original article

Necessity for replacing the filter media in the water treatment plant based on effective size and uniformity coefficient

Mohsen Memarzadeh[1], Mohammad Mehdi Amin[2], Hossein Mostafavi[1], Reza Kolivand[2], Mohsen Heidari[2,3]

[1]Isfahan Water Treatment Plant, Isfahan Water and Wastewater Company, Isfahan, Iran, [2]Environment Research Center, Isfahan University of medical Sciences (IUMS), Isfahan, Iran and Department of Environmental Health Engineering, School of Health, IUMS, Isfahan, Iran, [3]Department of Environmental Health Engineering, School of Public Health, Hormozgan University of Medical Sciences, Bandar Abbas, Iran

ABSTRACT

Aims: This study aims to compare the parameters in filtration unit of the plant with international guidelines. The results of this study would determine the necessity for replacing or renewing the anthracite and sand filter beds in phase I of IWTP.

Materials and Methods: In this field study, a total of 11 samples with a mass of 5 kg sand and anthracite media were analyzed. The media samples were evaluated in view of uniformity coefficient and effective size according to international soil classification. Data obtained were statistically analyzed using *t*-test at significance level ($P < 0.05$).

Results: Results of this study showed that the uniformity coefficients of anthracite and sand media were 3.6 ± 0.4 and 1.93 ± 0.11 mm, respectively. Also, the effective sizes of anthracite and sand media were 0.68 ± 0.08 and 0.63 ± 0.05 mm, respectively. These values exceeded the international guidelines and had a significance difference with them (*P*-value < 0.05).

Conclusion: The results were shown that the uniformity coefficient and effective size of sand and anthracite media in the filters used in phase I of IWTP exceeded the guidelines and they need to be replaced with new media. Finally, based on the current study, filter beds were renewed.

Key words: Isfahan water treatment plant, anthracite, sand, effective size, uniformity coefficient

Address for correspondence:
Eng. Mohsen Heidari,
Isfahan University of Medical Sciences,
Hezar Jerib Avenue, Isfahan, Iran.
E-mail: moheidari84@gmail.com

INTRODUCTION

Clean and safe water availability has continued to be an issue in the 21st century.[1] Water is getting polluted due to rapidly increasing population, urbanization, construction of new buildings, and deforestation. Consumption of such unsafe drinking water may cause a high proportion of the community to be exposed to the risk of outbreaks of intestinal and other infectious diseases. Hence, water pollution is a global problem threatening human existence.[2] At the turn of the millennium, the World Health Organization (WHO) and United Nations Children's Fund (UNICEF) estimated that about 1.1 billion people worldwide (mainly in developing countries) lacked access to safe water.[3,4] In addition, it was reported that about 3 billion people lack permanent access to safe water due to failing water supply systems and about 5000 people worldwide die from diarrhea every day.[5,6] Also, the lack of both safe water and sound sanitation is estimated

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to be responsible for annual health treatment costs of US$ 7.5 billion.[7] In fact, there can be no state of positive health and well being without safe water.[2]

The United Nations established the Millennium Development Goals (MDGs) with emphasis on water to accelerate progress toward universal access to water. The seventh (principle) goal of the MDGs is to ensure environmental sustainability by halving the proportion of the world's population without access to safe water by 2015.[3,4] Therefore, water to be supplied for public use must be satisfactory for drinking purposes in light of its chemical, physical, and biological characteristics. However, the raw water usually available from surface water sources is not directly proper for drinking purposes.[8] This scenario calls for efficient and effective treatment of water before use to avoid occurrence of water-borne and water-related diseases such as cholera and typhoid fever.[9] Water treatment plants with good design, construction, and operation are expected to provide safe and esthetically acceptable water to consumers.[10] In providing water on a large scale, conventional treatment units and processes including coagulation, flocculation, sedimentation, rapid filtration, and disinfection are mostly used.[9]

In a typical water treatment plant, filtration has usually been considered as the most important step in providing potable water. This step significantly enhances the quality of water by removing most suspended particles and bacteria present in the water, making it nearly potable.[11,12] This polishing process involves passing the water through a layer of porous granular material that result in the removal of suspended solids by trapping them in the pore spaces of the filter media.[13] Filtration involves a combination of complex physical and chemical mechanisms including straining, interception, diffusion, inertia, settling, and hydrodynamic action.[12] The main goal of any filtering devise is to remove as much harmful bacteria as possible. Although turbidity of drinking water does not directly affect people's health, it can be masking harmful bacteria. Therefore, removing turbidity helps to achieve this goal by leaving bacteria in the open and clearing the water to allow different methods (especially disinfection) to do a more thorough job of removing bacteria without being disturbed by dirt particles.[1] On the other hand, the physical removal of particles that may harbor viruses from disinfectants is thought to be a crucial barrier against the viral contamination of drinking water, especially when treating source waters of variable particulate quality.[14] Basically, the main goal of basic water filtration is to reduce the turbidity that consists of suspended particles (fine silts and clays), biological matter (bacteria, plankton, spores, cysts, or other matter), and floc.[1]

The selection of the filter type implicitly specifies the media type and its size distribution. The grain size distribution plays a strong role in the trade-off between headloss (larger media minimize headloss) and filtration efficiency (smaller media capture particles better). The primary design criteria and grain size distribution factors are effective size (ES) and uniformity coefficient (UC).[15] The effective size is the 10 percentile size, that is, the media grain diameter at which 10 percent of the media by weight is smaller, d_{10}. The uniformity coefficient is the ratio of the diameter of media at which 60 percent by weight is smaller to the 10 percentile sizes, d_{60}/d_{10}. Use of the 10 percentile was suggested by Allen Hazen. He observed that resistance to the passage of water offered by a bed of sand within which the grains are distributed homogeneously remains almost the same, irrespective of size variation (up to a uniformity coefficient of about 5.0), provided that the 10 percentile remains unchanged.[15-17]

One of the key units of Isfahan Water Treatment Plant (IWTP) is filtration system in which the filter media consist of two layers of anthracite and sand. Since the filtration system in phase I of IWTP has been used for more than two decades, its efficiency to remove turbidity and biological organisms might have reduced, which necessitates their replacement. With respect to the importance of effective size and the uniformity coefficient in regulating of filter headloss, backwashing process, and especially efficiency of filtration system, this study aims to compare the parameters in the filtration unit of IWTP to international criteria. The results of present study would determine the necessity of replacing or renewing the filter media in IWTP.

MATERIALS AND METHODS

Site description

The IWTP (32° 23′ 49 North 51° 17′ 36 East) is located at 55 km southwest of Isfahan city (in the central plateau of Iran) that supplies water for Isfahan city, 40 neighborhood cities, more than 400 villages, and a large number of industries in Isfahan province.

The IWTP serves a population of around four million people with a design flow rate of 12.5 m^3/s, through two phases (6 m^3/s and 6.5 m^3/s).[18] The plant consists of a multi-stage process including screening, flash mixing unit, circular clarifiers (including flocculation and sedimentation), dual-media filtration system, and disinfection unit as the final step [Figure 1]. Both phases are basically similar with an exception; the disinfection unit in phase I is chlorination, while ozone is applied to disinfect filtrate water in phase II. The filtration system in phase I involves 20 dual-bed filters (an upper layer of anthracite and a lower layer of sand) that have been in service for more than two decades.

Sampling and analyses

This full-scale study was conducted on the IWTP during 2008. A total of 11 samples were taken from middle depth of filters' media in phase I. A mass of 5 kg samples was analyzed in the points of physical properties including effective size (ES) and uniformity coefficient (UC).

After washing in a portable column, the media samples were placed in an oven for 24 h at 110 °C. The samples were weighed and transferred to the top sieve of an assembly of weighed US standard sieves (200 mm in diameter and 50 mm in height) with the following mesh sizes: bottom pan, 250 to 2800 μm, as well as a top lid. The samples were sieved for 6 min using a sieve shaker with automatic timer and the new mass of each sieve was determined to the nearest 0.01 g. As noted previously, effective size is the media grain diameter (or mesh size) at which 10 percent of the media by weight is smaller, d_{10}. The uniformity coefficient of media was calculated as follows:[19]

$U = d_{60}/d_{10}$ (1).

RESULTS

The studied parameters in this research were effective size (ES) and uniformity coefficient (UC) of filters media in phase I of IWTP. The parameters were compared with international guidelines including EN12904,[20] EN12909,[21] and the criteria suggested by KAWAMURA[17] and CLUMRB[22] [Table 1].

Table 2 shows data obtained for the ES and UC. The data include means, standard deviations, and standard error means of the parameters.

In order to compare the obtained results for effective size and uniformity coefficient with the recommended criteria, they were analyzed using a one-sample *t*-test at the 0.05 significance level. The results there are significant differences between the measured parameters and their criteria [Table 3].

Table 1: The guidelines recommended for ES and UC in dual-bed filters

Standard	Effective size (ES) (mm)	Uniformity coefficient (UC)
Sand		
EN12904 AWWAB100	0.63-0.85	< 1.4
Rec. by KAWAMURA	0.45-0.65	1.4-1.5
Rec. by GLUMRB	0.45-0.55[a]	≤ 1.65[a]
Anthracite		
EN12909 AWWAB100	1.5-1.65	< 1.4
Rec. by KAWAMURA	0.9-1.4	1.4-1.5
Rec. by GLUMRB	0.8-1.2[a]	≤ 1.85[a]

[a]In dual-bed media, sand at the bottom and anthracite coal on the top

DISCUSSION

The Interim Enhanced Surface Water Treatment Rule (IESWTR) promulgated by the U.S. Environmental Protection Agency (EPA) requires that the treated water turbidity level be 0.3 NTU in 95 percent of monthly measurements with no sample to exceed 1 NTU.[23] This limit implies that the filtration system must be designed and constructed from the media with the best material and physical properties. As noted previously, the most important physical properties of filter media to meet good effluent quality are effective size and uniformity coefficient.[17] The uniformity coefficient is a function of effective size and d_{60}. With respect to media material and operational conditions, the properties may change over time.[15] Since the filtration system in phase I of IWTP has been in service for more than two decades, there was an assumption that their physical properties may be changed than the early condition and be out of optimum condition. The studied filters are dual media consisting anthracite at the top and sand at the bottom, so both media were studied.

The results show that the effective size of sand was 0.63 ± 0.05 mm, while the optimum ranges proposed by EN12904 AWWAB100, KAWAMURA, and GLUMRB are 0.63-0.85 mm, 0.45-0.65 mm, and 0.45-0.55 mm, respectively. Therefore, the effective size of sand media was within the optimum range proposed by EN12904 and KAWAMURA, but exceeded the recommended range by CLUMRB [Figure 2a]. Statistical analysis on the comparison of effective size of sand and recommended criteria showed a significant difference between the measured effective size of sand and the criteria proposed by GLUMRB, the upper limit of the range proposed by EN12904, and the lower limit of the range proposed by KAWAMURA (*P*-value < 0.001). However, there was no significant difference between the effective size of sand and the lower limit of the range proposed by EN12904

Table 2: The ES and UC data for filtration system in phase I of the IWTP

Criteria	Mean	Std. Deviation	Std. Error Mean
Effective size (mm)			
Anthracite	0.67	0.08	0.02
Sand	0.63	0.05	0.01
Uniformity coefficient			
Anthracite	3.6	0.40	0.12
Sand	1.93	0.11	0.03

Table 3: The significance difference of the parameters and guidelines (*P*-value) (one-sample *t*-test)

Media	Criteria	EN12909		EN12904		KAWAMURA		GLUMRB	
		Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Effective size	Anthracite	< 0.001	< 0.001	-	-	< 0.001	< 0.001	< 0.001	< 0.001
	Sand	-	-	0.954	< 0.001	< 0.001	0.245	< 0.001	< 0.001
Uniformity coefficient	Anthracite	< 0.001		-		< 0.001	< 0.001	< 0.001	
	Sand	-		< 0.001		< 0.001	< 0.001	< 0.001	

(*P*-value = 0.954), and the upper limit of the range proposed by KAWAMURA (*P*-value = 0.245) [Table 3].

The effective size of anthracite was 0.67 ± 0.08 mm, that exceeded the optimum ranges recommended by EN12909 AWWAB100, KAWAMURA, and GLUMRB. Therefore, it is prospected that the mean effective size of anthracite media of the filtration system in phase I of IWTP has a significant difference with all subjected standards and guidelines (*P*-value < 0.001). As we see from Figure 2b, the effective size of anthracite media was far higher than the range of acceptable values.

Furthermore the uniformity coefficient of sand and anthracite media was very different from acceptable values proposed by the related references. The results shoed that the uniformity coefficient of the sand medium was 1.93 ± 0.11. This value was higher than the coefficients recommended by EN12904 AWWAB100 (< 1.4), KAWAMURA (1.4-1.5), and GLUMRB (≤ 1.65) [Figure 3a]). Also, one-sample *t*-test results indicate that the mean uniformity coefficient of the sand medium had a significant difference with the optimum values recommended by AWWA and the reference texts (*P*-value < 0.001).

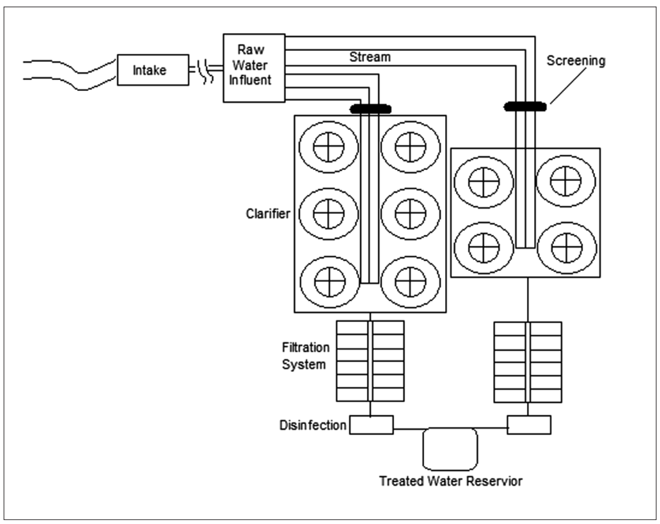

Figure 1: Schematic design of the IWTP

The situation for uniformity coefficient of anthracite was somewhat similar to sand. The uniformity coefficient of anthracite medium was 3.60 ± 0.40 that is very high in comparison to optimum values presented in Table 1 [see Figure 3b]. Similar to sand, statistical analysis illustrated that there was a significant difference between the measured uniformity coefficient of the anthracite medium and the optimum values proposed by EN12904 AWWAB100, KAWAMURA, and GLUMRB (*P*-value < 0.001).

This study was unique because its outcome was a decision basis for waterworks authorities to rehabilitate the filtration system in phase I of IWTP. The results imply that the effective size and uniformity coefficient of sand and anthracite media in the filtration system were not in good condition. This situation makes the filtration system potentially inefficient for the removal of turbidity and microorganisms from settled water. Subsequently, official authorities in Isfahan Water and Wastewater Company along with the manager of the IWTP decided to rehabilitate phase I of the filtration system by replacing aged media by fresh media. The replacement project started early in 2008. From all 20 filters in phase I of the filtration system, the media of 10 filters were renewed as previous arrangement in which a bed of anthracite was placed on top of a sand layer. However, a garnet layer was added to other 10 filters in addition to renewing sand and anthracite media. The approximate properties of garnet media were: effective size = 0.2-0.4 mm, uniformity coefficient = 1.3-1.7, hardness = 6.5-7.5 moh, porosity = 0.45-0.58, specific gravity = 3.6-4.2, while anthracite and sand have specific gravity 1.5-1.75 and 2.55-2.65, respectively.[24,25] Then, the arrangement of media in later 10 filters was garnet at the bottom, sand at the intermediate, and anthracite on the top.

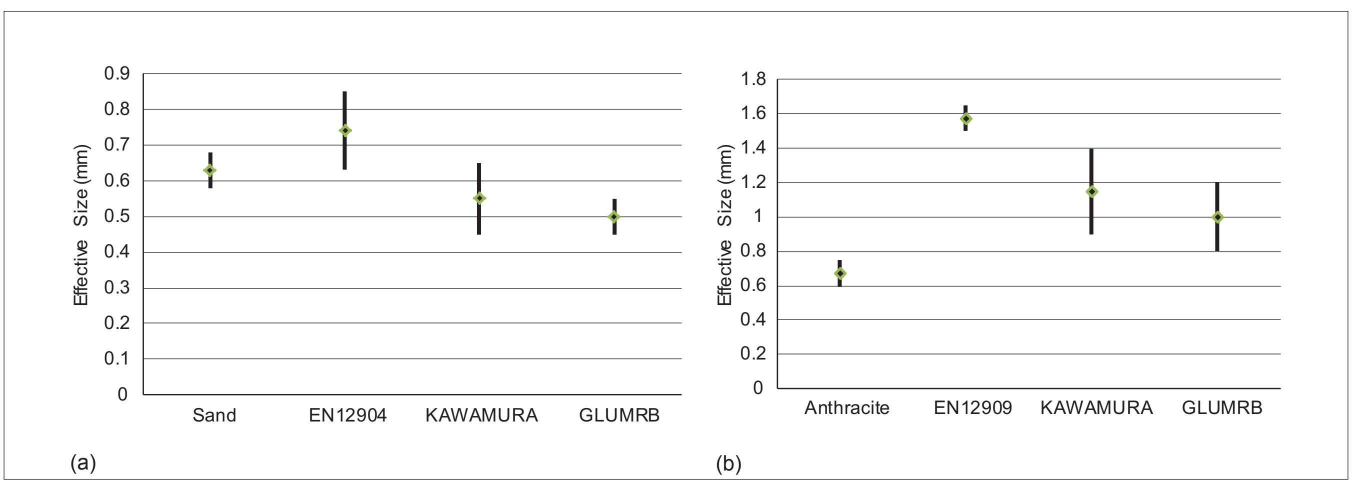

Figure 2: Comparison of the effective sizes of (a) sand and (b) anthracite media with recommended criteria in phase I of IWTP

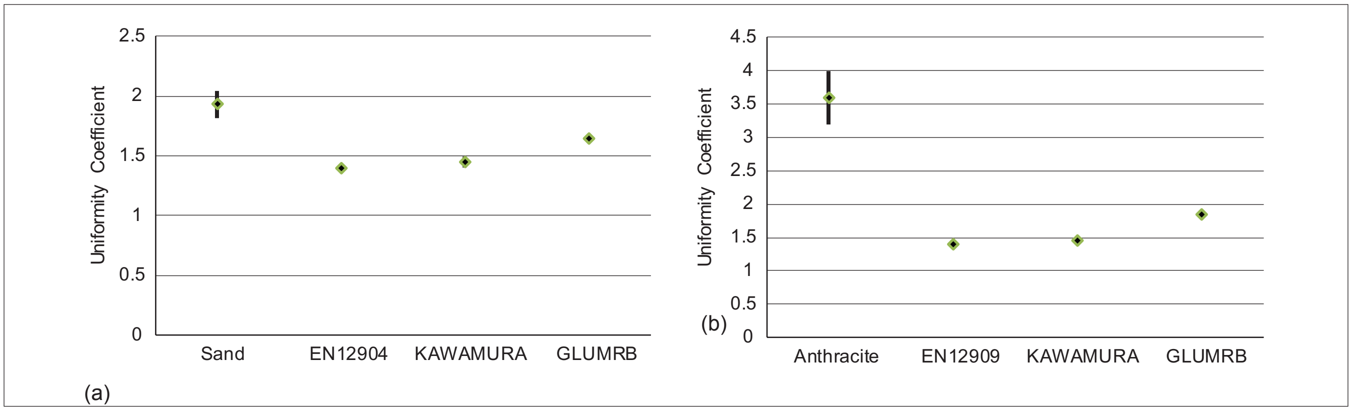

Figure 3: Comparison of the uniformity coefficient of (a) sand and (b) anthracite media with recommended criteria in phase I of IWTP

CONCLUSION

The filtration system must be designed and constructed from the media with the best material and physical properties. As noted previously, the most important physical properties of filter media to meet good effluent quality are effective size and uniformity coefficient. Since the filtration system in phase I of the IWTP has been in service for more than two decades, its media may be changed physically and be in undesirable condition.

The results showed that the effective size and uniformity coefficient of sand and anthracite media were mainly out of acceptable values recommended by EN12904, EN12909, KAWAMURA, and GLUMRB. Statistical analyses showed a significant difference between measured effective size and uniformity coefficient of sand and anthracite, and the international criteria.

The results imply that the effective size and uniformity coefficient of sand and anthracite media in the filtration system were not in good condition, so the authorities in the Isfahan Water and Wastewater Company along with the manager of the IWTP decided to rehabilitate phase I of the filtration system. In 2008, from all 20 filters in phase I of the filtration system, the media of 10 filters were renewed as previous arrangement , i.e a top layer of anthracite and a bottom layer of sand. Moreover, a garnet layer was added to other 10 filters in addition to renewing sand and anthracite media.

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