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A column study of effect of filter media on the performance of sand filter

Tae-hoon Kim[1], Heekyong Oh[2], Jungyeol Eom[2] and ChulHwi Park*[1]

[1]*Department of Environmental Engineering, University of Seoul, 163 Seoul siripdaero, Dongdaemun-gu, Seoul, Republic of Korea*
[2]*Plant Research Team, Daewoo E&C, 20 Suil-ro 123beon-gil, Jangan-gu, Suwon-si, Gyeonggi-do, Republic of Korea*

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Abstract. Sand filter is a key unit process for particle removal in water purification treatments. Its long-standing use is due to on-site customized retrofit. Proper selection of filter media is one of the retrofit approaches to improve filter performance. This study described a series of controlled laboratory column tests and examined the effects of media property on filtration and backwash. When sand media of 0.51 mm in effective size was replaced by sand of 0.60 mm, the filter run increased up to 5 times in the given bed depth. The change of media property required an increase of backwash rate by 0.05 m/min to satisfy the requirement of bed expansion, more than 20%. When the anthracite was changed with lower effective size and uniformity coefficient, correlation with sand in the filter bed could be satisfied within the permissible error between media and bulk characteristics. Besides, this selection resulted in a well-stratified configuration of media layers after bed expansion. The column study showed that the correlation of property between the dual media had a significant effect on the filter productivity and backwash interval.

Keywords: backwash; bed expansion; filter media; mixed layer; retrofit; ieve analysis

1. Introduction

Water treatment plants around the world are constantly being constructed, relocated to new site facilities according to urban planning and development, and are being retrofitted to improve the performance and capacity of the existing facilities. Various unit processes are selected, combined and optimized to achieve the target water quality and the design capacity at water treatment plants (Qasim *et al*. 2000, James and Mattew 2018, Mariya *et al*. 2017). The approaches through newly building and retrofitting should comprehensively review current and foreseen laws, regulations, and standards on water resources and drinking water, situation of infrastructure site, skill of operation and maintenance, cost for construction and production and etc. (Byod 2015, Interdepartmental water quality training board 2011, Kubota and Magara 2009). In Korea, after a water treatment plant is determined to construct newly or upgraded, it must be complied with the standards or guidelines of waterworks facilities for site-specific design (Korean Water Works Association 2010, 2017).

The climate change, industrialization and urbanization cause the degradation of raw water quality and the introduction of CECs (contaminants of emerging concern), resulting in needs to improve and retrofit the existing water treatment system. A water treatment method is typically determined by classifying the target contaminants into two categories: insoluble and soluble materials. Insoluble materials include macro and microparticles such as algae, bacteria, and other microorganisms, suspended and colloidal solids. Also, microplastics with less than 5mm of particle size can be classified within insoluble contaminants. Except for the microplastics, the existing conventional rapid sand filtration system is very good at removing those insoluble materials. Soluble contaminants are natural organic matters, disinfection by-products, taste and odor-causing compounds and *PPCPs* (Pharmaceuticals and Personal Care Products). Advanced water treatment processes such as oxidation and membrane filtration have been considered to solve those soluble contaminants (Bottino *et al*. 2011, Khulbe *et al*. 2012, Wang *et al*. 2018).

Filtration system such as a sand filter serves as the last barrier most commonly in water treatment plants where turbidity is physically removed from the water. The sand filter is applied alone or combined after being pre-treated with the coagulation, chlorine oxidation and powdered activated carbon (Huck *et al*. 2001, Emelko 2003, AWWA and ASCE, 2012). The latter system is called a rapid sand filter. Meanwhile, soluble materials cannot be sufficiently removed by a filtration process nor a combined filtration process with pretreatment. Therefore, the standard sand filters are followed by an advanced oxidation process (ozone, UV, and hydrogen peroxide), absorption processes using granular activated carbon and filtration using NF (Nanofiltration) to reduce soluble contaminants (Miklos *et al*. 2018, Sillanpää *et al*. 2018). As such, the sand filter has performed as a central unit process of the combined water treatments for safe drinking water. And the technology and experience of sand filters make them more sustainable and accessible to the operation staff through various modifications (Lin 2010). Even if the water treatment process is finalized based on the goal of water quality,

*Corresponding author, Professor
E-mail: chpark@uos.ac.kr

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Table 1 Status of sand filter applied in Korean drinking water treatments unit: capacity (10^3 m^3/d)

Waterworks type	D[2]	Filtration			Advanced Treatment[4]		Others	Total
		Sand		Membrane	RSF[3]	Membrane		
		Slow	RSF					
Local government	310	545	10,986	145	8,039	104	0.08	20,129
K-water[5]	0	0	4,160	57	2,656	20	0	6,893
Total	310	545	15,146	202	10,695	124	0.08	27,022
(%)[1]	(1.1)	(2)	(56.1)	(0.7)	(39.6)	(0.5)	(-)	(100)

1) Percentage of applicable capacity compared to overall facility capacity, 2) Only disinfection, 3) Rapid sand filter 4) Ozone or UV-AOP + GAC 5) Korea Water Resources Corporation

Table 2 Goals of filtrate turbidity controlled by Korean representative waterworks

Turbidity(NTU) \ Waterworks	Seoul	Pusan	Daegu	K-water	Korean Standard
Average	≦0.05	≦0.08	≦0.06	≦0.06	≦0.5
Maximum[1]	≦0.06	≦0.14	≦0.09	≦0.1	-
Goal for management	0.05	0.07	0.05	0.06	-

1) Maximum value of turbidities satisfied by over 95% in measurements

external and internal events in water quality continuously require the change of existing operation condition in unit process, addition of new unit process and modification of unit process (Carmen *et al*. 2018, Masaoki K *et al*. 2013, Shen *et al*. 2018, Nicolas *et al*. 2018, Alain *et al*. 2017). The performance of the total combined process can be maintained for the goal when the design and operation technology of the standard sand filter as a representative filtration is stabilized to remove the insoluble material sufficiently, including partial removal of soluble compounds. In addition, the sand filtration, which is essential for the water purification plants is still more economical to construct and operate than membrane filtration and adsorption process (Hoslett *et al*. 2018).

The status of water treatment processes in Korea summarizes in Table 1. When the total production capacity of the water treatment plants is divided by the applied capacity of the individual water treatment process, the rapid sand filter accounts for 56% and the advanced treatment process combined with a sand filter accounts for 40%. The sand filtration process still has a relatively high proportion of applications with 96% (Korean Ministry of Environment 2017). Therefore, it is still very significant to consider the optimization at the stage of design, construction, and operation for the sand filtration process. Water supply using the sand filter is still general in advanced countries like Korea and is actively applied into the developed countries with lower coverage of municipal water system. For the sustainability of sand filtration technology in the future, it is really required to perform continuous research on improvement and retrofit technology of sand filter.

The design and operation techniques of sand filters have been continuously accumulated and optimized through long operational experience. As a result, various case studies of retrofit of the sand filter have been introduced, verified and shared at on-site of waterworks. The filtration process shall produce filtrate to meet standard for Korean drinking water quality, especially for turbidity goal. Currently, municipal waterworks in Korea have applied stricter goals of final water turbidity more than the Korean standard of tap water (Table 2).

Therefore, it shall be possible to trap the floc and the particles within the sand filter medium, to satisfy buffering even under the variation of water quality and quantity, and to play backwashing to wash out the most trapped particles (Yu and Cho 1995). To satisfy these functions of sand filter, the design phase considers the size of filter medium, the composition and thickness of filter medium, the filtration rate, the backwashing method, etc.(AWWA and ASCE 2012, Qasim *et al*. 2000).

Filtration designs have been developed and are in use for slow sand, rapid sand, dual media, deep bed dual media, multimedia, downflow, up-flow, etc. In Korea, slow sand had evolved into rapid sand. Single media have been changed to dual and multi-media based on the philosophy of rapid sand filter. In recent deep bed designs using dual media are usually considered in new construction and retrofit works. As an advanced treatment process is demanded, especially for the algae blooming season, the multi-media filtration can respond to a large number of algae and by-products from algae, excellently remove the particles, and control microparticles (Zouboulis *et al*. 2007, Ongerth and Pecoraro 1995). Additionally, the dual and multi-media filters can provide high rates of filtration and produce more clean water in the same site, thereby enhancing the treatment capacity.

The configuration of the filter bed is crucial to the application of a multi-media filter in the newly constructed or retrofitted facility (Zouboulis 2007, Ongerth 1995, AWWA 2012, O'Melia *et al*. 1967). When a rapid sand filter consists of dual and multi-media with different gravities and effective sizes, some mixing in media inevitably occurs after repeated backwashing and even during filtration. But this can be managed by proper

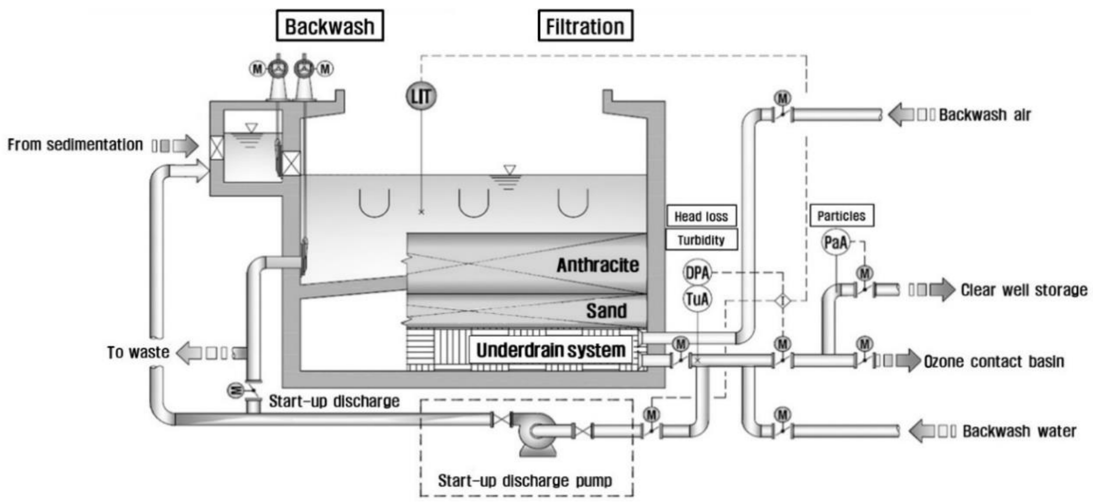

Fig. 1 Configuration and water flow concept of dual-media filter at the test bed

selection of the uniformity coefficients and effective size of the respective media. Also, operation conditions of the backwash process with the selected filter media can be carefully optimized to maintain reasonably well stratification of media layers. Therefore, a lab- or pilot-scale evaluation or sieve analysis of filter material at drinking water treatments is required in an examination phase or a basic design phase (Ahn and Yoon 2000, Shim 2011).

In this study, a controlled laboratory column tests using different filter media was conducted to identify the effect of media physical characteristics on filtration and backwash in a dual media filter. Also, the column device is transparent to show the fluidization of backwash and stratification after backwash. The apparent experimental results were used to determine the proper filter media before the media was deposited in the filter basin at a drinking water treatment.

Table 3 Specification of dual media filter at the test bed

Parameters	Specifications of design
Design capacity	Q=262,500 ㎥/day (1.05 times of facility capacity)
Size of basins	W 7.55m × L 16.5m, 10 basins
Filter bed configuration	Anthracite layer 900 ㎜ + Sand layer 300 ㎜
Filtration rate	210 m/day for 10 basins operation, 234m/day for 9 basins operation
Surface area of filter bed	124 ㎡(< 150 ㎡, Standard specifications of filtration)
Control of flow rate	Water level control type for controlling constant-rate filter
Backwash method	Backwash with simultaneous air and water

2. Materials and method

2.1 Characteristics of dual-media filter at the test bed

Table 3 presents the design specifications of the dual-media filter at the test bed which was designed to retrofit the existing rapid single media filter. Filter media should be chosen based on the given filter bed depth and filtration rate, resulting in the requirement of the filter column test. Especially, L/De value should be more than 1,000 in the case of dual-media filter, where L is media bed depth and De is the effective size of medium grain. The water treatment plant consists of three integrated treatment systems: pretreatment, dual media depth filter, and advanced water treatment. Surface water enters to a coagulation-flocculation and sedimentation basin followed by dual media filters. Raw water has high turbidity with hundreds of NTU during the rainy season and had ever clogged the filters by diatoms that occurred in the spring and autumn. In the winter, where the water temperature was lowered to 0 °C, the viscosity of bulk water increased, which resulted in the resistance in filtration.

Fig. 1 shows the configuration of dual-media filter at the test bed with retrofit, where the filter has an upper layer of anthracite and then a lower layer of silica sand. The larger size of anthracite permits a higher filtration rate and can carry solids more deeply into the filter media. A filter-to-waste flow system can be operated to prevent leak of turbidity from filtrate when the turbidity of filtrate is more than 0.1 NTU during the filtration right after backwash. Also, the filtration flow rate was controlled by adjusting the water level to respond stably to the variations in loads of feed water.

2.2 Experimental preparation and setup for filter column

The feed water of the column test was the same as the effluent of sedimentation from the test bed. The pre-treatment of the sand filter consisted of coagulation, flocculation and sedimentation. Table 4 shows the characteristics of water used for the column test. In this study, the performance of the column test was not evaluated in the terms of the water quality, because there were little difference on the removal of turbidity and TOC during the short operation period.

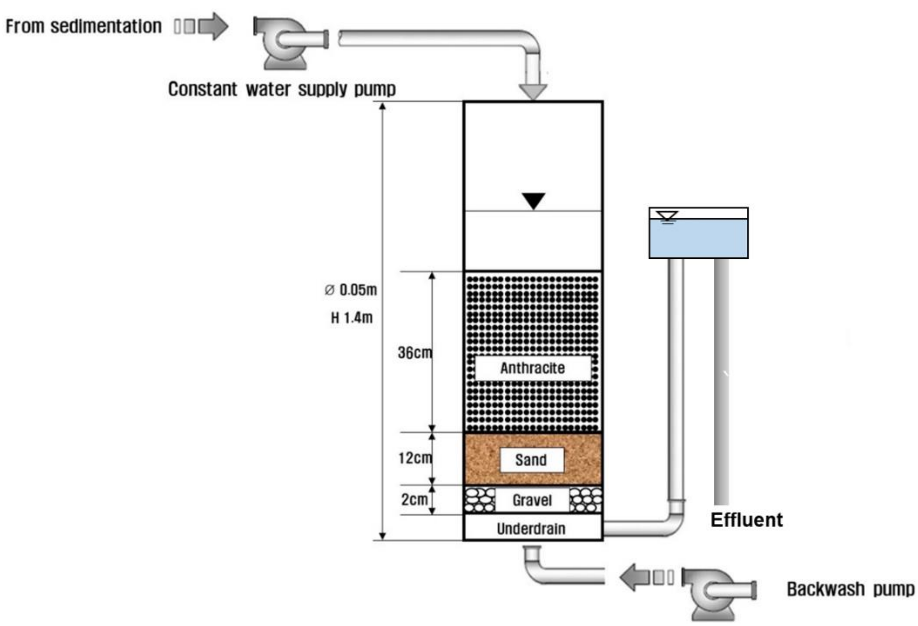

Fig. 2 Experimental setup of dual media filter column

Table 4 Characteristics of the feed water quality

Items	Raw water	Effluent of sedimentation	Filtrate of column
pH	6.8~7.3	6.6~7.2	-
Temperature (℃)	18.2~19.5	18.5~20.0	-
Turbidity (NTU)	10.1~12.3	0.08~1.0	0.05~0.06
TOC (mg/L)	2.55~3.24	1.50~1.80	1.48~1.69

Fig. 2 illustrates the filtration column set used in this experiment. The laboratory column device is of the dimensions Ø 0.05 m × H 1.4 m. The filter bed of the column device was filled with 12 cm of sand layer, and 36 cm of anthracite layer and had support media (gravel) under the sand layer. The depth of media was calculated based on the filter bed configuration of the dual-media at the case study of retrofit as shown in Table 3.

Media with two kinds of sand and anthracite were used to evaluate the filter run and the backwashing expansion ratio. Two kinds of sand with an effective size of 0.51 mm and 0.60 mm were also evaluated. Besides, the backwash expansion was evaluated according to the effect sizes of anthracite with 1.24 mm and 1.01 mm, respectively. The water level above the dual-media layer was controlled by setting the location of the effluent pipeline. Specifications for filter media generally follow the KWWA standard for granular filter material, KWWA F 100 and (Korean water and wastewater association 2009). The selection of filter materials requires physical and chemical characteristics including uniformity coefficient, effective size, specific gravity and acid solubility for their filtration methods. Table 5 summarizes the specification of common filter materials in a multi-media filter. Two or more materials should be selected within these general requirements of media in scope which is not very great in the differences.

Table 5 General requirements of filter materials in a multi-media filter

Filter material	Specific gravity	Effective size(mm) [1)]	Uniformity coefficient [2)]
Silica sand	2.55~2.65	0.45~1.0	≦ 1.7
Anthracite	≥ 1.4	0.7~1.5	≦1.5

1) A size opening that pass 10 percent of a representative sample of the filter (dry weight)
2) A ratio calculated as the size opening that passes 60 percent of a representative sample of the filter material divided by the size opening that just pass 10 percent of the same sample (dry weight)

The filtration rate of the experiment was based on 210 m/day of the design value at the drinking water treatment plant. Table 6 shows more detail operation conditions of the column test and experimental conditions for the filter bed expansion at different backwashing rates. Backwash water was only used to evaluate the bed expansion according to the backwashing flow rate. Filter bed expansion can be calculated by measuring the height of media expansion and total bed height such as Eq. (1). When the filter bed expansion becomes 20～30% during backwash in a dual-media filter, the layer separation between the applied media could occur.

$$\text{filter bed expansion (\%)} = \frac{height\ of\ media\ bed\ expansion(m)}{height\ of\ total\ bed\ (m)} \times 100 \qquad (1)$$

2.3 Hydraulic calculation of dual-media filter

When media materials are selected for dual-media filter at the site, the correlation between the used sand and anthracite in the filter bed and bulk should be calculated by

Table 6 Operation conditions of the experimental dual filter column test

Items	Experimental specification
Inflow rate	290 mL/min
Cross-sectional area of the filter column	0.002 m^2
Filter bed depth	Anthracite layer 36 cm + Sand layer 12 cm
Water level above filter bed	22 cm
Filtration rate	210 m/day
Conditions of backwash rate ($m^3/m^2\cdot min$)	0.65/0.70/0.75/0.80/0.85
Backwash flow rate to be adjusted (mL/min)	1,276/1,374/1,472/1,570/1,668

Table 7 Properties of sand media used in the experiment

Items	Korean Standard	On-site-Requirement	Sand A	Sand B
Specific gravity	2.55~2.65	2.63	2.61	2.62
Bed porosity (%)	50 or above	50 or above	50.4	54.2
Wear rate (%)	3 or below	3 or below	1.7	0.69
Effective grain size (mm)	0.45~0.7	0.55±0.05	0.51	0.60
Uniformity coefficient	1.7 or below	1.4 or below	1.31	1.31
Maximum grain size((mm)	2.0 mm or below	2.0 mm or below	1.34	1.17
Minimum grain size(mm)	0.3 mm or above	0.3 mm or above	0.31	0.44

Eq. (2), where the error on the left and right sides shall be within ±0.025(Korean Ministry of Environment 2014).

$$\frac{d_s \times UC_s}{d_A \times UC_A}(\text{Left} - \text{side term}) = \frac{(SG_A - SG_W)^{\frac{2}{3}}}{(SG_s - SG_W)^{\frac{2}{3}}}(\text{Right} - \text{side term}) \quad (2)$$

where, d_S = Effective grain size of sand (mm)
d_A = Effective grain size of anthracite (mm)
UC_S = Uniformity coefficient of sand
UC_A = Uniformity coefficient of anthracite
SG_S = Specific gravity of sand
SG_A = Specific gravity of anthracite
SG_W = Specific gravity of water (0.998 at a water temperature of 20°C)

The headloss in the dual-media filter system can be calculated using the specification of bed structure and the properties of media before operation at on-site. At the start of the filtration, hydraulic resistance occurs when water passes through the filter bed, which is referred to as the initial headloss, and calculated by Eq.(3) of Hazen and (4) of Darcy (Korean Ministry of Environment 2014).

$$k = c(0.7 + 0.03t){d_e}^2 \quad (3)$$

$$\Delta h = \frac{(L \times Q)}{(k \times A)} \quad (4)$$

where, k = coefficient of permeability (cm/s)
c = coefficient, 124 in case of the most sand filter media
t= temperature (℃)
D_e = Effective grain size of media (cm)
h = headloss(cm)
L =depth of filter media bed (cm)
Q = flow water (cm^3 /s)
A= area of filter bed (cm^2)

3. Results and discussions

3.1 Evaluation of the characteristics of dual-media filter

Table 7 shows the analysis of the sand media used in the experiment. The on-site requirements of sand material properties were more detailed and stricter than the general requirements from Korean standards. Sand A was the original medium to be delivered to meet the on-site requirement and Sand B was selected for retrofit the existing dual-media filter. Sand A and B were sufficiently satisfied with both requirements by Korean standard and on-site drinking water treatment. Sand typically functions as an underlying media and provides a finer filter media to stop solids passing through the anthracite of the upper layer. Larger effective size with 0.60mm (Sand B) was selected to compare the coarse-to-fine gradation and stratification of media layers during filter and backwash. Sand A had a greater difference between the maximum and minimum effective sizes than sand B.

Table 8 shows the analysis of the anthracite media used in the experiment. The on-site requirements of anthracite material properties were stricter than the general requirements from Korean standards, in the items of specific gravity and effective grain size. Anthracite typically functions ad a top coarse layer in dual media beds to provide a storage volume for a large amount of solids. Anthracite A satisfied the specification of the Korean standards, except for maximum grain size, however anthracite B satisfied all. Also, anthracite A could not satisfy the stricter specifications of specific gravity and uniformity coefficient required from the on-site water treatment plant. Anthracite B had larger specific gravity, lower effective size and uniformity coefficient than anthracite A. Besides, wear rate of anthracite A was measured somewhat highly at 2.4%. In this study, a combination of media mixture named A was filled in the column bed and compared with a media mixture B named.

3.2 Evaluation of filter run using different sand media

In the dual-media filter column experiment, the increase of water level above the media layer was evaluated according to the filter run time. The filtration flow rate was controlled by adjusting the water level in the water treatment plant, and the opening rate of the filter effluent valve was controlled to maintain a constant water level, thereby controlling the filtration flow rate. For the column experiment, constant flow rate maintained and variation of.

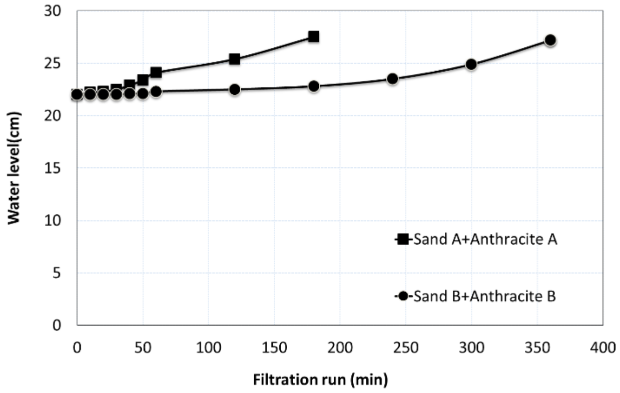

Fig. 3 Variation in water level above the filter bed

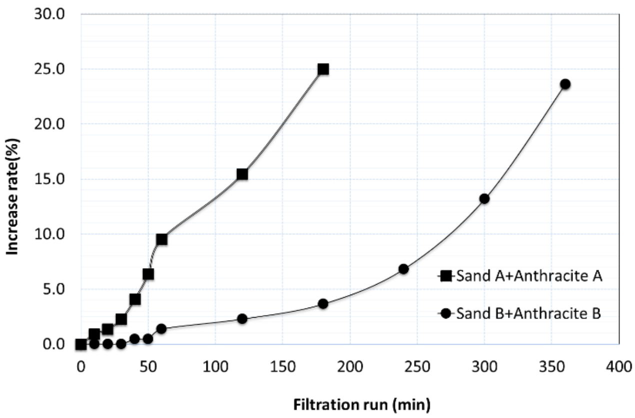

Fig. 4 Increase rate of head loss according to the combination of dual media

Table 8 Properties of anthracite media used in the experiment

Items	Korean Standards	Initial requirement	Anthracite A	Anthracite B
Specific gravity	≥ 1.4	≥ 1.6	1.53	1.70
Bed porosity (%)	≥ 50	≥ 50	50.4	54.2
Wear rate (%)	≤ 3	≤ 3	2.4	0.87
Effective grain size (mm)	0.7~1.5	1.0 ± 0.05	1.24	1.01
Uniformity coefficient	≤ 1.5	≤ 1.4	1.57	1.32
Maximum grain size((mm)	≤ 2.8	≤ 2.8	3.92	1.77
Minimum grain size(mm)	≥ 0.5	≥ 0.5	0.87	0.77

water level above the filter bed was monitored during filtration until the permissible water level was reaching.

Fig. 3 shows the results of the filter column experiment using sand A and anthracite A. The initial water level above the mixed bed was 22 cm. The water level and its increase rate were measured according to filtration time. The results showed that the water level increased exponentially until 60 min of filtration. Correspondingly, the water level increased by approximately 10% until 60 min of filtration as compared to the initial water level. When the filter run exceeded 180 min, the increase in water level was as much

Table 9 Theoretical estimations of head loss according to different effective sizes of media

Items \ Types of sand filter	Initial specification	Sand A+ Anthracite A	Sand B+ Anthracite B
Effective size of sand, de (mm)	0.055	0.051	0.060
Coefficient (c)	124	124	124
Permeability coefficient, k (cm/s)	0.4876	0.4193	0.6811
Head loss, h (cm)	16.69	19.41	11.95

Table 10 Bed expansion of dual-media filter according to backwash rate

Bed expansion (%) \ Backwashing rate (m/min)	0.65	0.70	0.75	0.80	0.85
Sand A+ Anthracite A	21.4	23.6	25.2	28.4	30.6
Sand B+ Anthracite B	18.6	20.4	22.3	23.8	25.1

as 25% and the filter run was stopped. When the filter column experiment was applied to the media mixture named B, the initial water level was maintained stable until the filter run of 30 min. Even when the filtration time was 60 min, the increase rate in the water level was only 2%. After 300 min of filtration, the water level above the filter bed increased by 10% as compared to the initial level. After 360 min of filter run, the increase rate of the water level was 25% and the filter run was stopped.

The newly combined filter bed with sand B and anthracite B could extend filter run up to 5 times until the water level increased by 10%, as compared to the case of existing filter bed with sand A and anthracite A(Fig. 4). Furthermore, the dual media filter with sand B and anthracite B could extend filter run 3 times than the existing dual media filter with sand A and anthracite A when the water level increased by 25%. The filter column test could not model the actual filter bed applied in water treatment plants, however, the difference between increases of water level in the different combinations of dual media could predict the shorter filter run and lower productivity. These results showed that the dual media filter with sand B and anthracite B functioned as a finer under laying sand media and as a top coarse layer in a dual bed.

3.3 Evaluation of loss head according to sand media

The increase rate in the water level during filtration varied depending on the type of sand medium. This was because the loss head varied according to the medium properties. In other words, the increase rate in the water level affected the filtration time, thereby impacting the filter performance. Theoretical estimations of the headloss was calculated with different types of sand filter using the Eq.(3) and Eq.(4). For the Darcy equation, flow rate (Q), depth of filter bed (L) and filter bed area (A) were applied with 0.271 cm^3/sec, 30cm and 0.49 m^2, respectively. Table 9 showed that the dual-media filter with sand B and anthracite B could maintain approximately 50mm lower head loss than

(a) Mixed layer formation using the dual media with sand A and anthracite A

(b) Stratified layer formation using the dual media with sand B and anthracite B

Fig. 5 Evaluation of dual-media bed stratification during backwashing

the existing one of sand A and anthracite A. In addition,when the water temperature was 5°C or below, the influence of viscosity increased and thus the head loss was expected to reach as large as 100mm.

3.4 Evaluation of filter bed expansion according to backwashing rate

Table 10 presents the result of the comparative analysis for the medium expansion ratios, which were obtained by applying various water-based backwashing velocity. The existing filter sand of grain size 0.55 mm showed an expansion ratio of 20% at the backwashing velocity of 0.65 m/min. However, considering the backwashing condition and safety factor at the real plant, the expansion ratio of 20–30% was expected to be maintained at 0.75–0.85 m/min of backwashing velocity. Regarding the new filter sand, the expansion ratio was over 20% at 0.70 m/min. However, the backwashing velocity was required to be set to at least 0.85 m/min or higher to conduct a stable backwashing process.

At the same backwashing velocity, the existing filter sand of grain size 0.55 mm showed approximately 3% higher expansion ratios than the new one with the grain size of 0.60 mm. Accordingly, when the new filter sand of grain size 0.60 mm replaced the existing one, the expansion ratio of 25% or higher could be achieved by increasing the existing backwashing velocity by 0.05 m/min.

3.5 Evaluation of expansion bed during backwashing according to properties of anthracite

The specific gravity and grain size of each medium in a dual-media filter affected the separation of layers during backwashing. This study evaluated the layer separation visually by filling two columns with the anthracite A and B, separately, and conducting a backwashing process. At the same backwashing velocity of 0.85 m/min, the anthracite A was mixed with filter sand owing to its specific gravity and maximum grain size as shown in Fig. 5(a). In other words, the layers were not well separated. After the backwashing process, the depth of the mixed layer was 5 cm or higher. As the specific gravity was below the requirement, the anthracite continued to be expanded and did not maintain its filtration layer but was mixed with filter sand. Additionally, as the maximum grain size of the anthracite was large, the filter sand permeated into the voids of the anthracite, which easily generated a mixed layer. Meanwhile, the anthracite B was slightly mixed with filter sand and the layers were stably separated during backwashing, as shown in Fig. 5(b). Consequently, when the specific gravity and the maximum grain size of anthracite exceed or are below the facility requirements, the anthracite is not well separated from filter sand during backwashing; however, a mixed layer is generated, which reduces the filter run time.

3.6 Correlation between sand and anthracite in the dual-media filter

Based on the correlation between filter sand and anthracite, the error range of ±0.025 must be satisfied with Standard Specifications for Water Supply Works (Korean Ministry of Environment, 2014). Accordingly, the correlation between the two media was analyzed using Eq. (2). The ideal and real correlation values were calculated based on the requirements of Korean standards, on-site

Table 11 Correlations between sand sizes and anthracite media

Items	Korean Standards	On-site Specification	Sand A+ Anthracite A	Sand B+ Anthracite B
Effective grain size of sand (mm)	0.55	0.50	0.51	0.60
Effective grain size of anthracite (mm)	1.00	0.97	1.24	1.01
Uniformity coefficient of filter sand	1.31	1.31	1.31	1.31
Uniformity coefficient of anthracite	1.39	1.39	1.57	1.32
Specific gravity of sand	2.63	2.63	2.61	2.62
Specific gravity of anthracite	1.68	1.68	1.53	1.70
Left-side term of Eq. (2)	0.518	0.486	0.343	0.590
Right-side term of Eq. (2)	0.559	0.559	0.478	0.572
Error	0.041	0.073	0.134	0.017

Table 12 The ratio of the media depth and the media effective size for filter designs

Filter Type	Material	Effective Size (de, mm)	Media Depth (L, cm)	Uniformity coefficient	L/de
Large dual-media	Anthracite	2.00	101.6	1.5	508
	Sand	1.00	50.8	1.3	508
Intermediate dual-media	Anthracite	1.48	76.2	1.5	515
	Sand	0.75	38.1	1.2	508
Mixed-media	Anthracite	1.00	45.7	1.5	457
	Sand	0.42	22.9	1.5	545
	Garnet	0.25	7.6	1.3	304
Dual-media at the test	Anthracite	1.01	90.0	1.32	891
	Sand	0.60	30.0	1.31	500

specifications, sand A+ anthracite A (existing dual-media) and sand B+ anthracite B (used for retrofit).

The evaluation of the correlation between filter sand and anthracite showed that the error range of ±0.025 was satisfied, which was required for the correlation between the sand B and anthracite B in the Standard Specifications for Water Supply Works (Table 11). The properties of sand B and anthracite B were proper for the given filter configuration within the error of 0.017 on the left and right sides of Eq. (2).

Filter efficiency is related to the physical characteristics of the filter bed that include the ratio of the media depth to media grain diameter (Kawamura S., 1975). A relationship between the depth of the filter media (L) and the effective size of the media (de) from filter designs in operation is summarized in Table 12. The average L/de ratio is around 1,020 and is based on the actual value of L and de. In this study at the test bed, the L/de ratio was greater with 1,391 (891 of anthracite and 500 of sand) because it had a smaller effective size of sand and deeper depth of filter bed, and lower uniformity coefficient of media than the other value suggested in the Table 12.

4. Conclusions

In this study, a series of controlled laboratory column tests conducted using different filter media to examine the effect of media property on filtering and backwashing in a dual media filter. The conclusions of this study can be summarized as follows.

1) When sand media of 0.51 mm in effective size was replaced by sand of 0.60 mm in the given depth of filter bed, the filtration run could be increased up 5 times, resulting in the improvement of filtration productivity. Lager effective grain size of sand within the given requirements could increase the porosity of filter bed and filter run time.

2) Change of filter media property required to optimize backwash rate of filter bed. In order to satisfy the bed expansion more than 20% during backwash, backwash rate should be increased when changing the effective size and specific gravity of dual-media.

3) When the anthracite was changed with lower effective grain size and uniformity coefficient, correlation with sand in the filter bed could be satisfied within the permissible error of ±0.025 mm between media and bulk characteristics. Also, the balancing between the sand and anthracite property in the given depth of filter bed, good stratification of dual-media bed could be identified right after backwash using the transparent dual-media filter column test.

4) The proper selection of anthracite media could provide the best performance of backwashing, resulting in a well-stratified configuration with media layers in filter bed expansion.

5) The results from the column test was important to decide the property of media before the selected media was applied to the real site

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