. This is based on the data that the amount of leaking particle from filter No. 2 was less than that of filter No. 1 because of the thick sand layer and filter No. 3 and No. 4 exhibited relatively stable water quality.

3. Increase of Filtration Velocity After 65 hours Running

Filters No. 6 (sand 75 cm) were removed from the experiment of inflow fluctuation since the available head loss within the filtration column was higher than 1 m. In the experiment of inflow fluctuation, total count and turbidity of all filter increased rapidly. Fig. 5 shows the total counts and turbidity each in effluent from each filter, and both figures exhibit a similar trend. The total counts and turbidity tended to increase, followed by filter No. 5 (sand 65 cm+ anthracite 10 cm), No. 4 (sand 55 cm+anthracite 20 cm), and No. 2 (sand 35 cm+anthracite 40 cm). And the filter No. 1 (sand 25 cm+ anthracite 50 cm) and No. 3 (sand 45 cm+anthracite 30 cm) showed a similar trend.

In contrast, after increases in the total count and turbidity, it was shown that the sequence of stabilization was in order of filter No. 2, No. 3, No. 4, No. 1 and No. 5. The total particle counts and turbidity were very high compared to the value, less than 50 counts/mL and 0.05 NTU, respectively, when the effluent quality was good as usual. Since the total count data evaluated 1 hour later showed 500 counts/mL, in all filters breakthrough actually occurred of the detained particles inside filter media, from which we can judge that the filters overran allowable filter run time.

From the results of the analysis of ability to cope with flow fluctuation, the dual media (anthracite+sand) filter is more effective to cope with the effect of flow-rate fluctuation on the performance of filtration than single media (sand). Especially, like filter No. 3 (sand 45 cm+anthracite 30 cm) and No. 4 (sand 35 cm+anthracite 40 cm), one make a plausible conclusion that the filter must have sufficient capacity to deal with shock effect of inflow fluctuation. However, in the case of insufficient layer of anthracite, a filter such as filter No. 5 (sand 65 cm+anthracite 10 cm), for example, was especially vulnerable to shock effect because the particle matter had made the sand layer excessively dirty.

From the results of column tests, the decision of optimal time to backwash, especially in the last stage of filtration, is the most important operation factor to prevent the leakage of particles. Consequently, determination of the backwashing point is very important due to poor ability to cope with fluctuation.

CONCLUSION

This study was conducted to evaluate the effect of daily flow-rate fluctuation on the performance of the sand filtration process, and to suggest the dual media composition for coping with that effect. The study results demonstrate that the daily fluctuation can change filtration velocity in short bursts and temporarily cause leakage of detained particles. Since it takes very short time (about 10 minutes) for the surface wave from the fluctuation of inlet flow to reach the filtration process, it is impossible to control the filtration rate stably. The major observations based on the filtration experiments using six different media composition are stated below.

The inlet flow fluctuation was propagated by aspect of surface wave to filter via rapid mixing/flocculation basin and sedimentation basin. Therefore, it can leak particles directly from the filter because of variation of filtration velocity. Also, it was impossible to decrease the shock in advance.

From the results of column tests, dual media, especially in the case of sand 45 cm and anthracite 30 cm, is more effective to cope with the effect of flow-rate fluctuation on the performance of filtration than single media (only sand). Especially, the filter should be composed of sufficient media depth as evaluated: media composition of sand 45 cm/anthracite 30 cm and sand 30 cm/anthracite 45 cm.

In addition, irrespective of dual media composition, managing the ability to cope with that fluctuation tends to be weak at the end of allowable filtration duration time. Consequently, optimal determination of the backwashing point is very important to prevent unexpected leakage of particles.

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