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Filter media washing prior to installation in stormwater treatment facilities

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ABSTRACT

As emphasized in various guidelines for the design of low impact development facilities, cleaning the filter media is a vital preparation step prior to installation to avoid sediment washout. In this study, a rudimentary media washing experiment was done to determine the cleaning intensity in terms of the volume of water needed per volume media. Eleven types of filter media, namely gravel, crushed rock, volcanic stone, coarse sand, vermiculite, zeolite, anthracite, bottom ash, woodchip, synthetic fiber, and pall ring, were studied. Also, basic cleaning models for each media were established for estimating wash water turbidity as a function of the cumulative wash water volume. The results revealed that vigorous manual washing by hand can clean gravel, crushed rock, volcanic stone, zeolite, and anthracite by 39% to up to 200% more as compared with simply passing water through an undisturbed column of the media. This is mainly due to the collision and abrasion causing the detachment of particles less than 20 μm during hand washing. Woodchip, synthetic fiber, and pall ring were proven to be relatively clean and do not need prior washing. For the rest of the media, it was recommended to use a volume of water that is 2–8 times the volume of the media to achieve a 90% decrease in the initial wash water turbidity or 5–11 times to achieve a turbidity less than 50 NTU. Moreover, empirical regression analysis shows that the wash water quality can be estimated by the volume of water used in cleaning the media and that the two parameters follow a power function whose coefficients increase with increasing difficulty of cleaning the media and the initial amount of attached solids on their surfaces.

Keywords: Filter media; Cleaning; Low impact development

1. Introduction

The success of stormwater treatment facilities in removing nonpoint source pollutants as well as in attenuating runoff volumes is directly related to the infiltration rate and permeability of the filter media used in their construction [1,2]. These properties are affected by several physical characteristics of the media and the required values are often provided in currently existing design guidelines and manuals to help in the design process [3–5]. As a result, suppliers in the industry offer products with different specifications to be able to provide the necessary materials that will meet the required hydraulic properties and pollutant removal capacity depending on the type of facility. These specifications are often tested and confirmed in laboratories before the delivery on site.

However, the filter media can be contaminated with dirt and fines during transport from the suppliers' storage to the construction site, as well as in the storage area at the site itself. Machines employed in handling the media could also add dust and other debris if not cleaned well before usage. This can compromise the cleanliness of the media which can affect its hydraulic properties once it has already been installed.

Although stormwater treatment design guidelines have always emphasized the usage of clean or washed media which are free from debris and other external materials, definitive measures or specifications regarding media cleanliness or washing have not been provided in any handbook [6–8]. Also, most of the literature at present discusses the mechanical washing of filtration systems or replacing the media after a period of usage to avoid clogging and treatment efficiency

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problems, but no study has asserted cleaning the media before its installation. Moreover, there is still a complete lack of published or agreed upon procedures in measuring the cleanliness of filter media [9]. Therefore, in this study, rudimentary or basic experiments were conducted to determine the cleaning requirements of different types of filter media. Empirical regression models were also established to be able to estimate the cleanliness of the media in terms of the wash water turbidity with respect to the volume of water used for washing.

2. Materials and methods

2.1. Filter media characterization

The study was conducted by investigating 11 types of commercially available media with grain size characteristics and porosities as shown in Table 1. Among all the media, gravel has the largest size followed by volcanic stone and crushed rock as indicated by the D_{10} (effective size), D_{50}, and D_{60} values. Uniformity coefficients ranging from 1.0 to 2.55 show that all the media are uniformly graded which is typical since these are commercial grade materials. On the other hand, porosities of the media ranged from 38.0% (coarse sand) to 93.2% (pall ring). Note that the media with higher uniformity coefficient and smaller size will tend to have a lower porosity because its grains can occupy more spaces when packed together in the column. Thus, coarse sand has the lowest porosity while pall ring, synthetic fiber, and woodchip had relatively higher porosities as compared with the other types of media. Furthermore, no pre-treatment procedure was applied to the media before they were subjected to the experiments.

2.2. Experimental setup and procedures

All the media were subjected to two types of cleaning procedure described as undisturbed column washing and manual hand washing. For column washing, 11 cylindrical columns were setup as shown in Fig. 1 containing the main media to be investigated and drainage layers at the top and bottom of the main media to facilitate the uniform distribution of flow and to avoid clogging as is typically set in the field. The configuration of the media was based on the recommended media layers of several low impact development manuals and guidelines from the United States and Canada [4,6,8]. Each column was fed with 2 L of tap water at an application rate of 2.8 mm/s (~250 m/d). This is the highest hydraulic loading rate that can be applied to all the columns without ponding. The tap water was allowed to gravitationally pass through the media creating a turbid wash water that was collected at the bottom of the column. Once the column has completely drained, a new batch of tap water was immediately fed to the columns. The feeding was done 10 times for a total wash water volume of 20 L. Samples of wash water from each cycle were collected for turbidity measurement and particle size distribution analysis.

For the hand washing procedure, a new batch of media with the same volume as that used in column washing was put in a rectangular strainer inside a container and were subjected to vigorous hand washing while spraying wash water for several cycles using a shower head (Fig. 1). To ensure the uniform distribution of water during each washing cycle, the shower head was moved from side to side while the media

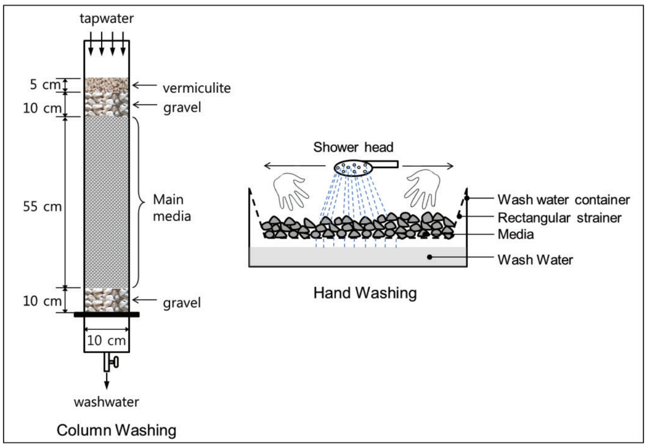

Fig. 1. Schematic diagram of the media cleaning procedures conducted.

Table 1
Grain size distribution and porosities of the media evaluated

Media	D_{10} (mm)	D_{50} (mm)	D_{60} (mm)	U[a]	Porosity (%)
Gravel	25.0	42.0	60.0	2.40	47.1
Crushed rock	15.0	22.0	33.0	2.20	54.1
Volcanic stone	23.0	42.0	58.0	2.52	62.5
Coarse sand	1.1	2.4	2.8	2.55	38.0
Vermiculite	6.0	7.8	8.0	1.33	69.6
Zeolite	4.5	6.0	6.8	1.51	60.2
Bottom ash	5.0	6.0	6.4	1.28	60.0
Anthracite	4.9	6.5	7.0	1.43	49.7
Woodchip	11.0	20.0	21.0	1.91	78.9
Synthetic fiber	10-cm diameter, 4-cm thick disks			1.00	90.1
Pall ring	2-cm diameter, 3-cm length tubes			1.00	93.2

[a] Uniformity coefficient (D_{10}/D_{60}).

were being mixed by hand in a specified time based on the flow rate of the shower head to ensure the usage of 2 or 4 L of water depending on the type of the media. After each cycle, the wash water collected in the container were also sampled for turbidity and particle size distribution analysis. This washing cycle is repeated until the wash water turbidity is less than 10–50 NTU.

A scattered light turbidimeter, 2100N Laboratory Turbidimeter (Hach Company, Loveland, Colorado, USA), was used to measure the turbidities while a laser-based particle size analyzer, PSS Accusizer^{TM} 780, was used to determine the particle size distribution. To establish possible equations relating the wash water quality to the volume of wash water, empirical regression analysis was conducted between the ratio of the wash water to tap water turbidity, C/C_0, and the ratio of the cumulative wash water volume to the volume of the media, V_{water}/V_{media}.

3. Results and discussion

3.1. Undisturbed column washing vs. hand washing

Fig. 2 shows the trend of the wash water turbidities from the undisturbed column washing procedure. Very high turbidities were observed in the initial wash water especially from vermiculite, zeolite, and anthracite, with 3,256; 3,280; and 2,475 NTU, respectively. This indicates a large number of fines that were attached to these media during its original condition. A sharp decrease in turbidities was observed during the second pass with a relatively gradual decrease during the succeeding passes. Relatively lower, but still considered very turbid wash water, were observed in the other columns.

The wash water from woodchip, synthetic fiber, pall ring, and bottom ash became clear (<50 NTU) after passing water that is twice the volume of the media while the rest took three to more than four times the volume to achieve a clearer wash water turbidity. Thus, it is apparent that employing materials in water treatment beds without proper cleaning can cause a large amount of turbidity causing solids to be washed out from these systems during the initial operation thereby contributing more particles instead of filtering them out from stormwater.

However, in spite of the washout of a significant amount of dirt as well as the low wash water turbidity at the end of the procedure, undisturbed washing by feeding tap water through the column was found to be insufficient to clean the media. When a fresh batch of media of the same volume was subjected to vigorous hand washing, a much larger amount of fine sediments were removed causing higher wash water turbidities, and the results are summarized in Table 2. The highest initial wash water turbidity came from anthracite at 6,140 NTU, followed by zeolite at 4,869 NTU, crushed rock at 3,625 NTU, and vermiculite at 3,390 NTU. Including gravel and volcanic stone, this corresponds to 39%–200% more washed out fines as compared with simply passing water through an undisturbed column of the media.

It is expected that manual washing by hand should remove more solids from the surface of the media because of several reasons. During hand washing, the grains of the

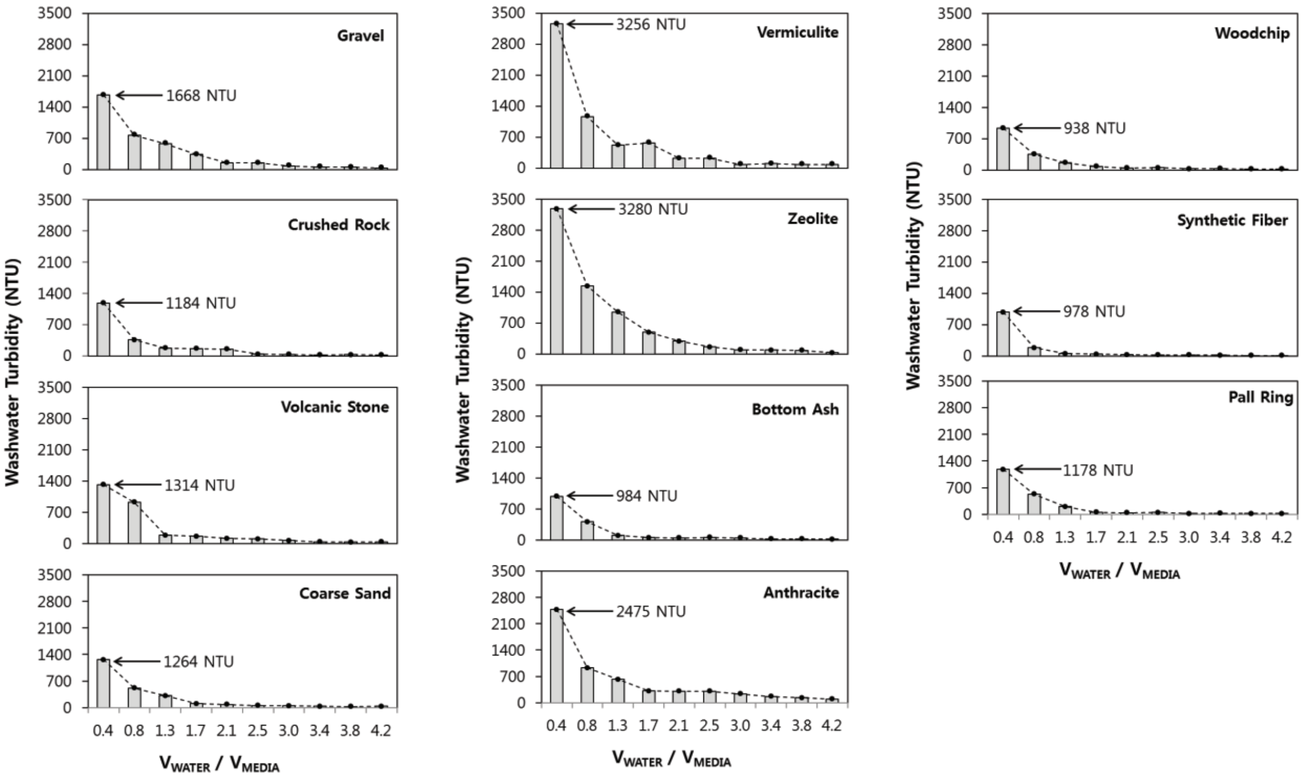

Fig. 2. Wash water turbidity with respect to the wash water ratio during undisturbed column washing.

Table 2
Summary of the results of the hand washing experiment

Media	Wash water turbidity (NTU)		Relative reduction (%)	Total volume used (L)	V_{water}/V_{media} at 90%	V_{water}/V_{media} at <50 NTU
	Initial	Final				
Gravel	2,320	37.0	98.4	52	2.5	10.2
Crushed rock	3,625	36.0	99.0	40	2.5	6.8
Volcanic stone	1,902	39.0	97.9	52	8.5	11.0
Coarse sand	353	28.9	91.8	28	5.9	5.9
Vermiculite	3,390	35.7	98.9	44	6.8	9.3
Zeolite	4,869	52.5	98.9	52	7.6	11.0
Bottom ash	368	36.2	90.2	20	4.2	4.2
Anthracite	6,140	37.9	99.4	40	2.5	4.2
Woodchip	46.5	8.2	82.4	14	3.4	–
Synthetic fiber	19.1	5.1	73.3	10	2.5	–
Pall ring	3.1	0.9	70.5	10	2.5	–

media are subjected to collision and abrasion which enhances the detachment of solids from its surfaces. Also, a uniform hydraulic shear is applied throughout the hand washing process whereas this cannot be achieved during column washing. Since the tap water is applied at the top of the column, the velocity of the water is maximum at that point. However, it tends to get lower as the tap water passes through due to head losses and the resistance of the media itself. Therefore, the media at the lower part of the column may not be subjected to the same hydrodynamic shear as those that are at the top of the column. In addition, the tap water application rate of 2.83 mm/s (~250 m/d) is lower as compared with the velocities usually used in backwashing mechanisms for filters [10,11] and may not cause a stronger hydraulic force than the adhesive forces between some particles and the surface of the media. In fact, the undisturbed condition inside the column is not conducive for cleaning since granular filter media are typically subjected to fluidized bed backwashing and that process also does not typically dislodge a significant number of particles from the surfaces of media [12]. Moreover, it is possible that some of the solids that were removed at the top of part of the media have been trapped at the lower part and are therefore not removed from the system. Nevertheless, undisturbed column washing was done to determine the amount of particles that can be washed out from the media and to compare it with the alternative manual hand washing procedure.

Oppositely, relatively lower initial turbidities were observed from coarse sand, bottom ash, woodchip, synthetic fiber, and pall ring as compared with that when they were column washed. This means that during column washing, some solids were also removed from the media in the drainage layers at the top and bottom of the columns and were accounted for in the observed turbidities. As shown in the previous section, the materials used in the drainage layers were gravel and vermiculite which were apparently among the types of media initially containing a lot of dirt attached to their surface. Notably, woodchip, synthetic fiber, and pall ring produced initial wash water turbidities of 46.5, 19.1, and 3.1 NTU, respectively during hand washing, and these turbidities continued to decrease with each washing cycle. This means that these types of media may not need washing prior to application in treatment facilities. One possible reason is that synthetic fiber and pall ring are plastic materials and often come in packagings that are not susceptible to accumulate dirt during transport. Woodchip also does not come from materials that produce fine solids when subjected to abrasion. Therefore, these media were relatively easier to clean as compared with the other types of media. However, the conditions to which filtering materials are subjected from processing and distribution can be different from place to place.

Relative reductions in turbidities were also computed to represent the fraction of removed turbidity with respect to that of the initial wash water. Table 2 shows that the turbidities were reduced by more than 90% for all the media except woodchip, synthetic fiber, and pall ring. These percentages do not represent the fraction of the solids removed from the media but rather the comparison of the final to the initial turbidities. It should be noted that determining the percentage of solids removed from the media is impossible since the initial amounts are unknown. Thus, the values shown merely expresses how well each media have been washed, with respect to the initial wash water turbidity. This also explains the lower percentages achieved for woodchip, synthetic fiber, and pall ring since the initial turbidities were low.

In terms of the total volume of water required for cleaning, it appears that gravel, volcanic stone, zeolite, vermiculite, crushed rock, and anthracite required the largest volume of more than 40 L corresponding to V_{water}/V_{media} of 8.5–11. However, to achieve a 90% relative reduction of turbidity, only volcanic stone, vermiculite, and zeolite required larger volumes of water with V_{water}/V_{media} values of 8.5, 6.8, and 7.6. On the other hand, to achieve a turbidity of less than 50 NTU, volcanic stone, vermiculite, zeolite, gravel, and crushed rock required 11, 9.3, 11, 10.2, and 6.8 times of water, respectively. Since woodchip, synthetic fiber, and pall ring were relatively clean, only 10–14 L of tap water were used for washing. Anthracite appeared to have the most turbid wash water among all the media but required less water to achieve a turbidity of less than 50 NTU. Therefore, in terms of the volume required for hand washing, bottom ash, coarse sand,

and anthracite are recommended. For the types of media that do not need vigorous manual washing, woodchip, synthetic fiber, and pall ring are suggested.

After hand washing and drying, the media were once again setup for the same column washing procedure. As a result of cleaning prior to installment, relatively clearer wash water was observed when tap water was passed through the media. As shown in Fig. 3, the initial wash water turbidity from all the media was less than 100 NTU corresponding to a reduction in the initial wash water turbidity of 94.2%–98.5% as compared with that when the media were not hand washed. However, in the case of woodchip, synthetic fiber, and pall ring, the initial turbidities were higher as compared with that when they were hand washed. This indicates that solids were washed out not only from the main media but also from the drainage layer mainly. Thus, the materials used for these layers, which are gravel and vermiculite, should undergo further cleaning to avoid compromising the whole system or should be replaced with alternative materials that are easier to clean. Nevertheless, the great reduction in the washed out solids shows the significance of washing the media in a vigorous manner before putting them in any water treatment facility.

3.2. Comparison of particle size distribution

The results showing turbidities were confirmed by comparing the particle size distribution difference between the wash water from undisturbed column washing and that from hand washing as presented in Fig. 4. It is evident that more particles especially those between 0.5 and 20 μm were removed by hand washing from all the media except for coarse sand, bottom ash, and woodchip. It has been previously reported that larger sized particles can be easily detached or released from surfaces by hydrodynamic forces because they experience a larger drag force [12]. Therefore, smaller sized particles require stronger forces to be able to be detached from media surfaces.

For coarse sand, bottom ash, woodchip, synthetic fiber, and pall ring, the higher concentration of particles from column washing also supports the higher turbidities that were previously observed and the fact that the solids came mainly from the gravel and vermiculite at the drainage layers in the column. The particle counts are somewhat varying even though the volume of media used for these layers are the same for all the columns because of the filtering capability of the different types of main media. It should be noted that during column washing, these layers were included at the top and bottom of the main media to facilitate proper drainage and avoid clogging. Thus, they cannot be removed from the configuration but can be further cleaned or replaced by other types of media that can cause less washout of particles.

Based on the results of the experiments, the different types of media were grouped in terms of the V_{water}/V_{media} required to achieve a clear wash water turbidity. Table 3 shows that among all the media, woodchip and bottom ash required the least amount of water with V_{water}/V_{media} of 1–2. Crushed rock, which is a commonly used media, is among those that produced the highest initial wash water turbidity but needs only moderate washing with V_{water}/V_{media} of 3–6 together with anthracite and coarse sand. Meanwhile, pebblestone, volcanic stone, vermiculite, and zeolite belonged to the group requiring the highest amount of water needed for cleaning.

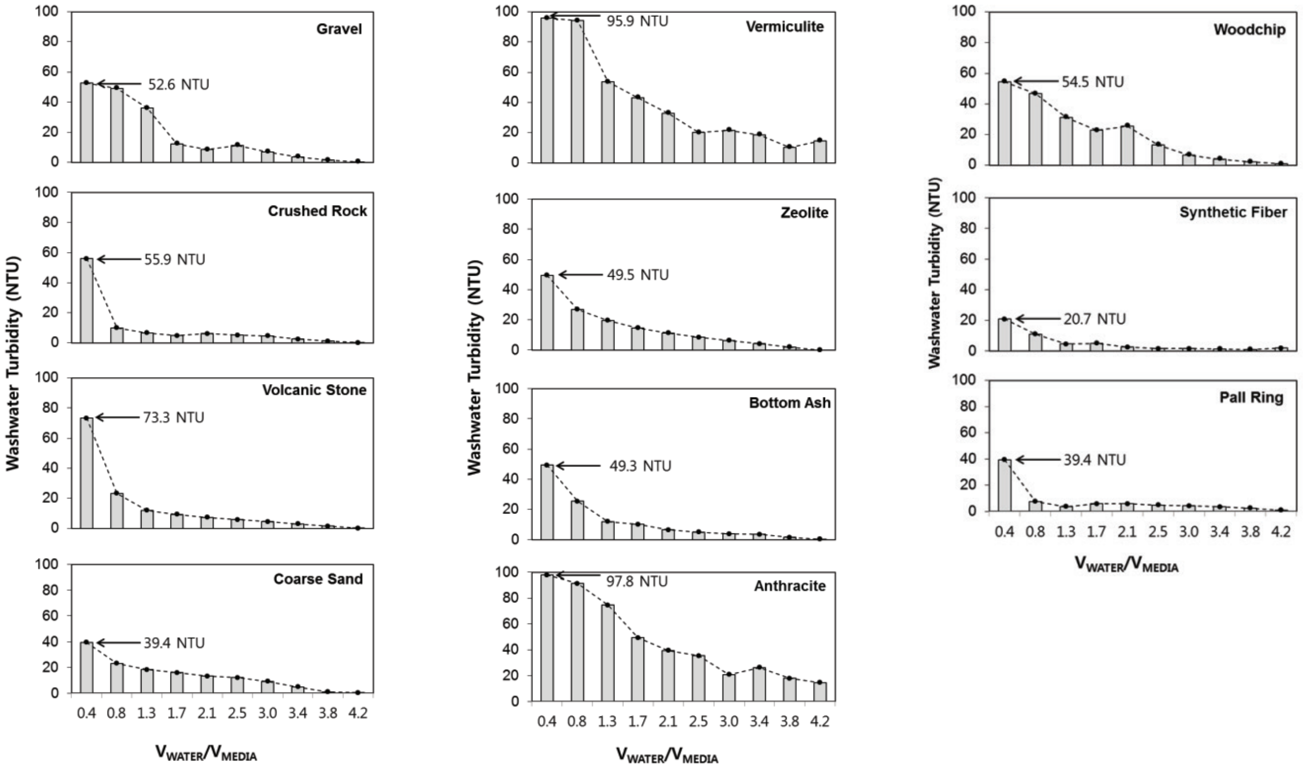

Fig. 3. Effluent turbidity with respect to the wash water ratio during manual hand washing.

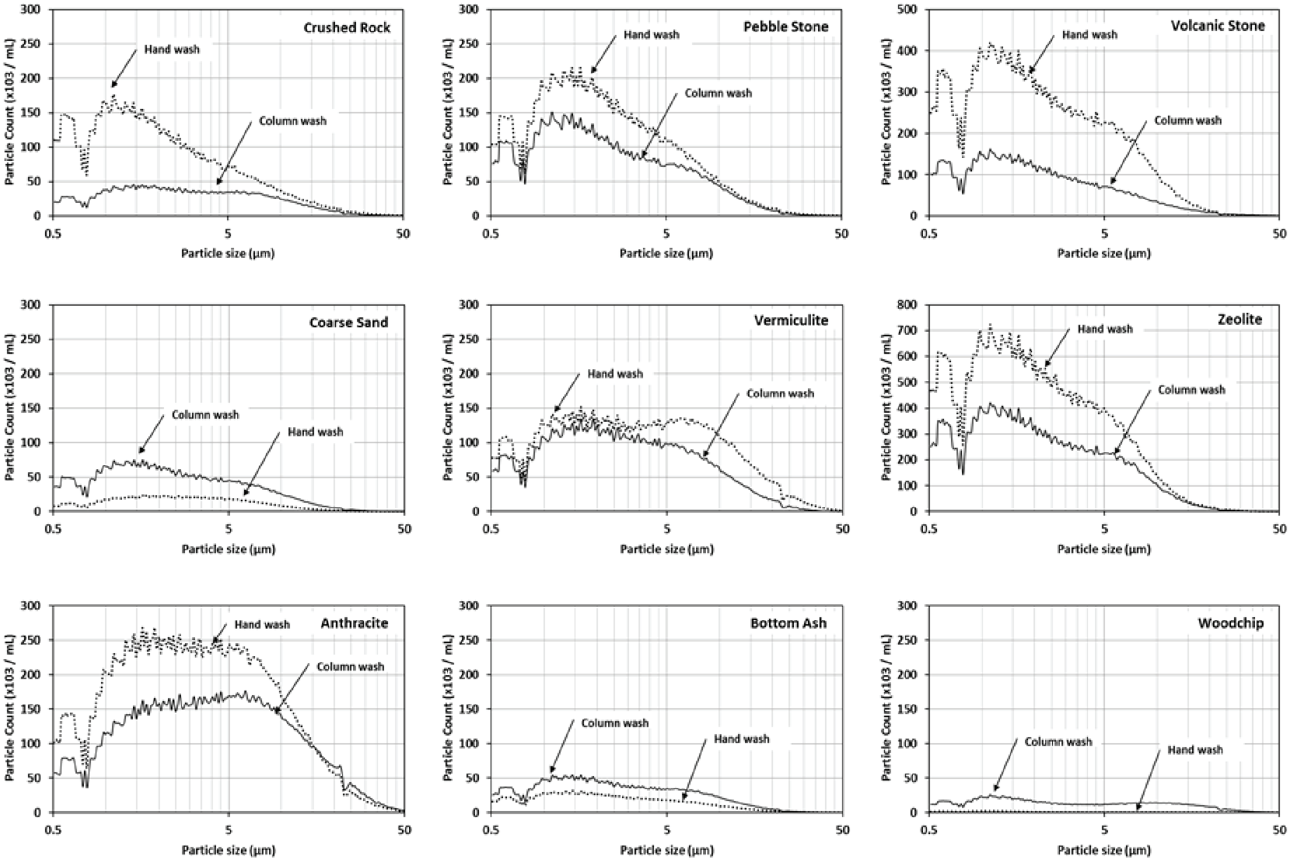

Fig. 4. Size distribution of particles in the initial wash water from column washing and hand washing of different media.

3.3. Empirical regression models and washing coefficients

It has been reported in previous literatures that the quality of the wash water is related to the volume of water used to clean the media. Amirtharajah [13] formulated an equation based on Nelson and Galloway's [14] mass transfer theory for the fluidized bed which considers the transfer of particles across a film around a collector (media) through diffusion. According to this equation, as an arbitrary volume of liquid traverses a bed, it would accumulate particles detached from the media surfaces. He also found out that the terminal wash water quality is dependent only on the total wash water volume as long as the washing mechanism remains unaltered. Thus, washing velocity and time were not considered as defining variables for this study. In addition, Niu et al. [15] reported a direct proportionality between the recovered solids and the cumulative washing water volume during the cleaning of porous synthetic fiber filter.

To determine the relationship between the wash water turbidity and cumulative wash water volume for the evaluated media in this study, the logarithmic values of C/C_0 and V_{water}/V_{media} for a sample media, gravel, is plotted and shown in Fig. 5. C_0 represents the turbidity of the tap water used for washing, C is the turbidity of the wash water, and V_{water} is the cumulative volume of wash water used to clean a certain volume of the media, V_{media}. As shown in Fig. 5(a), the logs of the two ratios were interrelated linearly with an R^2 value of 0.941. This means that they have a strong log–log relationship that can be represented by Eq. (1). In this equation, b is the slope of the linear correlation and log(a) is the y-intercept. The coefficient a can be considered as the washing coefficient whose value is higher if the number of particles attached to the media is higher. This means that more particles can be detached during the first few washing cycle resulting in the higher turbidity of the wash water. Oppositely, lower a values signify a relatively cleaner media resulting in a lower amount of detached particles during cleaning. On the other hand, b represents the rate at which the media can be cleaned. Thus, higher b values mean that the media is easier to clean while lower b values mean that the media is more difficult to clean and the volume of water needed to achieve a target final wash water turbidity is larger.

Table 3
Grouping of the media studied based on V_{water}/V_{media} ratio

Needs minimal washing (V_{water}/V_{media} = 1–2)	Needs moderate washing (V_{water}/V_{media} = 3–6)	Needs strong/intense washing (V_{water}/V_{media} = 7 or more)
Synthetic fiber	Crushed rock	Pebblestone
Pall ring	Coarse sand	Volcanic stone
Woodchip	Anthracite	Vermiculite
Bottom ash		Zeolite

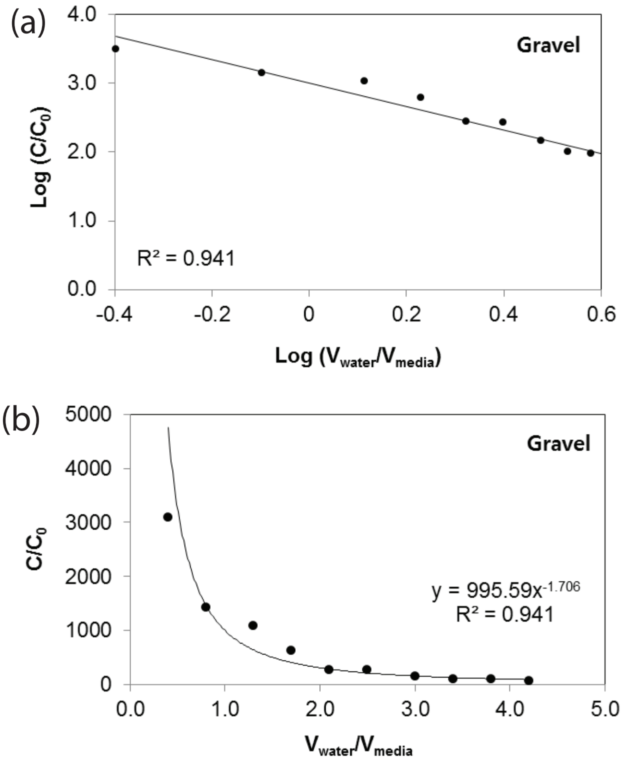

Fig. 5. (a) Log–log and (b) corresponding power relationship between the wash water turbidity and cumulative wash water volume.

$$\log\frac{C}{C_0} = \log(a) + b * \log\left(\frac{V_{\text{water}}}{V_{\text{media}}}\right) \quad (1)$$

$$\frac{C}{C_0} = a\left(\frac{V_{\text{water}}}{V_{\text{media}}}\right)^b \quad (2)$$

If Eq. (1) is transformed, a power regression equation will be achieved as in Eq. (2) corresponding to a trendline as shown in Fig. 5(b). This equation was used for the rest of the media types and the trendlines showing the power relationship between C/C_0 and $V_{\text{water}}/V_{\text{media}}$ for each type of media were also plotted. Fig. 6(a) shows the trend for column washing without prior hand washing while Fig. 6(b) shows the trend during column washing after the media had been hand-washed. It can be observed that for both conditions and for all of the media, the relationship of the two ratios follows a power function. This is due to the relatively high turbidity of the wash water during the first cycle followed by a sudden large decrease in the second cycle and gradual decrease in the succeeding cycles.

Also, it can be seen that the trendlines for zeolite, vermiculite, and anthracite in Fig. 6(a) were higher than the other trendlines corresponding to their high *a* values as shown in Table 4 and indicating that they are the ones that initially contained more particles on their surfaces. In Fig. 6(b), the gap between the trendlines of vermiculite and anthracite from those of the other media corresponds to their lower *b* values signifying a slower rate of detachment of particles for each washing cycle, again, indicating that they are more difficult to wash.

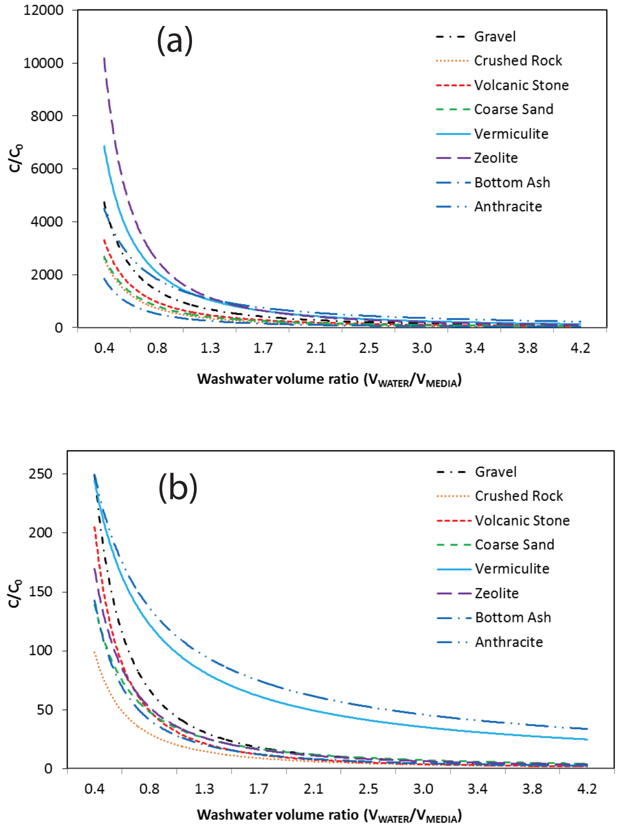

Fig. 6. Power regression trendlines showing the relationship between the ratio of the wash water to tap water turbidities and the ratio of the wash water to media volumes: (a) without hand washing and (b) after hand washing.

Table 4 also shows that column washing without prior hand washing produced a stronger power relationship between C/C_0 and $V_{\text{water}}/V_{\text{media}}$ with R^2 values ranging from 0.93 to 0.97, as compared with hand washed media, and creates a similar rate of decrease in wash water turbidity for all types of media as shown by the *b* values. After hand washing, the R^2 values somewhat became lower except for volcanic stone, vermiculite, and bottom ash probably due to the relatively cleaner condition of the media after hand washing. Nonetheless, the power regressions were still strong for all the media.

4. Conclusions and recommendations

The results of the study emphasize on the necessity of pre-cleaning filter media employed in most stormwater treatment facilities. It reveals that turbidity causing dirt and fines attached to the surface of the media can be potentially removed to up to 200% more by vigorous manual washing as compared with undisturbed column washing because of increased collision and abrasion between media surfaces that can detach more particles smaller than 20 μm. Depending on the type of the media, the amount of water

Table 4
Empirical regression analysis for each type of media

Media	Without hand washing			After hand washing		
	a	*b*	R^2	*a*	*b*	R^2
Gravel	995.6	–1.706	0.94	46.1	–1.464	0.81
Crushed rock	509.8	–1.787	0.94	21.1	–1.314	0.86
Volcanic stone	688.0	–1.736	0.95	33.0	–1.515	0.96
Coarse sand	580.1	–1.688	0.97	35.7	–1.154	0.65
Vermiculite	1499.7	–1.676	0.96	101.1	–0.968	0.97
Zeolite	1725.4	–1.944	0.93	37.4	–1.259	0.88
Bottom ash	367.5	–1.792	0.96	29.5	–1.413	0.95
Anthracite	1427.2	1.266	0.97	115.2	–0.846	0.88

needed to reduce the wash water turbidity by 90% is 2–8 times the volume of the media, while that needed to achieve a wash water turbidity less than 50 NTU is 5–11 times the volume of the media. Moreover, the amount of water required for washing can be estimated by empirical regression equations showing a power relationship between the wash water turbidity and cumulative wash water volume given that the washing procedure and volume used for each washing cycle is the same as what was conducted in this study. In terms of the ease in cleaning as well as in the amount of water required for washing, bottom ash and coarse sand are the recommended filter media to be used with 4–6 times volume of water required. Woodchip was relatively clean in terms of the wash water turbidity but should be checked for larger debris and woody materials before installation. Synthetic fiber and pall ring were also promising materials and may not need prior washing if properly packed and stored.

These results are empirical and the values obtained are rough estimates determined from a rudimentary washing experiment. These can vary depending on different factors such as the washing procedure, the type of the media, the source of the material, the processes it underwent, and the initial conditions and handling between production and delivery to the construction site. Moreover, the study was preliminary. Thus, several other considerations including the surface roughness of the media as well as the forces of interaction and mechanisms by which particles are detached from surfaces can be investigated and taken account of.

Acknowledgments

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