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The Efficiency of Multi-Media Filtration in Drinking Water Treatment Plants for the Removal of Natural Organic Matter

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ABSTRACT

Background: Filtration is a processing unit in a Drinking Water Treatment Plant (DWTP) that is used to remove particles from the water. This study is the result of pilot-scale research on Gravity Rapid Sand Filter (GRSF). The purpose of this paper was to evaluate the performance of the Triple Media Filter (TMF) (Granular Activated Carbon (GAC) + anthracite + garnet) and Dual-Media Filter (DMF) (anthracite + sand) in the removal of Natural Organic Matter (NOM) as a precursor of Trihalomethanes (THMs) and chlorination Disinfection by-Products (DBPs).

Methods: Filtration rate was performed at conventional (120 m/d) and a high rate (240 m/d) and compared with full-sized Single Media Filter (SMF) with a sand media. The removal efficiency of turbidity, color, and UV absorption at a wavelength of 254 nm (UV_{254}) and Dissolved Organic Carbon (DOC) parameters were investigated. Besides, the Specific Ultraviolet Absorbance (SUVA) was calculated from the ratio of UV_{254} to DOC.

Results: The results showed that the Multimedia Filter (MMF) at 120 and 240 m/d filtration rate had higher removal efficiency compared with a control SMF in removing measured parameters ($P<0.05$). Also, similar filters have shown the same efficiency relative to each other in different loading rates and there was an insignificant difference.

Conclusion: MMF can significantly remove organic pollutants and control the formation of DBPs during water treatment. The study suggests that SMF should be replaced with MMF to improve water quality.

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1. Introduction

One of the main problems with the use of surface water resources is the high concentrations of Natural Organic Matters (NOMs) that mainly create turbidity and color in water resources [1], which due to the impact on the performance of process units (such as oxidation, coagulation, and adsorption), the use of disinfectants and biological sustainability [2], are a major concern for the existence of NOMs in the process of drinking water treatment. In drinking water treatment, Disinfection by-Products (DBPs) are generally produced by the reaction of organic and inorganic matter with chemical disinfectants during water disinfection [3]. Because chlorination has been the dominant method of disinfection of water, chlorination DBPs have caused the most important health concerns and have been widely studied, including regulated DBPs, such as Trihalomethanes (THMs), Haloaceticacids (HAAs), chlorite, and emerging DBPs. such as halonitromethanes, haloacetonitriles, etc. [4]. The most important processes for removing NOMs are coagulation and flocculation, sedimentation, flotation, ion exchange, reverse osmosis, surface adsorption, and granular media filtration [5, 6]. Gravity Rapid Sand Filter (GRSF) is widely used as a kind of granular media filtration for drinking water treatment. The removal process in these filters is performed by various mechanisms, including screening, sedimentation, particle separation, and chemical reactions [7]. These filters are often used in single and multi-layers. In a single layer filtration, after the backwashing operation, coarser particles are deposited more rapidly than smaller particles, and this phenomenon is referred to as reverse layering. The main disadvantage of single-layer filters is reverse layering [8]. To solve this problem, we can use particles with a lower density. Anthracite has the highest content of carbon and energy compared with other types of coal, such as bituminous, lignite, brown charcoal, etc. and also has a volatile mass and very low moisture content with lighter layer so that the filter layer is not easily tightened and compacted; thus, filtration is carried out in both surface and deeper layers [9].

Dual-layer filters are a kind of filter that an anthracite layer is located above a fine sand layer, which is used as a structure for increasing the volume of filter pores. The filtration rate in the Rapid Sand Filter (RSF) is 40 times higher than the Slow Sand Flter (SSF). The constituent material of the filter media is placed on a granular media and underlying drainage system, which both collecting filtered water and distributing the backwash water are used to clean the filter media [8]. Dual and triple media filters have two main advantages: higher efficiency and production of improved water quality compared with Single Media Filter (SMF) [9]. The triple-layer filters are similar to the dual-layer filters, except that different types of media are used in them. Many types of media, including Granular Activated Carbon (GAC), anthracite, sand, and garnet are used in these filters. The media materials are arranged so that with any increase in depth, the specific density increases and the particle size decreases accordingly. These filters are improved dual-layer filters with longer operation time and better water quality [10]. Dual-layer filters are more used than single-layer filters, and they are able to trap larger particles in the upper layer and smaller particles in deeper layers without being abrasion the antistatic layer [9]. This function maximizes the trap capacity of solids in dual-layer filters than single-layer filters and reduces the time needed for backwashing [11].

In developed countries, Drinking Water Treatment plant (DWTP) is used using different methods, such as screening, sedimentation, coagulation and flocculation, different filtration methods, primary and final disinfection, etc. in surface water treatment [12]. Filtration and disinfection processes are required for removing residual matter, such as bacteria, viruses, and other soluble metals [13]. The most important filtration performance factor is the type of media in the removal of NOM. Various porous matters, such as sand, rubble, and GAC can be used as filter media. Filtration is a combination of various processes, including mechanical trapping, chemical and biological activity, adsorption, and sedimentation to eliminate all contaminants [10]. Many DWTPs use GAC, anthracite, or silica sand as filter media. In the DWTP, the GAC filter is installed and operated as a biological filter media, a biological filter cap, as a contact surface for adsorption of NOM, taste, and odor compounds, various micropollutants, and turbidity particles [14]. GAC is often used as an RSF or in combination with it, which reduces filtration time. This filter can also operate on an over hydraulic loading rate compared with RSF [15]. Many studies have shown the advantage of MMF performance compared with single-media filters [9, 16]. Most of these studies have focused on the type of media, as well as the filter media performance in the removal of various pollutants in the water and wastewater [17, 18]. In a study by Gholikandi et al., a dual-layer filter with Light Expanded Clay Aggregate (LECA) sand media compared with an anthracite-sand layer filter was a more suitable replacer for removing water turbidity [11]. Several studies have indicated the use of GAC and anthracite as the most commonly used media with good performance in DWTPs [14, 19]. The present study was conducted to compare the removal efficiency of NOM in a triple-media filter (GAC+ anthracite + garnet) and dual-media filter (anthracite + silica sand) with conventional control SMF (silica sand). The purpose of this pilot-scale research was to investigate the removal performance of NOM as the main factor in the production of chlorination DBPs in DWTPs.

2. Materials and Methods

Pilot plant study

The current research was a practical pilot study, which was carried out in a water treatment plant No.2 of Ahvaz city, Iran. This water treatment plant is one of the eldest plants in Ahvaz, consisting of typical treatment processes, including coagulation and flocculation, rapid sand filtration, and disinfection units.

In this study, two Plexiglas pilot filters were used. These pilots were constructed as two cylinders' columns installed on a stainless steel framework that for both pilot filter and cross-section diameter, the filter total height and the media depth without protective layer are 0.16, 2, and 0.6 m, respectively. The pilots consisted of several units, such as filter columns, flow meters, and filter backwash. The pilot design was based on the common design criteria in this field. The technical features of the pilots are shown in Table 1. Also, a schematic of the pilot-scale plant is displayed in Figure 1.

Pilots No. 1 and No. 2 were designed to evaluate the performance of the dual and triple-media filters, respectively. Input water into pilots was supplied through making a split in the clarifiers output in the DWTPs and was injected into it from the pilot's upper part by installing a flow meter in the direction of the inlet flow, based on the loading rate. At the entrance of both pilots, a shower was used for preventing turbulence in the media and for the uniform distribution of water. The loading rate of both pilots was applied in two different rates, including 120 m /d (120 m^3/ m^2.d) and 240 m/d (240 m^3/ m^2.d) for investigating the effect of changes in loading rate on the performance of the filters. All operating conditions were considered similarly for a better comparison of filters and repeated for both loading rates. The effective size and uniformity coefficient of the material used in both pilot filters are shown in Table 2. Different operating conditions in the pilot filter are shown in Table 3.

In this study, an SMF on a full scale was used as a control filter, which contained 5cm of coarse sand with an effective size of 8-10 mm as a retaining layer and 60 cm of silica-sand media with an effective size of 0.4-0.9 mm.

After applying the pilot filters, at the same hydraulic loading rate, they were allowed for maturation during 5-6 h and then sampled from the inlet and outlet water of both pilot filters. The quality of the treated water before the filtration process is presented in Table 4.

Sampling methods and experimental

All sampling methods and experimental procedures were carried out in accordance with the guidelines of standard methods for the examination of water and wastewater [20]. Sampling was done for three months in the spring season. Hourly turbidity was performed in the input and output of both pilots. Turbidity was measured based on the nephelometric method (Standard 2130-B) by HACH portable turbidity meter 2100-AN. The color was measured using the single-wavelength spectrophotometric method (Standard 2120-C) by HACH spectrophotometer DR-5000. DOC measurements were performed using the high-temperature combustion method (Standard 5310-B) by TOC meter (TOC-VCSH). UV_{254} (UV-absorbing organic constituents) was measured by the ultra-violet absorption method (standard 5910-B) using HACH Spectrophotometer DR-5000. SUVA value was calculated from the UV_{254} to the DOC ratio. All experiments were repeated three times, and the results represented the average of the data obtained.

Pilot filters were backwashed when the output turbidity was more than the filter backwashing base. The backwash procedure was done by the upflow of water with air. The backwash system was similar for both pilot filters. In order to make a uniform distribution or to unify the distribution of water and airflow at the backwash step, a porous Plexiglas plate was installed at the bottom of the filter and wrapped with an aluminum net to prevent particle escape. In the backwash stage, the flow of water and air was injected from the bottom into the filters with two separate tubes. A Backwash cycle was performed during the increased turbidity of the outlet. To prevent the escape and loss of anthracite and GAC, low pressure of water and longer duration were used. This study was conducted at an average of pH 7.40, Electrical Conductivity (EC) of 1250 µS/cm, and water temperature of 25°C. The backwash cycle was performed in single-, dual-, and triple-media filters every 24, 48, and 70 h respectively. The filtration time was 144 h. All statistical analyses were performed by SPSS (ver.22) software. The paired-samples t-test ($P<0.05$) was used to compare the removal efficiency of both pilot filters.

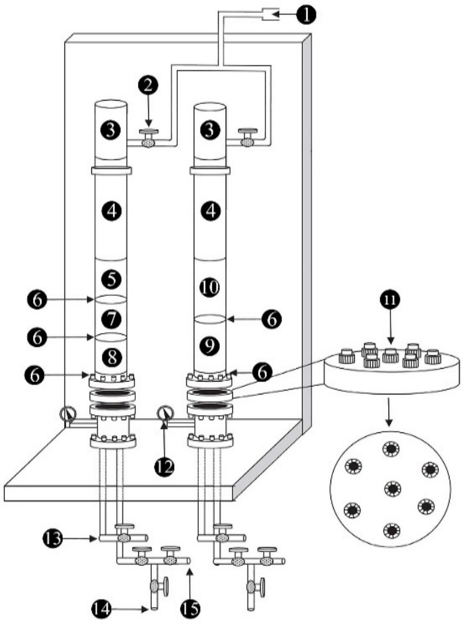

Figure 1. Schematic diagram of the pilot used in this study

1. Effluent of sedimentation unit and water influent; 2. Flowmeter; 3. Freeboard; 4. Water level; 5. GAC media; 6. Retaining layer; 7. Anthracite media; 8. Garnet media; 9. Sand media; 10. Anthracite media; 11. Drainage system; 12. Backwash air Gauge; 13. Backwash Air compressor influent; 14. Backwash water; 15. Treated water.

3. Results and Discussion

Turbidity and color removal

The results of the comparison of turbidity removal in TMF (GAC+ anthracite + garnet), DMF (anthracite + silica sand), and SMF (silica sand) at 120 and 240 m/d loading rate are shown in Figures 2A and 2B.

Based on the results of the turbidity test, at a loading rate of 120 m/d, the mean input turbidity of both pilots was 11.25 NTU, and the mean output turbidity from the triple-, dual-, and single-media filters was 0.33, 1.11, and 2.71 NTU, respectively. Also, at the 240 m/d loading rate, the input turbidity means of both pilots was 9.5 NTU and the output turbidity mean of the triple-, dual-, and single-media filters was 0.32, 1.32, and 3.33 NTU, respectively. According to Figures 2A and 2B, the percentage of turbidity removal average in single-, dual-, and triple-layer filters at 120 m/d loading rate was 75.85, 90.08, and 97.01%, respectively. In addition to the percentage of turbidity removal average in single-, dual-, and triple-layer filters at 240 m/d loading rate was 64.81, 86.00, and 96.66%, respectively.

The results of the comparison of the color removal in the triple-, dual-, and single-layer filters at 120 and 240 m/d loading rates are shown in Figures 2C and 2D.

Based on the results of the color test, at a loading rate of 120 m/d, the average input color of both pilots was 13.83 PCU, and the average output color of the triple-, dual-, and single-layer filters was 1.18, 3.68, and 8.33 PCU, respectively. Also, at 240 m/d loading rate, the average input color of both pilots was 13.83 PCU, and the average output color of the triple-, dual-, and single-layer filters was 1.43, 3.77, and 9.00 PCU, respectively. As shown in Figures 2C and 2D, the percentage of average color removal in single-, dual-, and triple-layer filters at 120 m/d loading rate was 39.51, 73.19, and 91.41%, respectively. In addition to the percentage of average color removal in single-, dual-, and triple-layer filters at 240 m/d loading rate was 35.12, 73.15, and 89.48%, respectively. The statistical significance of the measured parameters using paired-samples t-test between the pilot inputs and outputs

Table 1. Technical features of the pilot used in the research

Technical Features	Quantity	Technical Features	Quantity
Body material	Plexiglas	Filter ferry board (cm)	20
Geometric shape	Cylinder	Surface load (m/d)	120
Cross-section diameter (cm)	16	Type of drainage system	Porous plastic pipes
Filter total height (cm)	200	Filter washing method	Backwashing
Bed depth without protective layer (cm)	60	Filter backwashing base	5 NTU Turbidity
Retaining layer depth (cm)	5	Inlet valve location	Just before the water level 145 cm
Depth of water in the filter (cm)	90	Outlet valve location	Under drainage system

Table 2. Effective size and coefficient of uniformity of materials used in each pilot media

The Used Bed	Effective Size (mm)	Uniformity Coefficient (UC)
GAC	0.8-1.5	1.3
Anthracite	0.8-1.2	1.4
Silica sand	0.4-0.9	1.5
Garnet	1-2	1.6
Rubble	8-10	1.5

compared with the filtration unit and for comparing the pilot at 120 and 240 m/d loading rates is given in Table 5.

According to Table 5, the results of the paired-samples t-test at loading rates of 120 and 240 m/d showed a significant difference in the outlet of turbidity and color in the MMF compared with the control SMF, as well as the significant difference between dual and triple media pilot at similar and different loading rates ($P<0.05$). However, no significant differences were found for the similar MMFs at different loading rates (DMF at 120 m/d loading rate compared with DMF at 240 m/d loading rate and also triple-media filter at 120 m/d loading rate compared with the triple-media filter at 240 m/d loading rate ($P>0.05$). The results of the removal efficiency study in Figure 2 indicates the efficiency of MMF 1.27 and 1.18 times more than the control SMF for the removal of turbidity and also the efficiency of MMF 2.31 and 1.85 times more than the control single-media for the removal of color at 120 m/d loading rate that indicates higher efficiency of triple media filters than dual media and dual media higher than single media filter. The results of Figure 2 show the higher efficiency of the triple media filter in comparison with the dual media and the dual media than the single media at 240 m/d loading rate. In similar studies, Kazemi et al., Baraee et al., and Gholli Kandi et al. reported a higher efficiency of DMF than SMF, confirming the results of this study [9, 11, 19]. One of the most important reasons for these observations is the impaction of the maker particles of turbidity and color between the media pores of the multi-layer filters and the creation of self-purification by these particles. Also, the major part of the maker particles of turbidity and color is trapped in anthracite special surface pores of the dual-

Table 3. Operational conditions of the used pilots

Administrative Procedures of the Work	Type of Bed		Surface Load of Pilot Filtration (m/d)	
	Double-layer Filter Pilot	Triple-layer Filter Pilot	120	240
1st week	5 cm of coarse sand + 30 cm of sand and 30 cm of anthracite	5 cm of coarse sand +15 cm of anthracite +22.5 cm of GAC+ 22.5 cm of Garnet	*	
2nd week	5 cm of coarse sand + 30 cm of sand and 30 cm of anthracite	5 cm of coarse sand + 15 cm of anthracite +22.5 cm of GAC+ 22.5 cm of Garnet		*
3rd week	5 cm of coarse sand + 20 cm of sand and 40 cm of anthracite	5 cm of coarse sand + 15 cm of anthracite +15 cm of GAC+ 30 cm of Garnet	*	
4th week	5 cm of coarse sand + 20 cm of sand and 40 cm of anthracite	5 cm of coarse sand + 15 cm of anthracite +15 cm of GAC+ 30 cm of Garnet		*
5th week	5 cm of coarse sand +40 cm of sand and 20 cm of anthracite	5 cm of coarse sand + 15 cm of anthracite +30 cm of GAC+ 15 cm of Garnet	*	
6th week	5 cm of coarse sand +40 cm of sand and 20 cm of anthracite	5 cm of coarse sand +15 cm of anthracite +30 cm of GAC+ 15 cm of Garnet		*
7th week	5 cm of coarse sand +30 cm of sand and 30 cm of anthracite	5 cm of coarse sand +15 cm of anthracite +20 cm of GAC+ 20 cm of Garnet	*	
8th week	5 cm of coarse sand +30 cm of sand and 30 cm of anthracite	5 cm of coarse sand +15 cm of anthracite +20 cm of GAC+ 20 cm of Garnet		*

Table 4. The quality of the treated water before the filtration process

Parameters	Unit	Quantity
pH	-	7.40
Alkalinity	mg/L	128.01
Turbidity	NTU	21.30
Total Suspended Solid	mg/L	20.45

layer filter and GAC special surface pores of the triple-layer filter, which is due to better removal of turbidity and color in the multi-layer filters than in the single-layer filter. According to Table 5, the results of the paired-samples t-test to compare the output concentration of turbidity and color in the same pilots at loading rates of 120 and 240 m/d showed that there was an insignificant difference between the concentrations of the output of turbidity and color in the MMF (P>0.05). As the loading rate increases, the output concentration of turbidity of the filter increases and the removal efficiency decreases. The reason for this observation is that at 240 m/d loading rate, high loading rates are applied to the pilot. Given the specific ability of the media particles to remove pollutants, a higher surface loading rate, in addition to having higher pollution loads into the filters, provides a shorter time for the media particles for the filtration process, and consequently, removal efficiency decreases at the high loading rate [21]. In a similar study, the rate of turbidity removal at the 5 and 10 m/h loading rates was 71 and 57%, respectively, which is consistent with the results of this study [21]. Also, Chavan et al. obtained a 95% removal efficiency for turbidity and color removal. The reason for this difference in the removal efficiency compared with this study is the use of two-step removal, which can lead to increased removal efficiency [22]. The comparison of the DMF (anthracite + sand) used in this study with the dual-layer filter (sand + foam) used by Mishra and Tembhurkar showed that the dual-layer filter (anthracite + sand) is more effective for organic pollutants removal of surface water and consequently, higher quality of drinking water [23]. Borrull et al. investigated the removal of NOM in a DWTP treating raw water from the Ebro River (NE Spain) and their study showed that the most efficient removal technologies are ozonation and granular activated carbon filtration [24].

UV_{254} and DOC removal

The results of the comparison of UV_{254} removal in triple-, dual-, and single-layer filters at 120 and 240 m/d loading rates are shown in Figures 2E and 2F. Based on the results of the UV_{254} test, the mean input of UV_{254} in both pilots at 120 m/d loading rate was 0.021 cm^{-1}. The mean output of UV_{254} in the triple-, dual-, and single-layer filters was 0.003, 0.009, and 0.016 cm^{-1} respectively. Also, the mean input of UV_{254} in both pilots at 240 m/d loading rate was 0.024 cm^{-1}. The mean output of UV_{254}

Table 5. Significant results of measured parameters between pilot input and output and filtration unit in different filtration rate

Measured Parameters / Type of Comparison	Control Filter at $^{120\ m/d}$ With Pilot				Pilot No.1$^{120\ m/d}$ With Pilot			Pilot		
								No.1^{240} m/d	No.1^{120} m/d	No.1^{240} m/d
								With Pilot		
	No.1^{120} m/d	No.2^{120} m/d	No.1^{240} m/d	No.2^{240} m/d	No.1^{240} m/d	No.2^{240} m/d	No.2^{240} m/d	No.2^{120} m/d	No.2^{120} m/d	No.2^{240} m/d
Turbidity (NTU)	*	*	*	*	Non	Non	*	*	*	*
Color (PCU)	*	*	*	*	Non	Non	*	*	*	*
UV_{254} (cm^{-1})	*	*	*	*	Non	Non	*	*	*	*
DOC (mg/L)	*	*	*	*	Non	Non	*	*	*	*

Pilot No.1: Dual Media Filter (DMF); Pilot No.2: Triple Media Filter (TMF); 120 & 240 m/d: Surface Loading rate of filtration; *Significant (P<0.05), Non: Non significant (P>0.05).

in both pilots at the loading rate of 240 m/d from the triple-, dual-, and single-layer filters was 0.003, 0.012, and 0.018 cm^{-1}, respectively.

Figures 2E and 2F show that the average removal percentage of UV_{254} in single-, dual-, and triple-layer filters at the loading rate of 120 m/d was 22.84, 45.66, and 67.16%, respectively. Also, the average removal percentage of UV_{254} in single-, dual-, and triple-layer filters at the loading rate of 240 m/d was 23.12, 35.24, and 74.52%, respectively. The results of the comparison of the removal of the DOC in triple-, dual-, and single-layer filters at 120 and 240 m/d loading rates are shown in Figures 2G and 2H.

Based on the results obtained from the DOC test, at 120 m/d loading rate, the mean input of DOC in both pilots was 2.58 mg/L, and the mean output of DOC of the triple, dual-, and single-layer filter was 0.31, 0.87, and 1.65 mg/L, respectively. Also, the mean input of DOC in both pilots at 240 m/d loading rate was 3.73 mg/L, and the mean output of DOC of the triple-, dual-, and single-layer filters was 0.33, 1.31, and 2.53 mg/L, respectively. Figures 2G and 2H shows that the average removal percentage of DOC at 120 m/d loading rate in single-, dual-, and triple-layer filters was 35.83, 47.67, and 63.91%, respectively. Also, the average removal percentage of DOC in single-, dual-, and triple-layer filters at 240 m/d loading rate was 32.60, 48.22, and 74.10 %, respectively. According to Table 5, the results of the paired-samples t-test to compare the removal efficiency of DOC and UV_{254} showed a significant difference between MMF and control SMFs as well as triple- and dual-media filters at 120 and 240 m/d loading rates ($P<0.05$) and insignificant difference of the same filters at different loading rates (DMF at 120 m/d loading rate compared with DMF at 240 m/d loading rate, as well as triple-media filter at 120 m/d loading rate compared with triple-media filter at 240 m/d loading rate) ($P>0.05$). However, the results of the removal efficiency in Figure 2 showed the 2.01 and 2.94 times more efficiency of MMF compared with control single-media filters for UV_{254} removal, and 1.33 and 1.78 times more efficiency of MMF compared with single-media for DOC removal at 120 m/d loading rate, indicating higher efficiency of the triple-media filter in comparison with the DMF and DMF in comparison with the control single-media filter. These results also indicate the higher efficiency of the triple-media filters in comparison with the dual-media and the dual-media with the single-media at a 240 m/d loading rate.

In addition to the screening physical mechanism, the NOM removal follows a biological mechanism in MMF that was carried out by the adsorption of biofilm layer microorganisms for the decomposition and stabilization of NOM by anthracite media in a dual-layer filter (anthracite + silica sand) and GAC media in a triple-layer filter (GAC + anthracite + garnet). In this study, the higher removal efficiency of the MMF was observed compared with the single-layer filter. In addition, physical adsorption is also accrued between the media surface and pollutants. But in a single-layer filter with silica sand, it seems that the removal mechanism is more screening and surface absorption to the silica sand media and the biological mechanism did not occur due to the absence of GAC or anthracite in this layer. On the other hand, MMFs are more effective than single layers due to their multi-layers with different densities, effect sizes, and uniformity coefficients in removing suspended and colloidal particles of water. Koppanen et al. removed NOM in a full-scale drinking water treatment plant using GAC and reported that sand and GAC filtration removed DOC to a level below 0.15 mg/L. Also, GAC removed 25% of total organic carbon [25].

Al-Ubaidy and Abbood showed that GAC in MMF plays an effective role in biological elimination and the biological elimination maximum for COD and BOD was reported to be 89.99 and 88.99%, respectively [26]. De Vera et al. also showed that a 20% reduction of final head loss in DMF and 40% in MMF significantly are affected in the removal of Assimilable Organic Carbon (AOC), Total Organic Carbon (TOC), turbidity, and particles count [14].

According to Table 5, the results of the paired-samples t-test to compare the removal efficiency of DOC and UV_{254} at 240 m/d loading rate showed that there was an insignificant difference between the removal of DOC and UV_{254} in dual and triple-media filters at different loading rates ($P>0.05$). With an increase in loading rate, the outlet of DOC and UV_{254} values increased and the removal efficiency reduced. In continuous operation and loading of NOM, GAC adsorption sites reduce and the removal of contaminants occurs mainly through the biological decomposition of the biofilm layer attached to the filter media. In other words, the biofilm layer is formed in dual and triple filters on the GAC surface and anthracite surface, which results in the removal of NOM by these filters.

The ability to absorb and the porous surface of GAC allow the absorption of organic contaminants with low biodegradability or matter with longer contact times. The percentage of NOM removal increases with increasing contact time and a low loading rate. Biomass growth in full-scale biological GAC filters reduces filter run times

Table 6. Guidelines on the nature of Natural Organic Matter (NOM) [29]

SUVA[1] (L/mg. m)	Composition
< 2	- Mostly non-humic - Low hydrophobicity - Low molecular weight
2–4	- Mixture of aquatic humic substances and other NOM - Mixture of hydrophobic and hydrophilic NOM
> 4	- Mostly aquatic humic substances - High hydrophobicity - High molecular weight

1. Specific Ultraviolet Absorbance

and is a potential source of biomass sloughing [27]. Feng et al. showed that dual-media filters (GAC + sand) have a good performance on reducing COD in the DWTP [28].

SUVA value

SUVA (L/mg .m) is a value for the quantity amount of humic substances present in water. It is a value for the nature of NOM in the removal of precursors NOM, TOC, and DBPs. SUVA offers a simple description of NOM based on UV absorption by a water sample according to the DOC, which is calculated by the following Formula 1:

$$1.\ \mathrm{SUVA} = \frac{\mathrm{UV}_{254}(\mathrm{cm}^{-1})}{\mathrm{DOC}(\mathrm{mg/L})} \times 100$$

This value is important for determining the potential for the formation of DBPs. The SUVA Interpretation Guide is presented in Table 6.

The calculations showed that the SUVA average at 120 m/d loading rate for the input of both pilots was 0.8 (L/mg.m) and the average output from the triple-, dual-, and single-layer filters was 1.04, 1.08, and 0.96 L/mg. m, respectively. Also, the mean SUVA at 240 m/d loading rate and for the input of both pilots was 0.63 L/mg.m, and the mean output from the triple-, dual-, and single-layer filters was 0.92, 0.95, and 0.72 L/mg. m, respectively. Because in this study the SUVA value was less than 2 L/mg.m, the nature and type of the NOM in the inlet and outlet water of both pilots are mostly non-humic and with low hydrophobicity and low molecular weight. The quality of water entering the DTWPs is the cause of this result. The reason for the formation of DBPs is often humic matters with high molecular weight; therefore, due to the good water quality, NOM compounds are often non-humic with a low molecular weight that reduce the amount of NOM in water and consequently, reduce the potential for the formation of DBPs, such as THMs. Marais et al. reported a positive significant correlation between the NOM with high molecular weight and the formation of TTHM and chloroform [30]. In addition, Piche et al., reported the formation of DBPs in a DMF (anthracite + sand) 33 to 35% less than conventional single-layer filter (sand) [31]. Chen et al. reported that dual-media filters compared with single-layer filters had higher removal efficiency and lower heat loss in particle removal. In a similar study, sand filtration was compared with ultrafiltration in drinking water treatment for removal of organic matter and disinfection by-product formation. The results of NOM removal indicated that sand filtration conferred a slightly higher removal rate for UV-absorbing compounds, humic-like substances, and protein-like substances than ultrafiltration, with removal efficiencies of 21.9%, 19.8%, and 26.1%, respectively [32]. Abdelrady et al. investigated the impact of organic matter on the removal of organic micropollutants during filtration. Their findings indicated that these hydrophobic compounds are effectively removed during filtration regardless of the environmental conditions [33].

4. Conclusion

This study was carried out in a GRSF with the aim of investigating the removal efficiency of NOM as a precursor of THMs and DBPs in DWTPs. For this purpose, a comparison of the MMF and control single-media filters was made at 120 and 240 m/d loading rates. The results showed that the triple- and dual-media filters at 120 and 240 m/d loading rates, respectively, have a higher removal efficiency compared with a single-layer filter in removing NOM from drinking water, which is due to the presence of two or more types of matters with different densities and properties in the filter media, which leads to the longer operation time for these filters. The

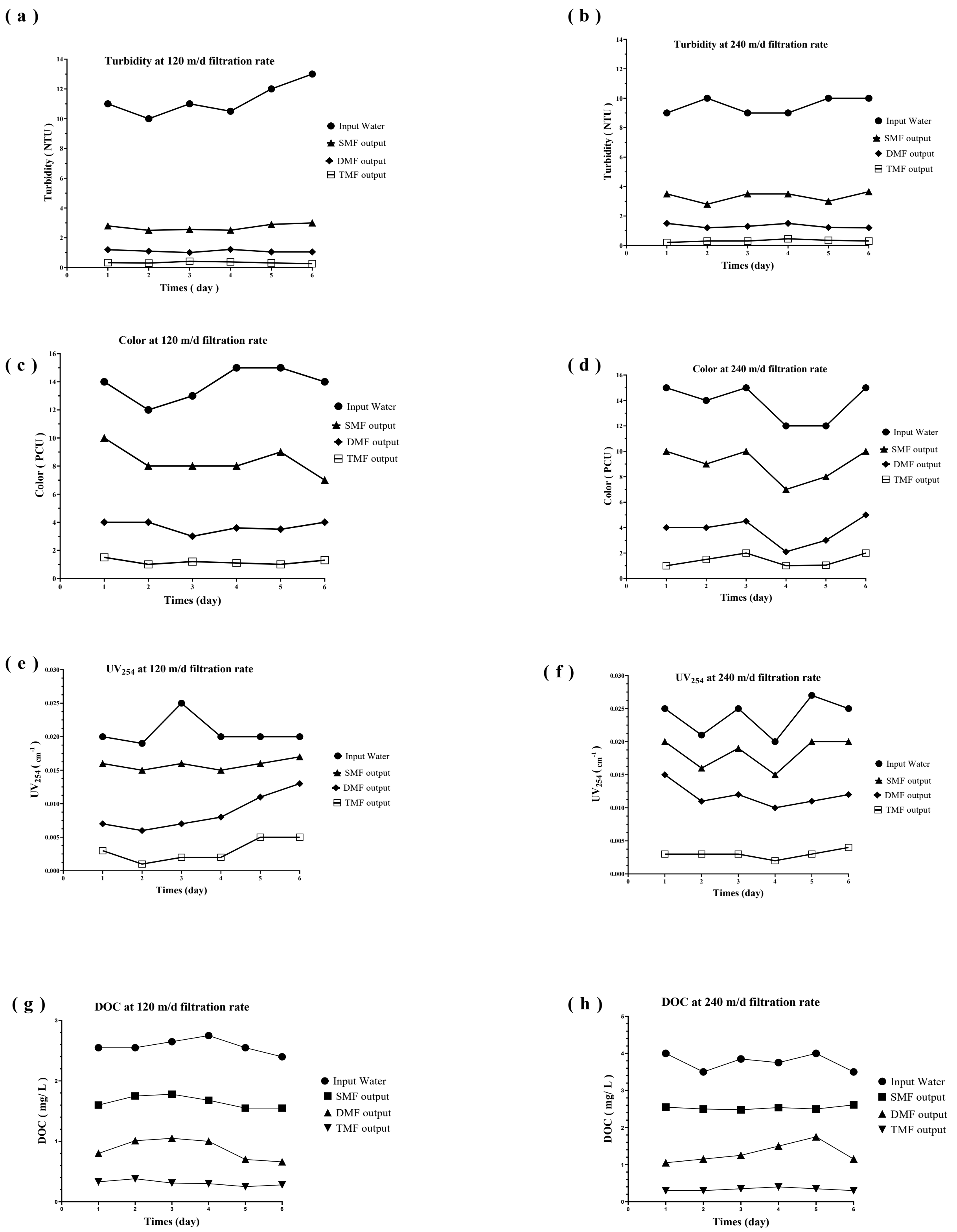

Figure 2. The chart of turbidity, color, UV_{254}, and Dissolved Organic Carbon (DOC) removal in the single-, dual-, and triple-media filters at different filtration rates

same filters showed the same efficiency at different loading rates. One of the main problems and limiting factors is the use of single-layer filters, high head loss, reverse gradation, and rapid obstruction of filter pores. Using a garnet along with other media, allows us to apply high aeration and backwash the filter that is very important for both the pilot and full scale in DWTPs. The TMF has a higher efficiency compared with the dual- and single-layer filters in removing NOM from the water. The reason for the superiority of the performance of MMF compared with single-layer filters is that in MMF, all the media are involved in the removal of particles, but in the SMF, only a few centimeters in the upper surface of the media are involved. This study suggests that with regard to the proper performance of MMF, the SMF should be replaced with MMF to improve water quality. For further studies by researchers, it is recommended to repeat this study in the winter season due to the different qualities of input raw water and the result be compare with this study. It is also suggested to use low-pressure water and more time during backwashing.

Ethical Considerations

Compliance with ethical guidelines

There were no ethical considerations to be considered in this research.

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Authors' contributions

Conceptualization and supervision: Afshin Takdastan and Reza Jalilzadeh Yengejeh; Methodology: Behnam Kazemi Noredinvand; Investigation, writing – original draft, and writing – review & editing: All authors; Data collection: Behnam Kazemi Noredinvand; Data analysis: Behnam Kazemi Noredinvand; Funding acquisition and resources: Behnam Kazemi Noredinvand, Afshin Takdastan, Reza Jalilzadeh Yengejeh, and Farshid Ghanbari.

Conflict of interest

The authors declared no conflict of interest.

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