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Pilot investigation of two-stage high speed filtration for the water treatment in Northwest China

Xin Geng[a,b], Feng Xiao[a,*], Hui Xu[a], Dongsheng Wang[a,*]

[a]*Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, No. 18 Shuangqing Road, Beijing, 100085, China, Tel. +86-10- 62849144, email: xingeng_st@rcees.ac.cn (X. Geng), Tel. +861062849143, email: fengxiao@rcees.ac.cn (F. Xiao), Tel. +86-10- 62849143, email: xhwan_1985@aliyun.com (H. Xu), Tel. +861062849138, email: wgds@rcees.ac.cn (D. Wang)*
[b]*University of Chinese Academy of Sciences, No. 19A Yuquan Road, Beijing, 100049, China*

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ABSTRACT

In this paper, an innovative two-stage filtration technology that could separately backwash the two filter columns was employed in a drinking water treatment plant, located in Northwest China, Yinchuan. Effects of filter layer configuration features on the filtration efficiency and head loss were thoroughly studied. Eight types of granular package filter media were investigated and compared to the conventional filtration process. Twelve runs of various filter media and packing height (of totally 1,000 mm depth) were conducted at a constant filtration rate of 20 m h^{-1} using the settled water (1–3°C) from the drinking water treatment plant as raw water. The removal efficiencies for turbidity and UV_{254} by two-stage high speed filtration technology were similar to those by other conventional filters under the acceptable head loss development. However, the filtration rate of this filter was two times higher than those of other filters while the backwash water rate was only one-third of the conventional filtration technology.

Keywords: Two-stage filtration; High speed filtration; Drinking water treatment; Backwash water rate

1. Introduction

Filtration process, as a final polishing process for drinking water production, plays a crucial role for water quality in water treatment plants [1–3]. In the filtration process, a porous medium is used to remove suspended solids when water passes [4]. Generally, filtration can be classified into single-, dual-, or multi-media filtration by media types; slow, rapid, or high filtration by flow rate; upflow or downflow filtration by direction of flow; or gravity or pressure filtration by driving force [5]. No matter which kind of technology is used, the basic principle of filtration is the same [4].

There are two main mechanisms of filtration: deep filtration and cake filtration [6], and deep filtration is the more important one. When the suspended particle size is smaller than the medium pore diameter, these particles will enter the internal medium, approach to channel wall, and be removed from the fluid through sedimentation, interception, and diffusion. Particles with an average equivalent diameter smaller than 1 μm are removed dominantly through diffusion due to Brownian motion [7], while particles with an average equivalent diameter bigger than 1 μm are removed dominantly through sedimentation and interception [8]. Deep filtration will make the pores of the filter media reduce gradually. When the pore size is smaller than the particle size, the smaller particles are blocked and form cake on the surface of media, which form cake filtration mechanism [9]. At the same time, the real effect on the interception of particle is the filter cake, and filter medium only plays the role of supporting filter cake. Good filter is designed to prevent the cake formation on the filter surface, due to the fact that head loss of the filter will increase rapidly [10].

*Corresponding authors.

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Filtration rate is one of the most critical design parameters for filtration process [11,12]. Filtration rate is the flow rate normalized by filter section area, which is typically proportional to the production capacity of the filter. The section area of the desired filter can be reduced, thereby greatly reduce the construction cost of water treatment plant, by designing a higher filtration rate filter. However, the filter's treatment efficiency will reduce with the filtration rate increasing. Therefore, the most effective filter is to maximize filtration rate based on acceptable water treatment efficiency [12]. Although dual- or multi-media filter can increase filtration rate, the filter media may be intermixed during backwash [8].

In the Northwest China, it has long winter frozen period, in which the surface water temperature drops to 0–4°C, and turbidity reduces to 10–30 NTU, even below 10 NTU. Because of low turbidity and small colloidal particles, the probability of particle aggregation is reduced. On the other hand, as a result of low water temperature and the higher zeta potential of the particles, the repulsive potential energy is larger, and the Brownian motion of the particles is weakened. The viscosity coefficient is improved, which makes the colloidal particles hard to be destabilized. The drinking water treatment in this region becomes a major problem due to the surface water properties of low temperature and low turbidity [13].

The objectives of this pilot study were to investigate the feasibility of the two-stage high speed filtration technology (20 m h^{-1}) for the treatment of surface water in Northwest China. Settled water from water treatment plant was adopted in this pilot experiment. The efficiency of filtration was evaluated by turbidity removal efficiency, and the removal efficiency for organic matter represented by UV_{254} removal. Effects of filter layer configuration features such as type, size, composition of filter media, thickness of filter on the filtration efficiency, and head loss were studied. In order to extend the application, backwash water rate and energy cost were also evaluated in this study.

2. Materials and methods

2.1. Water source and properties

This study was conducted using the settled water from one of the drinking water treatment plants in the upper reaches of the Yellow River (in Ningxia, China), which typically treats 200,000 m^3 d^{-1} of surface water. The main processes of this drinking water treatment plant include the following steps: (1) Raw-water screening – raw water passes through a bar rack and a fine grid to remove coarse debris; (2) coagulation – the addition of polymeric aluminum chloride (20–24 mg L^{-1}) and polyacrylamide (0.08–0.10 mg L^{-1}) to destabilize colloidal particles and facilitate their flocculation with other suspended particles; (3) flocculation – the agitation of coagulated water by agitator to promote the aggregation of suspended matter to form flocs; (4) sedimentation – using inclined tube settler to promote the settling of suspended solids and flocs; (5) filtration – settled water is filtered by 1.5 m high quartz sand filter at the filtration rate of 7 m h^{-1} to retain remaining fine particles in the water; finally (6) disinfection – the addition of chlorine gas to maintain a chlorine residual in the distribution system.

During the study period, a slipstream from the main pipeline connecting sedimentation tank and filter was used to cover the needs of the study. The settled water quality was characterized by a turbidity of 2.4 ± 0.3 NTU, UV_{254} value of 0.061 ± 0.011, Total organic carbon (TOC) value of 4.77 ± 0.57 mg L^{-1}, pH of 8.1 ± 0.3, and temperature of 2 ± 1°C.

2.2. Experimental instruments

The pilot-scale experimental equipment adopted two-stage filtration technique, which was designed to be connected with two downflow filter columns in series. The two filter columns can be backwashed separately; thus, different filter media cannot be mixed like the dual filter. The two-stage filter design was also used to achieve different functions in the two-section filter columns. The first stage, called as receiving pollution (RP) stage, was considered to trap the larger solids and had the capacity of receiving more pollutants. The second stage, called as intercept turbidity (IT) stage, was considered to hold back the particles from the effluent of RP stage and prevented the smaller particles from penetrating. This function considerably maximizes the solids' holding capacities of two-stage filters in comparison with the existing single-filter bed, hence increases the time of filtration cycle, and substantially reduces the necessary time for backwashing.

The schematic diagram of the pilot-scale experiment set is shown in Fig. 1. The columns of RP stage and IT stage are made of plexiglass with an inner diameter of 50 mm and a height of 800 or 1,000 mm, separately. The two ports with valves are settled at the top of each column filter: One acts as a water flow inlet, and the other acts as exhaust port at the beginning of filter run, as pressure port in filtration process, as wastewater outlet for filter backwash water. The two ports with valves are also arranged at the bottom of each column filter: One is used as a water flow outlet, and the other is used as pressure port in filtration process, which is also used as backwash water inlet during backwashing. Settled water from water treatment plant inflows into constant head feed tank by gravity, then agitated by 30 rpm to prevent deterioration of outlet from the bottom of the tank because of the longer hydraulic residence time (HRT). In order to prevent the breakage of floc particle into the RP stage column, the outlet of constant head feed tank is directly connected with the inlet of the RP stage column, and the water is drawn out by the filter pump at the outlet of the RP stage column. The outlet of the filter pump is connected with the inlet of the IT stage column; therefore, the two-stage columns can be connected in series. In the device, permeate tank and backwash pump are arranged to meet the requirement of the backwashing.

2.3. Experimental filter media

Eight types of granular package filter media were used in this study, which contained three types of sand (two kinds of particle size per each type), anthracite (ATR), and activated carbon. Sand and ATR, because of its low

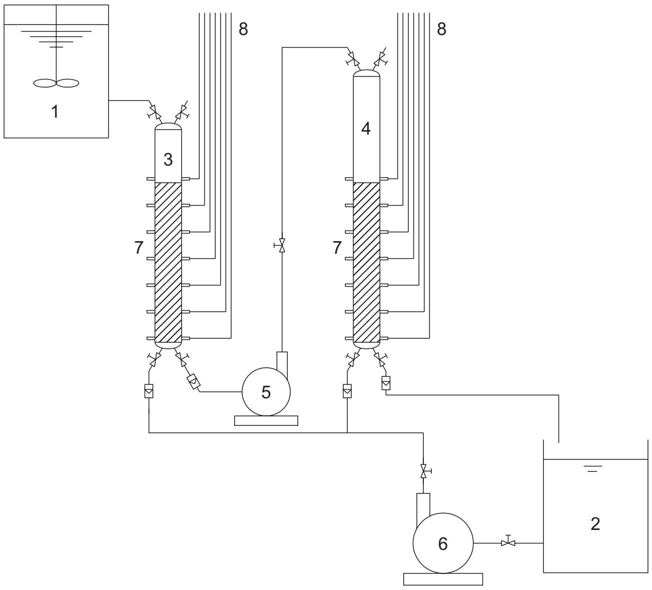

Fig. 1. The schematic diagram of the pilot-scale experiment set: (1) constant head feed tank, (2) permeate tank, (3) RP stage filter column, (4) IT stage filter column, (5) filter pump, (6) backwash pump, (7) sampling ports, and (8) piezometers.

cost and ease of operation, are widely used in water treatment plants [14]. The sand filter can be divided into quartz sand, sea sand, and manganese sand. Quartz sand has rough surface with edges, which is made of natural quartz ore by crushing. Sea sand has smooth surface, but with high salt content. Sea sand is cheaper than quartz sand since it is directly from the ocean, without crushing. Manganese sand is made of high-quality natural manganese ore, which has effects on the removal of metal from water [15,16]. Activated carbon has the large specific surface area and can remove heavy metals [17] and disinfection by-products precursors [18,19] from polluted surface water. It is gradually accepted for water treatment because of the decline of the prices for raw materials and production. The characteristics of the materials are listed in Table 1.

2.4. Filtration procedures

The pilot experiment was divided into two steps. The first step was to study the five kinds of coarse particle filter materials (coarse quartz sand [CQS], coarse sea sand [CSS], coarse manganese sand [CMS], ATR, columnar activated carbon [CAC]) for the RP stage column, which were completed in five experiments, respectively. In each experiment, the RP stage column was filled with one coarse filter material with a depth of 600 mm and runs 48 h continuously. Based on the results in the first step, two kinds of filter media, ATR and CAC, were identified as the presupposed filter materials of RP stage column to conduct the second step experiment. In the second step, the total removal efficiency of the two-stage filter was studied. Twelve combinations of filter media and packing height were studied, which contained two kinds of filter media for RP stage column, three kinds of filter media for IT stage column, and two kinds of packing height (600 mm in RP + 400 mm in IT or 400 mm in RP + 600 mm in IT). All the filtration experiments run 48 h continuously.

All the filtration experiments were performed at a constant filtration rate of 20 m h^{-1}, and the performances of the filter columns were monitored continuously. Piezometers located throughout the filter columns were used to determine the head loss through the filters. Samples of interstitial water within the filter bed at different depths were collected in the prewashed flasks.

The surface morphology and elemental chemical composition of the granular filter media were observed by field emission scanning electron microscopy (FE-SEM; SU8000 Series UHR FE-SEM, Hitachi, USA) coupled with energy dispersive X-ray spectroscopy (EDS, Hitachi, USA).

A scattered light turbidimeter (Model 2100N, HACH, Loveland, CO, USA) was used to measure the turbidity of filter influent and final filter effluent. Each sample was characterized for UV_{254} using an ultraviolet-visible spectrophotometer (Model 2910, Hitachi Inc., Japan) before tests and after the filtration. Prior to analysis, samples were filtered through 0.45 µm nitrocellulose membrane. TOC concentration was determined by a TOC analyzer (Model TOC–5000, Shimadzu Co., Japan).

Three-dimensional fluorescence excitation-emission matrix (3D-EEM) spectra of influent and effluent were measured using a luminescence spectrometer (F-7000, Hitachi, Japan), and the matrix spectra were obtained by collecting

Table 1
The characteristics of granular filter media used in this study

No.	Media type	Abbreviation	D10 (mm)	K80	Particle density (g cm^{-3})	Bulk density (g cm^{-3})
1	Fine quartz sand	FQS	0.54	1.53	2.65	1.62
2	Coarse quartz sand	CQS	1.36	1.36	2.63	1.57
3	Fine sea sand	FSS	0.51	1.59	2.67	1.53
4	Coarse sea sand	CSS	0.83	1.43	2.66	1.48
5	Fine manganese sand	FMS	0.57	1.65	2.66	1.84
6	Coarse manganese sand	CMS	1.52	1.34	2.65	1.75
7	Anthracite	ATR	1.04	1.39	1.57	0.94
8	Columnar activated carbon	CAC	Φ = 1, L = 1.0–2.5		–	0.52

excitation and emission spectra over a range (excitation wavelength (Ex) between 200 and 400 nm, emission wavelength (Em) between 220 and 550 nm, at 5 nm sampling intervals). Instrumental parameters were excitation and emission slits, 5 nm; response time, 0.01 s; and scan speed, 2,400 nm min^{-1}. Data were analyzed by software origin 8.0. Spectral subtraction was performed to remove blank spectra mainly caused by Raman scattering.

3. Results and discussion

3.1. Characterization of the filter media

The surface morphology and elemental compositions of different filter media were characterized by FE-SEM coupled with an EDS, which were shown in Fig. 2. Sea sand had smooth clean surface, while the quartz sand, which was obtained by breakage of larger particles, had irregular rough shape and a coarse surface. They all contained only silicon dioxide. On the contrary, each surface of manganese sand was apparently occupied by iron oxides and manganese oxides, and had a rough surface. ATR particles exhibited smooth surfaces, while CAC obviously showed the porous structure. Both of them were just made of carbon.

3.2. Comparison of coarse granular filter media for the RP stage column

Five different filter media were performed in the first step experiments to determine the optimum filtration media for RP stage column. Effluent turbidity as a function of time for different filter media is presented in Fig. 3. The positive effect of decreasing the granular size of filter media on removal efficiency is also shown in Fig. 3. Superficially, when CSS was used as media, the effluent turbidity could achieve the optimum effect, which could below 0.8 NTU. Meanwhile, when CMS was used as media, the effluent turbidity reached up to 1.5 NTU. As expected, the effluent turbidity was mainly related to the granular sizes of filter media rather than the types. Although the size of CAC was bigger than CQS, the removal efficiency was the better, due to the properties of porous which could provide more surface area to accept suspended matter in water.

Effluent turbidity was quickly stabilized within the first 1 h when CSS was used as media. The cumulative interception of suspended solids made the pores of the filter media reduce gradually. In the case of constant filtration rate, the head loss was increasing with filter run (Fig. 6), which finally caused turbidity breakthrough [20]. After 48 h, the turbidity exceeded 1.5 NTU. By contrast, for ATR, the initial period as long as 3 h was needed for achieving stable effluent turbidity, which could not be penetrated in the 48 h.

Effluent UV_{254} as a function of time for different filter media is presented in Fig. 4. It is obvious that when CAC was used as filter media, the effluent UV_{254} was the lowest, which was just 0.009 at the beginning, gradually increased with the filter run, finally reached 0.033 at 48 h. As predicted, CAC could adsorb more dissolved organic matter owing to its larger surface area and pore volume [21,22]. In sand filter media, CMS had the optimum performance, whose effluent UV_{254} could stable at 0.042, owing to the character of CMS. CMS is a type of silica medium coated with iron oxides and manganese oxides (Fig. 2). P.-Y. Hu et al. [23] found that manganese-coated sand had more micro pores and higher specific surface area, owing to attachment of manganese sand. The special surface structure made manganese sand have a strong adsorption of organic matter.

For all filter media tested, the majority of turbidity removal occurred in the top few decimeters of media, consistent with the current understanding of particle removal mechanisms. A time series analysis of turbidity removal efficiencies throughout the filter runs revealed that the first measurable particle removal occurred in the top section of the media, and the deeper sections become more important with the filter runs. This trend was similar for all filter media (data not shown).

Relative turbidity as a function of depth profiles for different filter media at 40 h are presented in Fig. 5. The increase in removal efficiency with the decrease in granular sizes can be seen. Turbidity removal efficiencies throughout the entire filter media were greatly increased when granular sizes decreased from 1.52 mm (CMS) to 0.83 mm (CSS) at 40 h. For example, relative turbidity removal decreased from 64% to 35% at a media depth of 300 mm and from 55% to 32% across the entire filter media when granular sizes decreased from 1.52 mm to 0.83 mm.

Head loss of filter across the entire filter media as a function of time for different filter media is shown in Fig. 6. It is shown that head loss developed apparently when the granular size was smaller. Head loss throughout the entire filter media was greatly increased when granular sizes decreased from 1.52 mm (CMS) to 0.83 mm (CSS) in the filter run. Head loss increased from 24 to 48 mm at the beginning of filter run and from 208 to 724 mm across the entire 48 h when granular size decreased from 1.52 to 0.83 mm [24].

Normalized increase of head loss as a function of depth profiles for different filter media at 40 h is shown in Fig. 7. The pressures at different depths of the entire filter column were measured to monitor changes in head loss during the filtration process. In order to normalize the data for various filer media section, the head loss (ΔH) was divided by the clean-bed head loss. The increasing of the normalized head loss ($\Delta H/\Delta H_0$–1) was proportionate to the mass of deposited particles [25], which provided a qualitative comparison of particle aggradation features for different depths of filter media. The aggradation features were measured at 40 h, which was nearby shut down for most filter works. From this analysis, some significant conclusions about the effect of filter media performance can be made.

In each media section, the normalized head loss ($\Delta H/\Delta H_0$–1) tended to vary inversely relative to filter media grain size. As the result, the mass removed throughout the filter bed was reduced by greater gain sizes. It was consistent with the effluent quality data. For greater grain sizes, decreased particle aggradation at the top of the media will cause higher particle concentrations in deeper media sections, because particle removal is a function of particle aggradation, and the deeper sections will experience increased particle capture. The differences between grain sizes in the filter bed may explain the phenomenon.

As observed, decreasing the degree of grain sizes could improve both removal efficiency and head loss across the

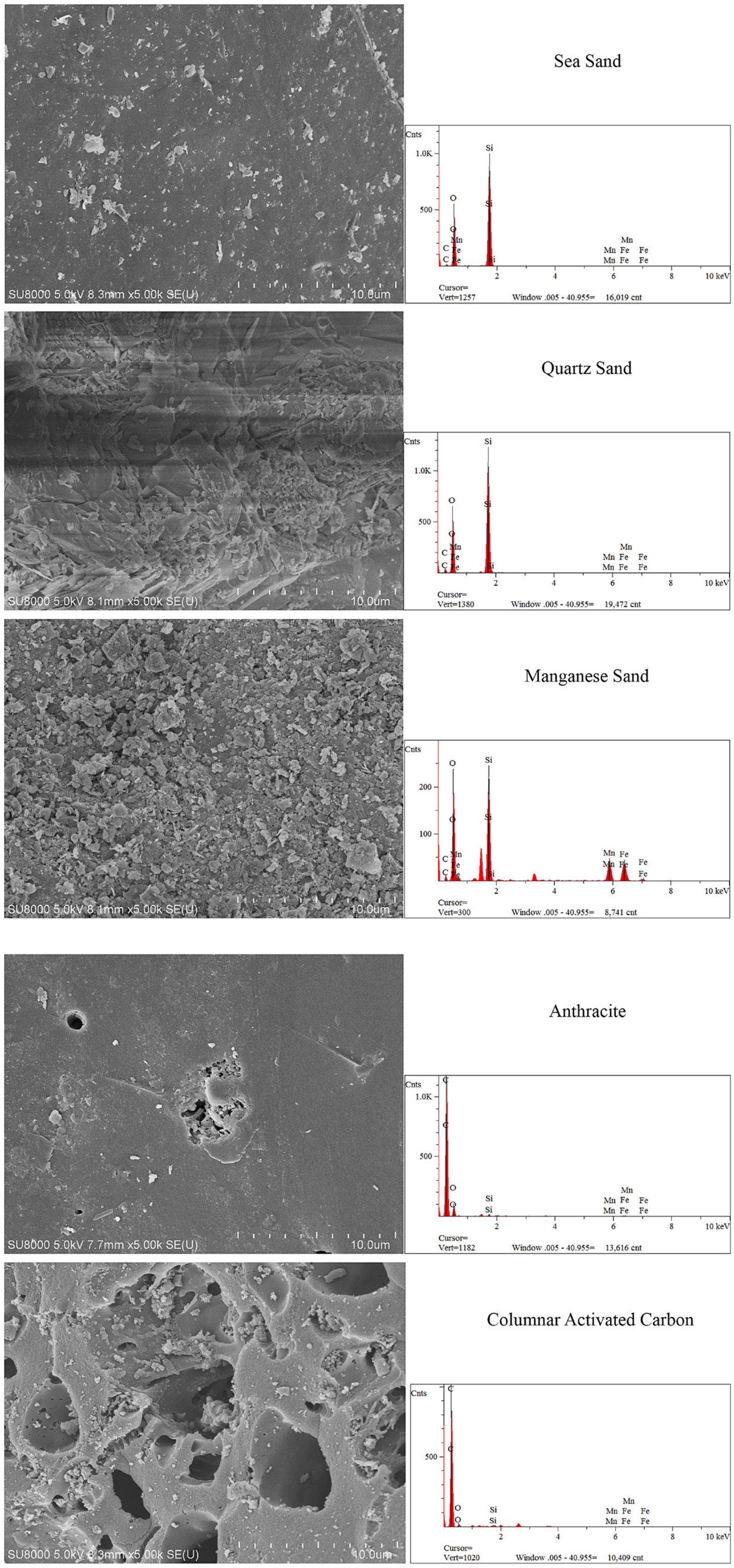

Fig. 2. FE-SEM photographs and EDS analysis of different filter media.

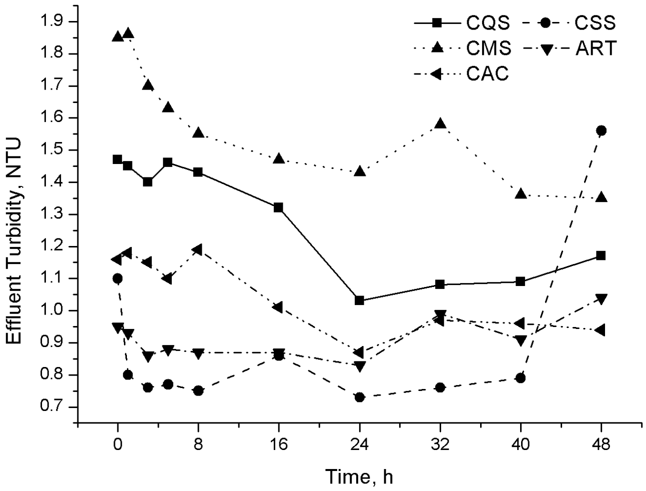

Fig. 3. Effluent turbidity during filter run for different coarse filter media.

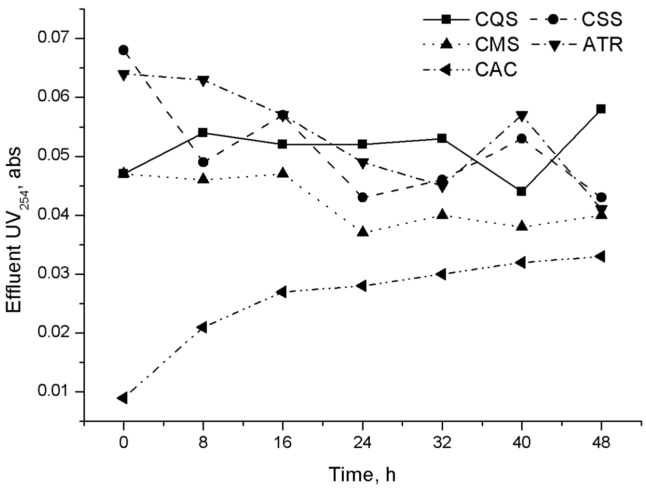

Fig. 4. Effluent UV_{254} during filter run for different coarse filter media.

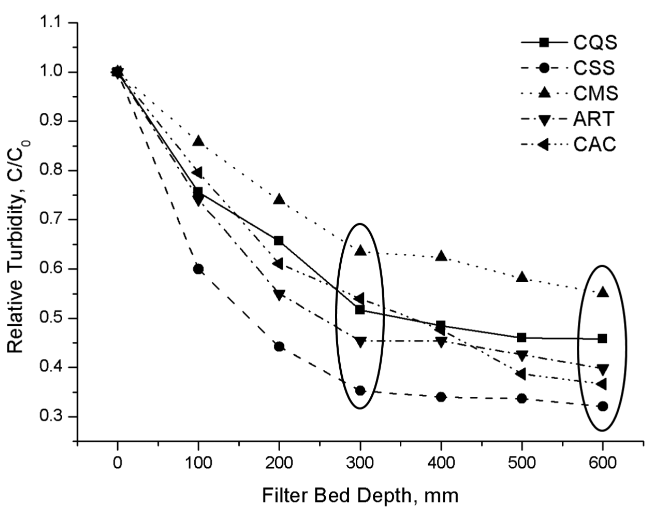

Fig. 5. Relative turbidity removal vs. filter bed depth for different coarse filter media.

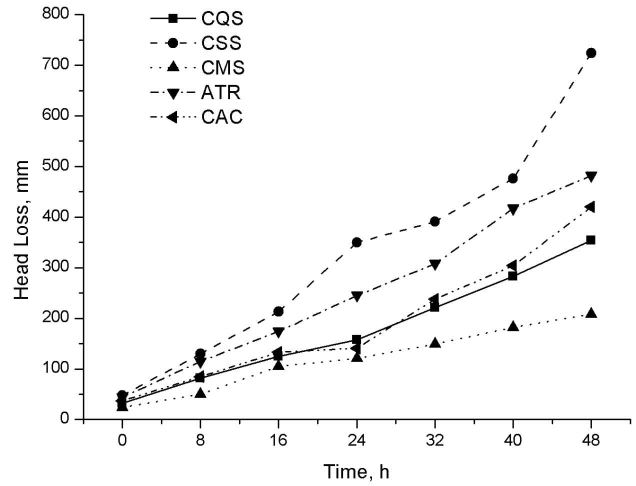

Fig. 6. Head loss during filter run for different coarse filter media.

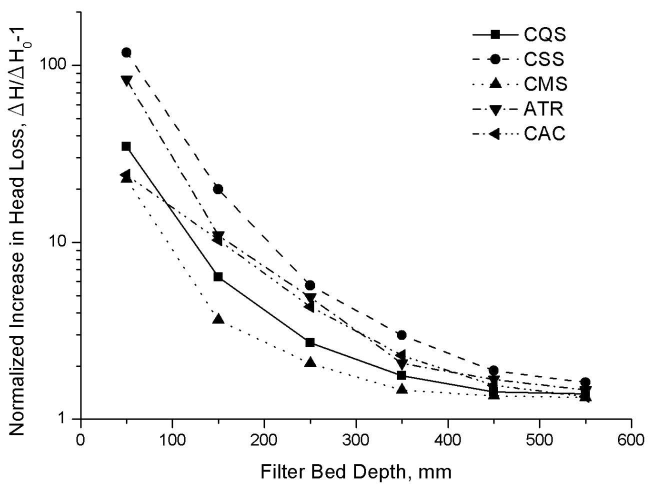

Fig. 7. Normalized increase of head loss vs. filter bed depth for different coarse filter media.

filter media. There was a suitable grain size for the RP stage column that ensures the desired effluent quality while keeping head loss across the filter media at reasonable levels. ATR and CAC, whose effluent turbidity were consistently below 1.2 NTU, with acceptable head loss development at a high filtration rate of 20 m h^{-1} (Fig. 3), were identified as the presupposed filter material of RP stage column to carry out the following experiment.

3.3. Comparison of the filter media combinations for two-stage filtration

Twelve combinations of five different filter media were performed in the second step experiments to determine the optimum assembly in the device at high filtration rate (20 m h^{-1}) for the treatment of surface water in Northwest China. Two types of filter media were installed in two-stage column separately in each experiment to prevent them from mixing. Settled water was still used in each experiment.

Effluent turbidity of each experimental filter was recorded in 48 h, to compare filter performances at different combinations of filter media and packing height. Effluent turbidity as a function of time for different combinations are plotted in Fig. 8. As shown, effluent turbidity decreased obviously at all type of filtration media, when the height of fine particle filter media increased. But when FMS and fine sea sand (FSS) were used as the filter media of IT stage column, effluent turbidity was worse than fine quartz sand (FQS) at almost the same granular size, which was owing to the rougher surface of FQS. From the curves plotted in Fig. 8, it can be concluded that, for the height of IT stage column between 400 and 600 mm when FQS was used, effluent turbidity would be equal to or lower than 0.2 NTU. It is worth noting that the turbidity limit recommended by the legislation is 1.0 NTU in China.

Effluent UV_{254} as a function of time for different combinations are plotted in Fig. 9. It is shown that when CAC was used as the filter media in the RP stage column, removal efficiency of UV_{254} was improved with the increase of the height of RP stage column, which was derived by using all of the effluent turbidity data recorded continuously throughout the entire period of the filter run. However, the height of RP stage column had no significant effect on the effluent UV_{254}, when ART was used as the filter media in this column. It is shown that the removal efficiency of UV_{254} by CAC surpassed all the others (Fig. 4). Meanwhile, when CAC was used in the RP stage column, effluent UV_{254} gradually increased with the filter run in all height combination, and when ART was used, the opposite occurred.

However, increasing the height of IT stage column also led to an increase in head loss, as shown in Fig. 10. The head loss increased gradually along with the filter run, due to the partial block of the pore spaces in the filters resulted from the accumulative deposition of particles. It was worth mentioning that all combinations, except for 60 mm CAC + 40 mm FQS, could make the total head loss reaching or getting higher than 2,200 mm in the 48 h, which far exceeds the actual design of the drinking water treatment plant, 1,500 mm.

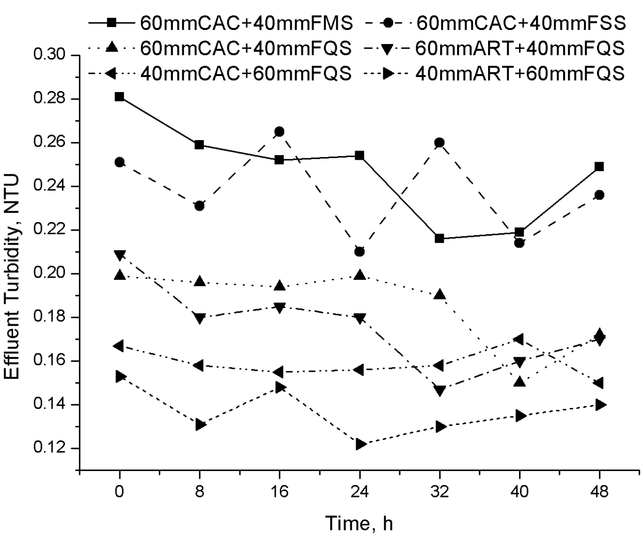

Fig. 8. Effluent turbidity during filter run for different combinational filter media.

Based on the comprehensive evaluation with respect to two-stage high speed filtration performance, the combination of 60 mm CAC + 40 mm FQS was regarded as the optimal value for the filtration media. When this combination was used as the filter media, effluent turbidity was consistently lower than 0.2 NTU, and UV_{254} was lower than 0.030 during entire period of the filter run with acceptable head loss development at a high filtration rate of 20 m h^{-1}.

The above results can be seen that the two-stage high speed filtration has a good performance to treat surface water in Northwest China. There are two main reasons for this: (1) The design of filtration equipment. The filtration equipment adopts two-stage filtration technique, which is designed to achieve different functions in the two section filter columns. The first stage column is filled with coarse filtration media, which can remove more suspended particles at deeper filter bed [26]; while, the second stage col-

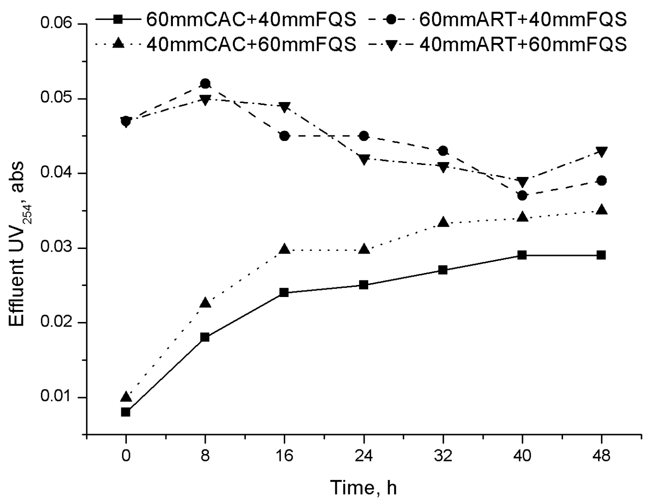

Fig. 9. Effluent UV_{254} during filter run for different combinational filter media.

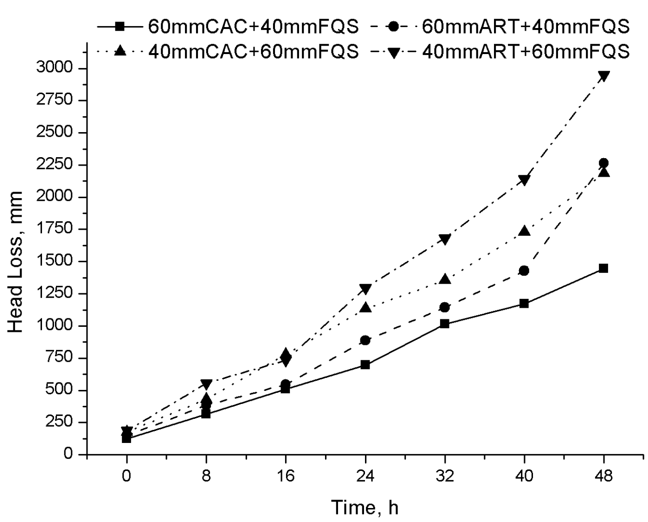

Fig. 10. Head loss during filter run for different combinational filter media.

umn is filled with fine filtration media, which can prevent the smaller particles from penetrating. Thus, the internal pore size is reducing in the deeper filter bed with filter run. When low temperature settled water pass through the filter, the deposited particles play a promotion role in the interception of the suspended matter. (2) The selection of filtration media. In this filter, CAC is used in the first stage column. It has large specific surface area and obvious porous structure, which cause turbulence when the water passes by. Suspended particles easily approached the surface of filter media, in the role of turbulence, and were removed from water.

3.4. Overall evaluation for two-stage high speed filtration

Based on the above experiments with respect to the removal of turbidity, UV_{254}, and development of head loss, the optimal filter layer configuration (60 mm CAC + 40 mm FQS) for the two-stage high speed filtration for water treatment in Northwest China was determined. The optimal configuration will be overall evaluated in the field of organics removal and backwash water rate during the following discussions.

3D-EEMs of influent and effluent of two-stage filter with 60 mm CAC + 40 mm FQS were measured, and the results were illustrated in Fig. 11. The influent of the filter shows maxima at three peaks: Ex = 275 nm and Em = 335 nm, Ex = 245 nm and Em = 390 nm, and a very weak intensity at Ex = 240 nm and Em = 350 nm. The fluorescence regional integration (FRI) method was employed to analyze the five excitation–emission regions [27] in order to better understand the EEM fluorescence characteristics of DOM in water. According to this research [27], these peaks corresponded to soluble microbial by-product-like zone, fulvic acid-like zone, and aromatic protein II zone. In general, those peaks located at intermediate excitation wavelengths (250–280 nm) and shorter emission wavelengths (<380 nm) are related to soluble microbial by-product-like material (Region IV) [28,29]. Peaks located at the excitation wavelengths (200–250 nm) and the emission wavelengths (>380 nm) represent fulvic acid-like substances (Region III) [30] while peaks at shorter wavelengths (<250 nm) and shorter emission wavelengths (<350 nm) are related to simple aromatic proteins such as tyrosine and tryptophan (Regions I and II) [31]. From 3D-EEM of the effluent, it could be seen that the three peaks in the effluent decreased compared with that of the influent, and that could be due to the adsorption of fluorescence substances by filter media.

It is certainly worth noting that the establishment of three quality criteria, operation time, effluent turbidity, and head loss is normally used to evaluate the appropriate operation of filtration process. In order to avoid problems as a result of the buildup of a biological layer on the filter media surface, one of the filter normal cycles was set to about 48 h. While the effluent turbidity limit was set based on existing guidelines for drinking water, the total head loss can meet the design requirements. Whichever criteria were covered, the filtration process was turned to the backwash process.

In the two-stage high speed filtration technology, effluent turbidity and head loss cannot meet the criteria in 48 h, so filter run is set as the maximum residence time, 48 h, at filtration rate of 20 m h^{-1}. However, the rapid sand filter in the drinking water treatment plant just ran at filtration rate of 7 m h^{-1} for 24 h before backwashing, which used the backwashing intension of 15 L s^{-1} m^{-2} for 10 min to carry out backwashing. The same method is used to backwash two columns separately. The percentage of total water used for backwashing in the pilot study and the actual water treatment plant was computed using the following expression:

$$R = Q_b / (Q_b + Q_f)$$

where R = backwash water rate (%); Q_b = water consumption of backwash water (L); and Q_f = total filtered water (L).

According to the calculation results in Table 2, the two-stage high speed filter reduces backwash water rate to 1.84%, compared with the actual water treatment filter of 5.08%. The ability to reduce the amount of backwash water has significant cost implications with respect to sizing the water treatment processes. Under the same water production, the two-stage high speed filter greatly reduces the amount of backwash water used and thereby reduces the cost of water treatment.

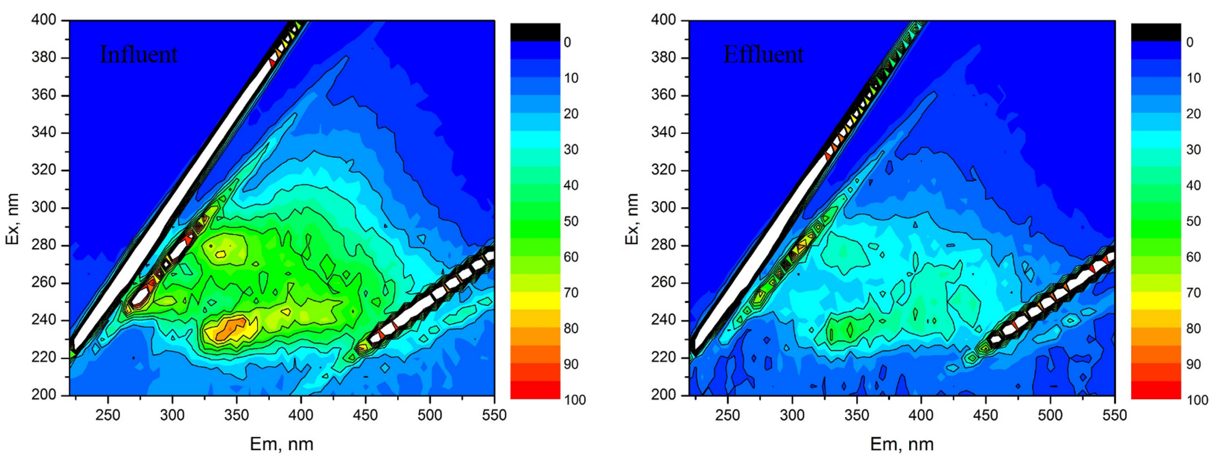

Fig. 11. The EEMs of organic compounds in influent and effluent of two-stage filter.

Table 2
Calculation table of backwash water rate

	Filtration time (h)	Filtration rate (m h^{-1})	Filter area (m^2)	Backwash intensity (L s^{-1} m^{-2})	Backwash time (min)	Q_f (m^3)	Q_b (m^3)	R (%)
This filter	48	20	2n*	15	10	960n	18n	1.84
Actual filter	24	7	n	15	10	168n	9n	5.08

*Using n to calculate Q_f, and using 2n to calculate Q_b, due to backwash two-stage column separately.

Typical dual media filter used ATR and quartz sand as filter media, of which filtration rate is about 7 m h^{-1} [13,14,32,33]. The innovative two-stage filtration technology in the study can effectively prevent different filter media from intermixing. Arbitrary combinations of type or height of filter media can be accepted without considering the effect of particle density of the media. The combination of 60 mm CAC + 40 mm FQS was regarded as the optimal value for the filter media at filtration rate of 20 m h^{-1} by experiments. The backwash water rate of the two-stage filter was only one-third of those of typical filters under the same water production. The innovative two-stage filtration technology has a certain reference value for the improvement of the water treatment plant, especially for water shortage area like Northwest China.

4. Conclusion

In this paper, the innovative two-stage high speed filtration technology is proved to be feasible to treat surface water in Northwest China, in which the two filter columns can be backwashed separately to prevent different filter media from mixing caused by the different densities as opposed to traditional dual filter. Its performances, with respect to removal of turbidity, UV_{254} and development of head loss, are similar to the performances of other more conventional filters with the exception that filtration rate is two to three times more than that of other filters and the backwash water rate is only one-third of those of other filters. In the first part of the experiment, ATR and CAC, which effluent turbidity was consistently below 1.2 NTU, with acceptable head loss development at a high filtration rate of 20 m h^{-1}, were identified as the presupposed filter material of RP stage column based on performance comparisons of five kinds of coarse particle filter media. In the second part of the experiment, twelve combinations of filter media and packing height were studied; the combination of 60 mm CAC + 40 mm FQS was regarded as the optimal value for the filtration media. When the above combination was used as the filter media, effluent turbidity was consistently low than 0.2 NTU, and UV_{254} was lower than 0.030, with acceptable head loss development during entire 48-h filter run.

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