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Removal of organic matter from drinking water by single and dual media filtration: a comparative pilot study

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ABSTRACT

This pilot-scale research was conducted at Ahvaz water treatment plant to investigate the performance of a dual-media filter with anthracite and silica sand layers for the removal of total organic carbon (TOC) and chemical oxygen demand (COD) as the measuring indices of organic matter in water. In addition, the performance of this dual-media filter was compared with a control single-media filter with a conventional layer. The hydraulic loading rate or water flux during the filtration was in the range of 7–14 m/h. All the experiments were carried out according to the standard methods, and the obtained results were analyzed using statistical tests such as paired-samples *t*-test. The average concentration of COD and TOC in the input water into the pilot was 7.93 and 2.73 mg/L, respectively. The average efficiency for TOC removal in the single-media and dual-media pilot filters at the loading rate of 7 m/h was 34.10 and 65.59%, respectively, whereas the corresponding values for COD removal in the single-media and dual-media pilot filters were 28.26 and 63.95%, respectively. Furthermore, the mean efficiency for TOC removal in the single-media and dual-media pilots at the loading rate of 14 m/h was 30.25 and 64.56%, respectively. At this loading rate, the corresponding efficiencies for COD removal in the single-media and dual-media pilot filters were 25.51 and 62.23%, respectively. The results of this research showed that the use of anthracite as a layer of dual-media filter increases the efficiency of organic matter removal compared with the single-media filter.

Keywords: Organic matter; TOC; COD; Filtration; Dual-media filter; Water treatment

1. Introduction

Waters containing organic compounds as well as chemical oxygen demand (COD) and total organic carbon (TOC) are biologically instable. The presence of organic and inorganic electron donors in water causes significant problems such as trihalomethane formation following disinfection with chlorine, taste and odor problems, and the regrowth of bacteria in distribution systems. The excessive use of water resources and the discharge of wastewater into these resources have caused various kinds of pollution. On the other hand,

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the increasing expansion of industries and the entrance of resistant organic matter into water resources are threatening the health of consumers of such water resources. Of course, natural waters also contain organic matter resulting from the decomposition of plants and other organisms. The most important organic matters are humic, tannins, lignin, phenolic, amino acids, hydrocarbons, and fatty acids. Among the humics as precursors, trihalomethanes are highly emphasized particularly when the early disinfection is done on entering raw water by chlorine [1–3].

In drinking water treatment, the filtration processes are used principally for the removal of particulate materials such as clays and silts, microorganisms, metal ions, and precipitates of organics from the water. Filtration is one of the unit processes used in the production of drinking water. Eliminated particulates may be those already present in the water source or those formed during the treatment processes [4–6].

The presence of organic matter in drinking water can cause many problems including color, taste, and odor problems; it can be a source for regrowth in the distribution system and therefore impacts on the biostability of the drinking water. In addition, organic matter can react with disinfectants and consequently produce disinfection by-products (DBPs). Membrane fouling and poor oxidation of iron and manganese are other problems resulting from the presence of organic matter in water [7–10].

Organic matter in surface water can be removed by anion exchange because the chief part of organic matter, humic, fulvic, and organic acids is negatively charged [8,9,11,12].

Biological treatment (e.g., bio-filtration involving, for example, biologically active GAC filters, anthracite, or sand) is based on aerobic biofilm processes that offer several advantages over physicochemical processes in regard to drinking water treatment. Granular activated carbon (GAC) provides a large surface area for the accumulation of microorganisms as a biofilm. Several European countries (e.g. France, Germany, and Netherlands) and Japan include biological processes in the treatment train in an effort to remove nutrient levels in the treated water and thus obtain biologically stable water, which limits the regrowth of microorganisms in distribution pipes and reservoirs. However, certain bacteria such as Pseudomonas grow in biofilms even at TOC concentrations below 10 mg/L. Three important factors affecting biodegradable organic matter removal by biofilters are the presence of chlorine in the backwash water, media type, and temperature [1].

Biological filters (GAC or anthracite) remove contaminants by three main mechanisms: biodegradation, adsorption of micro pollutants, and filtration of suspended solids. The microbial consortia attached to the filter media (biofilm) consume the organic matter that would otherwise flow through the treatment plant and ultimately into the distribution system. The end products are carbon dioxide, water, biomass, and simpler organic molecules. Particle filtration takes place on the bare filter media as well as in the biofilm. GAC is often used to provide the necessary surface to promote the development of the biofilm [3].

Biologically active carbon filters are typically used in place of conventional filtration, as a biologically active layer in dual-media filters, or downstream of conventional filters. In the first configuration, conventional filter media is replaced with activated carbon, which performs biodegradation and particle removal. In the second configuration, the top layer (activated carbon) of a dual-media filter provides biodegradation and some particle removal and additional particle removal is achieved in the sand layer. In the third configuration, particle removal is achieved by the conventional filter, and the biologically active GAC column is used as polishing step [2].

In all cases, filter sloughing can be a problem leading to possible taste and odor problems and release of bacteria in the finished water. This problem is of greater concern for smaller systems that use biofilters for denitrification and may compromise proper secondary disinfection [5].

Key factors in controlling biofilter performance include temperature, contact time, backwash operations, and water quality parameters like pH, alkalinity, turbidity, and TOC. In particular, temperature controls bio-growth kinetic [4].

Several studies have been done on the use of multi-layer substrates in order to filter the pollutants. In a study, TOC and COD were considered as the effective parameters determining the quality of water as the representatives of organic contaminants and microorganisms and the level of pollutants [13]. In another study, the performance of the single-media filters in the removal of organic matter and turbidity was investigated. In that study, the single-layer filters contained a layer of one meter sand and dual-media filters contained 60 cm sand and 40 cm anthracite coal, and it was determined that the efficiency of organic matter removal in dual-media filter was higher than single-media filter [14]. In another study conducted in a pilot scale in a treatment plant in China, it was concluded that biological active carbon effectively removed dissolved organic carbon, and microbial population increased over time as well [15]. In studies on double filters, the researchers could remove ammonia and manganese in different loadings using aeration system [16]. In a similar study, with the exception that it was as a multilayer and dual-media filter with the layer of GAC–silica sand, they could remove ammonium, microorganisms, and ultimately inorganic nitrogen as much as 35.2% [17]. Of course, filters are also used to remove hardness, COD, and turbidity. In a pilot-scale study carried out in a treatment plant in China as the electrical coagulation pretreatment in reverse osmosis membranes, it was concluded that the maximum removal for the hardness, COD, and turbidity was 85.82, 66.4, and 93.80%, respectively [18]. This research investigated the efficiency of a dual-media filter with anthracite and silica sand layers at the hydraulic loading rate of 7 and 14 m/h in a rapid gravity sand filter for the removal of TOC and COD as the indices of measuring organic matter in water at Ahvaz water treatment plant. The efficiency of the dual-media filter for COD and TOC removal was compared with a control single-media filter with conventional layer during the filtration.

2. Materials and methods

This research is an experimental-applied research, which was conducted in pilot scale to investigate the rate of filtration and removal of organic matter in the water entering into the Ahvaz water treatment plant. Technical characteristics of the pilot used in the research are displayed in Table 1.

Schematic diagram of dual-media and single-media filters of both pilots used in this research are displayed in Fig. 1.

The water entering into the pilot was supplied through making a split in the sedimentation unit in the treatment plant and was injected into it from the upper part of the pilot by installing a flowmeter in the direction of the input flow according to the considered surface load. In order to avoid turbulence in layer and for the uniform distribution of water, the water was distributed like a shower in the entrance. The layer and the operational terms of the pilots are shown in

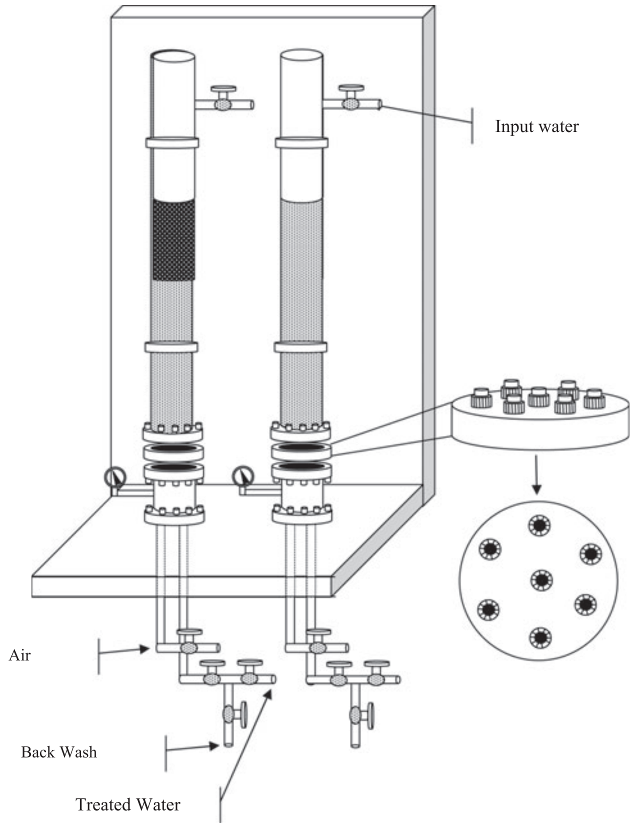

Fig. 1. Schematic diagram of the both pilots used in this research.

Table 2, and the effective size of the Layer fillers was shown in Table 3. The ratio of combination of sand and anthracite used in the layer of filters were selected according to the normal criteria of the filter layer design described in the literature [19].

All the experiments were carried out in the Central Laboratory of Water Treatment Plant according to the instructions of the book of standard methods for water and wastewater examinations [20]. Total organic carbon was measured by means of a TOC analyzer (TOC-VCSH Model) according to the standard method

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	Reverse washing
Bed depth without protective layer (cm)	60	Filter washing base	5NTU Turbidity
Retaining layer depth (cm)	5	Inlet valve location	Just before the water level 145 cm
Depth of water in filter (cm)	90	Outlet valve location	Under drainage system

Table 2
Operational conditions of the used pilots

Administrative procedures of the work	Type of bed		Surface load of pilot filtration (m/h)	
	Single-layer filter pilot	Double-layer filter pilot	7	14
1st week	5 cm of coarse sand + 60 cm of silica sand particles	5 cm of coarse sand + 30 cm of sand and 30 cm of anthracite	*	
2nd week	5 cm of coarse sand + 60 cm of silica sand particles	5 cm of coarse sand + 30 cm of sand and 30 cm of anthracite		*
3rd week	5 cm of coarse sand + 60 cm of silica sand particles	5 cm of coarse sand + 20 cm of sand and 40 cm of anthracite	*	
4th week	5 cm of coarse sand + 60 cm of silica sand particles	5 cm of coarse sand + 20 cm of sand and 40 cm of anthracite		*
5th week	5 cm of coarse sand + 60 cm of silica sand particles	5 cm of coarse sand + 40 cm of sand and 20 cm of anthracite	*	
6th week	5 cm of coarse sand + 60 cm of silica sand particles	5 cm of coarse sand + 40 cm of sand and 20 cm of anthracite		*

*Type of surface load of pilot filtration.

Table 3
The effective size of the materials used in the layer of both pilots

Name of used bed	Effective size (mm)	Uniform coefficient (UC)
Sand (retaining layer)	8–12	1.8
Sand (bed)	0.2–0.8	1.5
Anthracite	0.9–1.1	1.6

of 5310-B, and COD was measured through return digestion package and the standard method of 5220-D. All the statistical analyses were done by Microsoft Excel 2013 and SPSS (Ver. 22) software.

The quality of the water before the filtration process is presented in Table 4.

A backwashing cycle was performed at every 24 h during hydraulic losses using air and chlorinated water. Therefore, the filter cycle time in pilot filter at hydraulic losses was 24 h. The time of filtration was 144 h.

Table 4
The quality of the treated water before filtration process

Parameters	Unit	Quantity
Temperature	℃	25.90
pH	–	8.04
EC	μS/Cm	1,960
Turbidity	NTU	22
Color	TCU	18
Alkalinity	mg/L	131.05
TSS	mg/L	21
TDS	mg/L	1,280
Hardness	mg/L	546.6
Ca^{2+}	mg/L	144
Mg^{2+}	mg/L	46.6
Organic matter (OM)	mg/L	12
Cl^{-}	mg/L	327.2

3. Results and discussion

The results obtained from the laboratory pilot that was run based on single-media and dual-media filter are mentioned in the following. As it is shown in Fig. 2, the data related to the removal of COD and TOC in dual-media filter with sand and anthracite layer (1/2 sand and 1/2 anthracite) were compared with the single-media filter at the loading of 7 m/h.

According to the obtained results, the average percentage of COD removal in the single-media filter (sand) and dual-media filter (1/2 sand and 1/2 anthracite) at the loading of 7 m/h is 27.35 and 64.23%, respectively, which indicates better efficiency of the dual-media filters than the single-media filters.

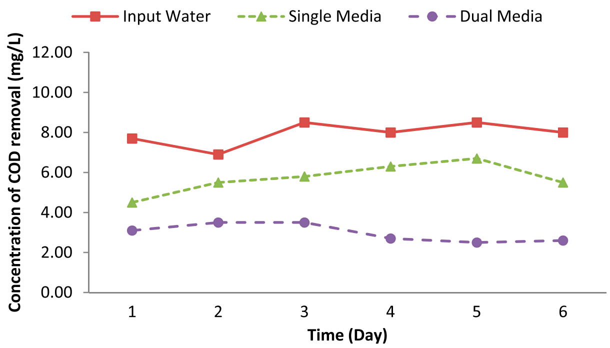

Fig. 2. Diagram of COD removal over time in the single-media and dual-media filters at the loading rate of 7 m/h (1/2 sand and 1/2 anthracite).

The obtained results also show that the average percentage of TOC removal in single-media filter (sand) and dual-media filter (1/2 sand and 1/2 anthracite) at the loading of 7 m/h is 32.56 and 64.08%, respectively (Fig. 3). Zouboulis et al. [21] investigated the performance of a single-media and a dual-media filter for the removal of organic compounds in full scale. Their results showed that the outflow of water from the dual-media filter had the same quality as the outflow of water from single-media filter except that the dual-media filter produced a 10% higher water compared with the single-media one.

The results of the study conducted by Badalians Gholikandi et al. [22] on the application of modified qualitative index for surveillance of water filtration process in turbidity removal by different media showed that particle index was a suitable index as a substitute for turbidity and escaping particle number as indices.

Comparison of the efficiency of the dual-media filter and single-media filter showed that the average percentage of COD removal in single-media and dual-media filters at the loading of 7 m/h was 26.74 and

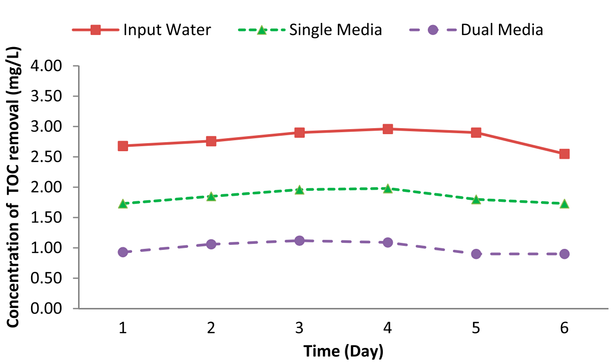

Fig. 3. Diagram of TOC removal over time in the single-media and dual-media filters at the loading of 7 m/h (1/2 sand and 1/2 anthracite).

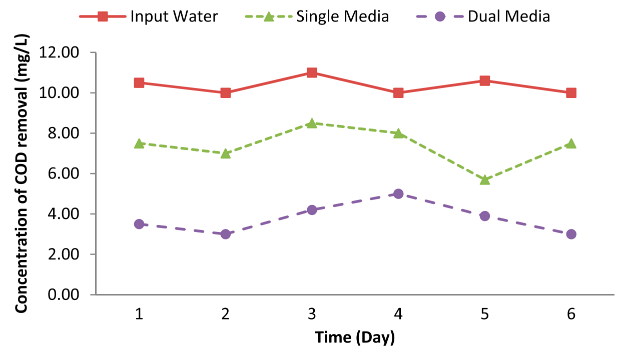

Fig. 4. Diagram of COD removal over time in single-media and dual-media filters at the loading of 7 m/h (1/2 sand and 2/3 anthracite).

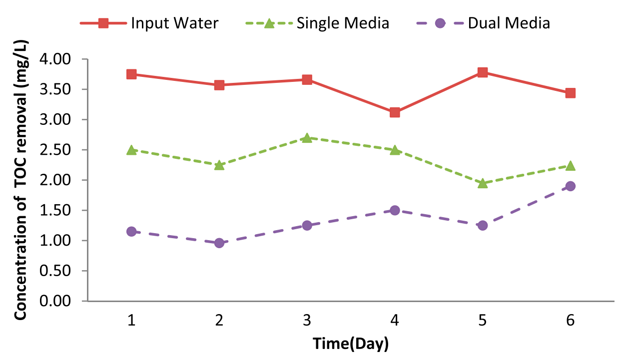

Fig. 5. Diagram of TOC removal over time in single-media and dual-media filters at the loading of 14 m/h (1/2 sand and 2/3 anthracite).

63.28%, respectively, which indicates the increased efficiency of organic matter removal in dual-media filters in comparison with the single-media filters (Fig. 4).

The performance of water treatment at the filtering unit depends on the involved mechanisms. In this research, the higher performances were observed while the filtering unit setup based on both physical and biological stages (in double layer). In fact, while the screening removed the particles physically, the biofilm would consume the organic matter. The biofilm also would improve the physical absorption at the screening media; however, the biofilm could not be grown at the sand layer. The double filtering unit has higher performance in suspension removal than the single filtering unit because of having better uniformity coefficient and higher effective particle size.

Further analyses showed that the average percentage of TOC removal in single-media filter and dual-media filter at the loading of 7 m/h was 31.96 and 64.58%, respectively (Fig. 5). In the study conducted

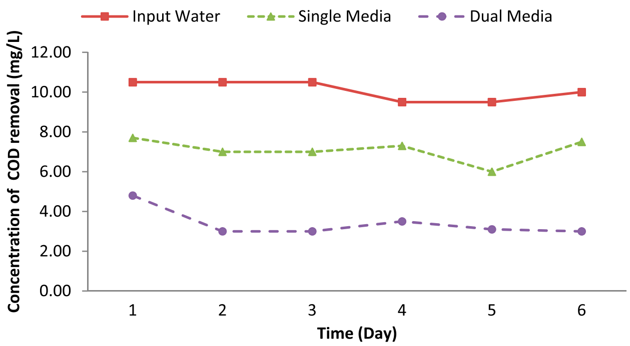

Fig. 6. Diagram of COD removal during different periods of time in single-media filters (sand) and dual-media filters (2/3 sand and 1/3 anthracite).

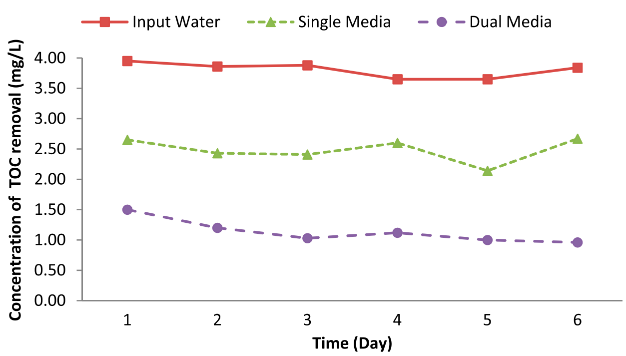

Fig. 7. Diagram of TOC removal during different periods of time in single-media filters (sand) and dual-media filters (2/3 sand and 1/3 anthracite).

by Zouboulis et al. [21], similar results were obtained on the improvement of the organic matter removal by promoting rapid sand single-media filters to dual-media filters with sand and anthracite.

In Figs. 6 and 7, the removal of COD and TOC in dual-media filter with sand and anthracite layer (2/3 sand and 1/3 anthracite) is compared with single-media filter at the loading of 7 m/h. The results indicate that the average percentage of COD removal in single-media filter and dual-media filter is 26.56 and 61.75%, respectively.

According to the measured data, the average percentage of TOC removal in single-media filter and dual-media filter is 32.01 and 66.57%, respectively. Mitrouli et al. [23] conducted a study on the use of new granules in the layer of dual-media filters in seawater filtration. Their results showed that the single-media and dual-media filters had similar performance in the removal of suspended particles and the quality of filtered water to be entered the reverse osmosis system. However, in high-speed filtration (10–15 m/h), the rate of water treated by single-media filters was less than that of dual-media filters, and higher pressure drop was observed in single-media filters.

The number of samples, the mean, and standard deviation of COD and TOC and the output of each pilot are displayed in Table 5, and the results of paired-sample *t*-test of the measured parameters in single-media and dual-media filters are presented in Table 6.

According to Table 6 and the results of paired-sample *t*-test, there is significant difference between the efficiency of COD and TOC removal in single-media and dual-media filters at different loadings ($p < 0.05$).

The pilot output analysis and organic matter removal in single-media and dual-media filters at different loadings are displayed in Table 7.

Our results indicate that the average removal of COD and TOC in single-media filter at the loading rate of 7 m/h were 28.26 and 34.10%, respectively. The corresponding values obtained for the loading

Table 5
The number of samples means and standard deviation of COD and TOC, and the output of each pilot

Group Statistics						
Measurmented parameters	Type of filter	SOR (m/h)	N	Mean	Std. deviation	Std. error mean
COD	Single-layer	Conventional (7m/h)	18	6.6111	1.06599	0.25126
		High rate (14m/h)	18	7.0556	1.22629	0.28904
	Double-layer	Conventional (7m/h)	18	3.3167	0.74538	0.17569
		High rate (14m/h)	18	3.5944	0.84608	0.19942
TOC	Single-layer	Conventional (7m/h)	18	2.1828	0.35691	0.08412
		High rate (14m/h)	18	2.4444	0.39921	0.09409
	Double-layer	Conventional (7m/h)	18	1.1339	0.27541	0.06491
		High rate (14m/h)	18	1.2378	0.25742	0.06067

Table 6
The results of paired-sample t-test of the measured parameters in single-media and dual-media filters

Statistic Pair	Statistic analyze of measured parameters	Paired differences					
		Mean	Std. deviation	Std. error mean	t	df	Sig. (2-tailed)
Pair 1	COD single-media with COD dual-media	3.37778	0.84214	0.14036	24.066	35	0.0001
Pair 2	TOC single-media with TOC dual-media	1.12778	0.31665	0.05278	21.369	35	0.0001

Table 7
Comparison of the efficiency of organic matter removal (COD and TOC) in single-media and dual-media filters at different loadings

Type of filter	Surface load (m/h)	Average COD of inflow (mg/L)	Average COD of outflow (mg/L)	Average percentage of COD removal (%)	Average TOC of inflow (mg/L)	Average TOC of outflow (mg/L)	Average percentage of TOC removal (%)
Single-layer	7	9.25	6.61	28.26	3.32	2.18	34.10
	14	9.44	7.06	25.51	3.51	2.44	30.25
Dual-layer	7	9.25	3.32	63.95	3.32	1.13	65.59
	14	9.44	3.59	62.23	3.51	1.24	64.56

rate of 14 m/h were 25.51 and 30.25%, respectively. In comparison, the average COD and TOC removal in dual-media pilot filter, at the loading rate of 7 m/h, was 63.95 and 65.59%, respectively. The corresponding values for the loading rate of 14 m/h (in dual-media filter) were 62.23 and 64.56%, respectively.

4. Conclusion

The obtained results showed that the mean of TOC removal in single-media and dual-media pilot was 34.10 and 65.59%, respectively; and the mean of COD removal in dual-media and single-media pilot was 63.95 and 28.26%, respectively. The results of the research showed that the use of anthracite in the layer of dual-media filters increased the efficiency of organic matter removal (TOC, COD) in comparison with single-media filters (sand). Therefore, it is recommended to promote single-media filters to dual-media filters. Of course, it should be noted that the primary designing of the filters and appropriate layering in terms of optimum height of each one of the layers should be done very carefully with regard to the credible scientific resources and the others' experiences.

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