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Factors controlling the ripening of manganese removal filters in conventional aeration-filtration groundwater treatment

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ABSTRACT

Relatively long operational time is required to achieve effective manganese removal in conventional aeration-filtration groundwater treatment with virgin filter media. Ripening period depends on water quality, operational parameters, and the filter media used. This study assessed the role of filter media type, backwashing and iron loading on the time required to achieve very effective manganese removal. Filter runs were conducted with two set-ups each with six pilot filters with virgin sand or anthracite, and different types of manganese oxide coated sand/anthracite (MOCS/MOCA). Pre-treated groundwater (aeration-rapid sand filtration), either directly, or after an additional pre-treatment (ultrafiltration-UF), was used as feed water. UF pre-treatment eliminated head loss development in pilot filters and backwashing was consequently not required. Filters that received feed water without UF pre-treatment required backwashing after 14 d of continuous operation. Use of virgin sand and anthracite resulted in comparable ripening time (25 d and 14 d for feed water without and with UF pre-treatment, respectively). Use of fresh MOCS/MOCA directly taken from operational filters, eliminated the need for ripening of virgin filter media, while dried MOCS was less effective than fresh one, while the total period required to achieve highly effective manganese removal (≥95%) was not shortened.

Keywords: Filter backwashing; Filter media ripening (manganese oxide coated sand/manganese oxide coated anthracite); Groundwater quality; Groundwater treatment; Manganese removal

1. Introduction

In many European countries the removal of manganese from groundwater is predominantly achieved by aeration-rapid sand filtration [1]. This treatment approach requires no chemicals (to oxidize Mn^{2+}), in contrast to manganese removal based on oxidation-filtration that is commonly applied in US and some other countries [2], is easy to operate, and very cost-effective. Application of this process, is, however, associated with a number of challenges including the long ripening period of virgin filter media required to achieve very effective manganese removal [3–5]. Several parameters are suggested to influence virgin filter

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media ripening period, including groundwater quality, type of filter media, and intensity and frequency of filter backwashing [1,6].

Removal of manganese (Mn^{2+}) in aeration-rapid sand filtration, which is often believed to be an auto-catalytic adsorption-oxidation process [7,8], can be supported by biological manganese oxidation [9–12]. Formation of manganese oxide (MnO_x) is likely initiated biologically, and over a prolonged filter run time, MnO_x becomes of predominantly physico-chemical origin [13].

Many researchers have shown that the removal of dissolved manganese (Mn^{2+}), can be facilitated by adsorption on manganese oxide coated filter media [14–17]. Filter media suggested to be the most efficient is manganese oxide coated sand/anthracite – MOCS/MOCA [18–25]. Addition of a layer of fresh MOCA in the filter with virgin anthracite was reported to completely eliminate filter media ripening time, while at an another testing location provision of a layer of dried MOCS did not result in any reduction [26]. It was hypothesized that differences in MOCS/MOCA performance at two testing locations could be explained by dissimilar conditions, under which the tests were carried out, such as water quality, mode of backwashing and different characteristics of manganese oxide coated media.

The aim of this research was to study the effect of backwashing, and, the type of virgin filter media on the duration of the ripening period required to achieve very effective (>90%) manganese removal. In addition, the potential of freshly taken manganese coated filter media, from very effective operating manganese removal filters (MOCS as well as MOCA), to reduce ripening period of manganese removal filters with virgin filter media was investigated. Also dried manganese coated media (with a potential loss of biological activity and adsorptive properties) were tested.

2. Materials and Methods

Manganese oxide coated materials used in this study were obtained from three full scale aeration-filtration groundwater treatment plants (GWTPs). Fig. 1 gives an overview of the process schemes of the GWTPs, and the filters from which Manganese Oxide Coated Sand (MOCS)/Manganese Oxide Coated Anthracite (MOCA) samples were taken.

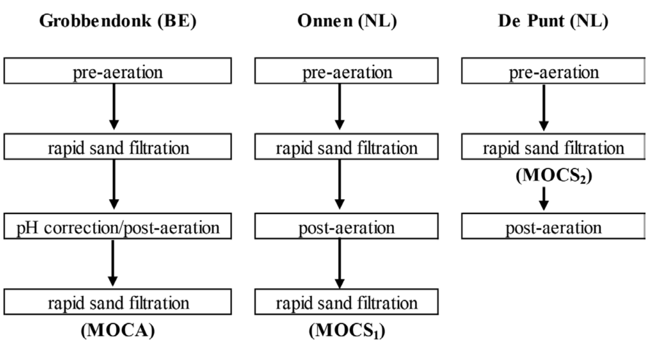

Fig. 1. Treatment schemes of GWTPs and filters from which MOCS/MOCA samples were taken.

Table 1 gives an overview of quality of feed water to filters, from which MOCS and MOCA were taken.

Fresh MOCA and $MOCS_1$ were taken from well operating filters (manganese removal ≥95%), and directly (without drying) used in pilot filter columns. In addition, two batches of dried $MOCS_1$ and $MOCS_2$ (taken out of manganese removal filters and subsequently dried in open air, and stored for 2 and 6 mo, respectively), were also used in this research. Dried coated filter media was included in the research having in mind that it is not always possible to obtain fresh manganese coated media that can be used for a start-up of manganese removal filters with virgin filter media. Prior to using, all filter media samples were rinsed, to flush out fines.

The pilot filters operated at GWTP Grobbendonk (Belgium). The experimental set-up (Fig. 2) consisted of two sets each with 6-columns installed in a parallel.

Based on full scale experiments in Grobbendonk, a filter media layer of 30 cm was used. The pilot filter columns had a diameter of 10°cm, and the filter bed length was 80°cm, composed of 50°cm support material (virgin sand) and 30°cm virgin sand, anthracite, MOCA or MOCS as follows:

- A1/B1: virgin sand (reference for MOCS layers);
- A2/B2: virgin anthracite (reference for MOCA layers);

Table 1
Quality of feed water to filters, from which MOCS samples were taken

Parameter	Grobbendonk	Onnen	De Punt
Iron, mg/L	0.09 (0.03–0.1)	0.11 (0.02–0.5)	5.9 (5.2–6.4)
Manganese, mg/L	0.13 (0.10–0.15)	0.06 (0.03–0.15)	0.23 (0.19–0.27)
Ammonium, mg/L	0.08 (< 0.02–0.20)	0.06 (0.05–0.09)	0.46 (0.34–0.61)
pH	7.6 (7.7–7.9)*	7.5 (7.4–7.6)	7.1 (7.0–7.1)
Oxygen, mg/L	9 (8–9.5)	8 (6.8–9.1)	10 (9.3–10.6)

* pH mainly found to be between 7.5 and 7.6.

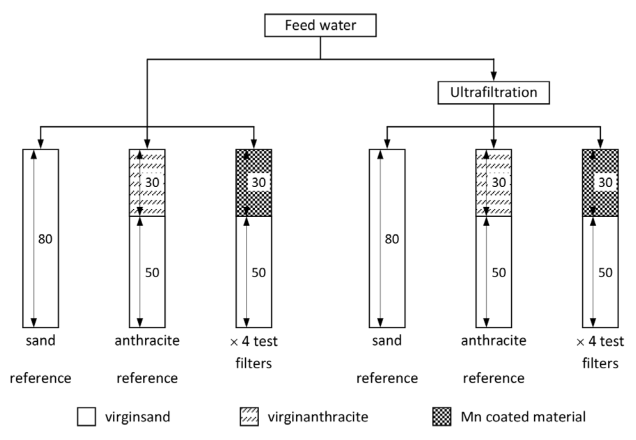

Fig. 2. Pilot set up at GWTP Grobbendonk.

Table 2
Physical properties of fresh MOCS, MOCA, and virgin sand/anthracite, chemical composition of the coating and the Freundlich adsorption isotherm constants for Mn^{2+} adsorption on fresh MOCS and MOCA

Parameter	$MOCS_1$	$MOCS_2$	MOCA	Virgin sand	Virgin anthracite
Grain size (d_{10}–d_{90}), mm	1.3–2.0	1.6–3.1	0.8–1.5	0.4–0.8	0.8–1.6
Uniformity coefficient	1.21	1.58	1.52	1.30	1.42
Bulk density, kg/L	1.376	1.177	0.650	1.459	0.635
Particle density, kg/L	2.332	2.326	1.176	2.586	1.400
Porosity, %	46.0	49.4	44.7	43.6	54.6
pH_{PZC}	7.8	7.2	8.0	6.1–6.5	9.1
Mn, mg/g	30.4	12.8	13.5	-	-
Fe, mg/g	21.4	158	2.2	-	-
Ca, mg/g	7.8	8.9	2.5	-	-
Al, mg/g	2.4	0.5	0.3	-	-
K, (mg/g)/(mg/L)	0.70	0.45	0.91	-	-
$1/n$	1.25	1.31	1.34	-	-
r^2	0.97	0.91	0.91	-	-
q_e, mg/g at C_e = 0.2 mg/L	0.193	0.132	0.276	-	-
q_e, g/L at C_e = 0.2 mg/L	0.265	0.155	0.179	-	-

- A3/B3: MOCA (fresh);
- A4/B4: $MOCS_1$ (fresh);
- A5/B5: $MOCS_1$-dried;
- A6/B6: $MOCS_2$-dried.

The physical properties of MOCS and virgin sand/anthracite, the chemical composition of the coating and the Freundlich adsorption isotherm constants for Mn^{2+} adsorption on $MOCS_1$, $MOCS_2$ and MOCA (all fresh) are given in Table 2.

Supernatant layer of 0.3 m was provided above filter media. The pilot filter columns were operated in down flow mode at constant filtration rate of 5.1 ± 0.5 m/h. The columns in test set A were backwashed after approximately every 2 weeks of continuous operation. Backwashing was carried out with water only, at a backwash rate of 30–35 m/h, resulting in approximately 10–20 % filter bed expansion, with typical duration of 10 min. The columns in the test set B, that received water after additional UF pre-treatment, were not backwashed during the whole study period, because no increase of head loss was observed

The filtrate from the first stage of the full scale GWTP Grobbendonk was used directly, or after ultrafiltration -UF (Inge, dizzer 500SB, pore size 0.02 µm), as feed for the pilot filter columns. UF filtration was applied to retain particles present in the feed water. It was assumed that ultrafiltration would prevent, or at least strongly reduce, head loss development in the filter bed, with associated reduced backwashing frequency. Filtrate of the first filtration step is also feed to full scale manganese removal filters at this plant (Table 1). Composition of pilot feed water is given in Table 3.

Manganese in feed water was in dissolved (Mn^{2+}) form, while iron was present predominantly as (hydr)oxide.

Table 3
Quality (average and range) of feed water to pilot filters, with and without UF pre-treatment

Parameter	Without UF	With UF
Iron, mg/L	0.09 (0.03–0.1)	< 0.02
DOC, mg/L	1.58 (1.51–1.68)	1.46 (1.33–1.60)
Manganese, mg/L	0.13 (0.10–0.15)	
Ammonium, mg/L	0.08 (< 0.02–0.20)	
pH	7.6 (7.5–7.9)*)	
Oxygen, mg/L	9 (8–9.5)	
Redox potential, mV	+250 (+200 – +290)	

* most of the time pH ranged from 7.5 to 7.6.

Samples of feed water and filtrate (a sampling point just below the top layer of 30 cm), were taken daily, and the manganese concentration was analysed with ICP-MS.

3. Results and Discussion

3.1. Filter ripening with virgin media and the effect of filter backwashing

Fig. 3 shows the comparison of virgin sand and virgin anthracite ripening time, and the effect of UF pre-treatment on the ripening period during the first 25 days of filter run with virgin filter media.

From Fig. 3 it can be seen that ripening time required to achieve effective manganese removal with virgin sand and anthracite, was similar when the same feed water pre-treatment was applied. The results imply that different physi-

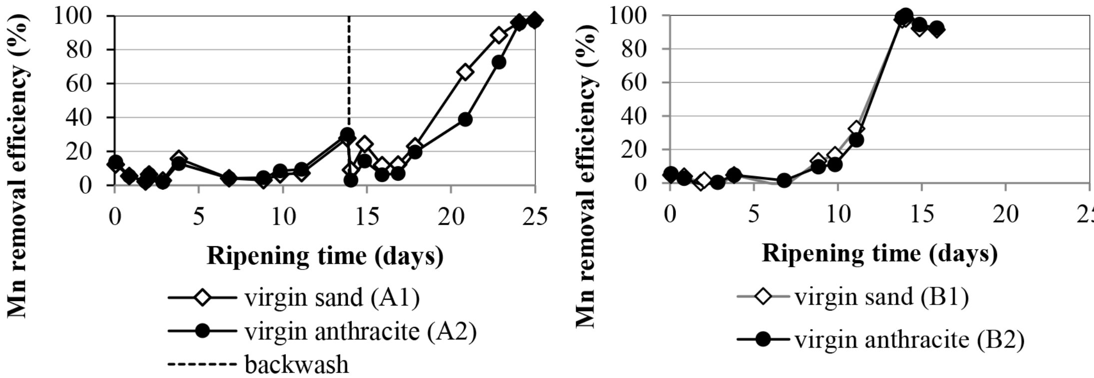

Fig. 3. Mn removal efficiency (%) as a function of the filter ripening time, type of virgin filter media and UF pre-treatment; feed water without (left), and with UF pre-treatment (right).

cal properties of sand and anthracite (e.g. particle size and pH_{PZC}, see Table 2.) did not significantly affect Mn^{2+} adsorption, and related rate of Mn-coating development. However, UF pre-treatment of feed water (Fig. 3 right) resulted in faster filter media ripening. Highly effective manganese removal (≥95%) was achieved after approximately 14 d, as compared to 24 d in the filters when no UF was applied. The difference in media ripening time of the two set-ups could be presumably attributed to the effect of backwashing on development of the Mn-coating [13]. Mn-coating is known to be essential for effective manganese removal in aeration-rapid sand filtration treatment [14–17]. In general, it is known that the oxidation-reduction potential (ORP) influences the manganese removal efficiency. However, in this research the influence of ORP was limited. During the whole test, ORP was close to around +250 mV. Also after each backwashing.

During the first two weeks no filter backwash was applied (head loss developed in filter bed was compensated by opening and adjusting a flow control valve to allow operation of pilot column at constant filtration rate) and the ripening of all filters with virgin filter media in both set-ups was very similar, irrespective of applied pre-treatment. Backwashing of filters A1 and A2 conducted after 14 d of continuous operation, however, resulted in reduction of the Mn^{2+} removal efficiency from 28 % to <10 % (Fig 3 left). Due to the UF pre-treatment, the feed water of columns B1 and B2 contained no particulate matter and as a consequence no filter backwashing of columns B1 and B2 was required (Fig 3 right). Although the backwashing used in this study was gentle and performed only after 14 d (Fig. 3 left, fine dotted line), the observed differences in Mn removal efficiency suggest that backwashing has a substantial effect on the ripening time of filter media.

Negative effect of backwashing during the ripening phase on manganese removal could be likely attributed to:

- (partial) removal of bacteria responsible for oxidation of Mn^{2+} that developed on virgin filter media during ripening period [9–13]; and/or
- (partial) removal of freshly formed MnO_X (Birnessite), which has highly autocatalytic properties to adsorb and subsequently oxidize Mn^{2+} (25, 27).

Fig. 4 shows the effect of the filter backwashing on manganese removal during the total testing period of approximately 70 d. Manganese concentration in filtrate was analysed before and after each backwash cycle.

From Fig. 4 it can be seen that directly after each backwash cycle, the manganese removal efficiency decreased. The decrease was most pronounced after the first backwash cycle (manganese removal reduced from 28% to <10%), carried out 14 d after the start of the filter operation, when the manganese removal was still rather ineffective presumably due to only limited partial media coating with birnessite [25]. Backwashing at that stage of ripening period likely partially removed initial birnessite deposits, and bacteria responsible for Mn^{2+} oxidation, and, consequently had a strong negative impact on the Mn removal efficiency. After the second and the third backwash cycles (performed after 28 and 42 d of filter operation), the reduction of manganese removal efficiency was less pronounced, but still obvious—from 94% to 84% after the second backwash cycle, and from 98% to 93% after the third backwash cycle. After the fourth backwash cycle (57 d of the filter operation), no significant decrease of manganese removal efficiency was observed, showing that there was sufficient birnessite on filter media, and partial removal due to backwashing did not significantly hampered manganese removal.

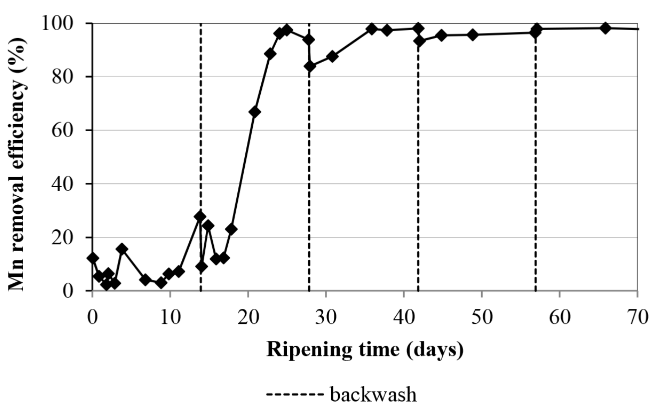

Fig. 4. Effect of filter backwashing on manganese removal efficiency during filter media ripening with virgin sand.

Filters treating iron and manganese containing groundwater need to be periodically backwashed to remove particles caught in filter bed voids, causing head loss development. The majority of these particles are iron (hydr) oxides formed by oxidation of dissolved iron with oxygen. The backwashing of pilot filters in this study was carried out with a very low frequency (approximately once in 14 d) due to low iron concentration in the feed water (up to a maximum of 0.1 mg/L for the set-up A), and as a consequence, iron loading in the columns was limited (approximately 0.1 kg Fe/m^2 filter area, per filter run). In practice, however, iron loading can be much higher, introducing the need for more frequent backwash cycles (e.g., the backwash frequency of GWTP Noordbargeres, water company Drenthe (NL), is more than once per day, because of high iron concentration in the feed water of approximately 14 mg/L, with iron loading of 1.35 kg Fe/m^2/filter run). Under such conditions, the negative effect of backwashing on duration of ripening period required to achieve very effective manganese removal with virgin filter media will be much more pronounced (very effective manganese removal in the filter is typically achieved after more than 4 mo).

In Fig. 5 the filter media ripening time of the pilot filter from this study was compared with the filter ripening time of the full scale filter GWTP Grobbendonk [26]. In both cases the virgin anthracite was used as filter media. Feed water quality for both filters was the same (Table 3, column "without UF"). However, the applied filtration rate, and consequently iron loading and backwash frequency were, different. In addition, the depth of the anthracite layer was different (0.5 m and 0.3 m in the full scale and the pilot filters, respectively). Inspection of the anthracite layer after completion of filter run showed that the manganese was removed mainly in the top 0.10–0.15 m of the filter, suggesting that different heights of the anthracite layer did not affect the results.

Highly effective manganese removal (≥95%) was achieved after approximately 16 days in the full scale plant, and after 24 d in the pilot filter column. The difference in applied filtration rate (2.5 m/h and 5.1 m/h, for full scale and pilot filters, respectively), resulted in different iron loadings (0.05 and 0.1 kg Fe/m^2 filter area, per filter run). As a consequence, the pilot filter column had to be backwashed earlier, than the full scale filter (14 and 30 d, respectively). The first backwashing of the pilot column took place just when manganese removal efficiency started to rapidly increase (black arrow in Fig. 5), while for the full scale filter, the first backwashing was applied only after 30 d, when the highly effective manganese removal was already achieved.

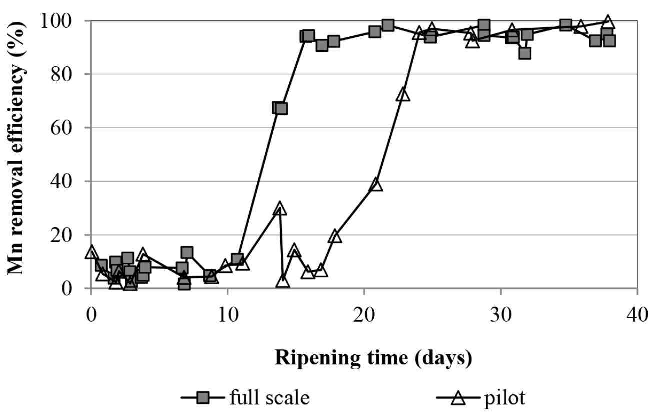

Fig. 5. Comparison of the Mn removal efficiency as a function of the filter ripening time for full scale and pilot filters with virgin anthracite (filtration rate: V_f = 5.1 m/h pilot filter and V_f = 2.5 m/h full scale filter).

Iron concentrations in feed water of drinking water treatments plants may range from < 0.02 mg/L to more than 30 mg/L, with related iron loading from less than 0.01 to over 10 kg/m^2 filter area, per filter run [1]. As a consequence, the backwash frequency in practice can vary between once per month to more than once per day. Findings emerging from this study, suggest that the ripening time required to achieve very effective manganese removal with virgin filter media is strongly affected by the applied backwash frequency, that is correlated to the iron loading. High iron loading, and consequently high backwash frequency, could be reduced by operating filters with lower filtration rate during the ripening period. Another option is to recirculate part of the filtrate, thus lowering the iron loading and consequently the backwash frequency. The reduction of the plant operational capacity during the ripening period will in most cases not be a problem because water with high manganese concentration, has to be disposed anyway. Backwashing with water only is recommended during the ripening period to limit removal of bacteria and MnOx deposits developed on the filter media, since backwashing with air and water, which is normally used, is much more abrasive.

3.2. Filter ripening with addition of a layer of manganese coated media

Fig. 6 shows the manganese removal efficiency of pilot filters with virgin sand containing a layer of fresh MOCA or MOCS$_1$ during the initial 2–3 weeks of operation.

Fig. 6 shows that the addition of a layer of either fresh MOCA or MOCS$_1$ on top of the virgin sand resulted in very effective (>90%) manganese removal already after one day of filter operation, irrespective of UF pre-treatment. It has been shown, that birnessite presence in filter media coating is essential for an effective removal of dissolved manganese [25]. The results from this study show that MOCS or MOCA, freshly taken from well performing manganese removal filters were auto-catalytically active. This assumption was supported by calculation of the maximum adsorption capacity of the MOCS/MOCA layers (2.35 litres). Based on the adsorption isotherms (Table 2) Mn^{2+} adsorption capacity (at Ce = 0.2 mg/L) was calculated to be 623, 365 and 420 mg Mn^{2+} for MOCS$_1$, MOCS$_2$ and MOCA, respectively. Given the daily filtrated volume through each column (960L) and the average Mn^{2+} concentration in the feed water (0.13 mg/L) the adsorption capacity of MOCS layers expected to be exhausted after 5.0; 2.9 and 3.4 d, for MOCS$_1$, MOCS$_2$ and MOCA, respectively. Fig. 6 shows that manganese removal was still very effective after 25 d of continuous pilot filters operation. This strongly suggests the presence of birnessite, that enables an efficient auto-catalytic adsorption and subsequent oxidation of Mn^{2+} [25,27]. Therefore replacing the top layer of a new (virgin) filter by 'active' manganese

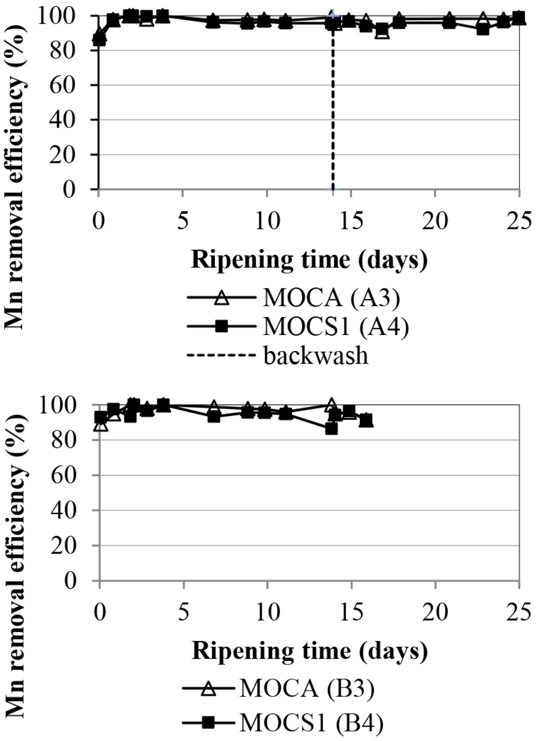

Fig. 6. Mn removal efficiency (%) as a function of the filter run time for pilot filters containing a layer of fresh $MOCS_1$ or MOCA; feed water without (left) and with UF (right) pre-treatment.

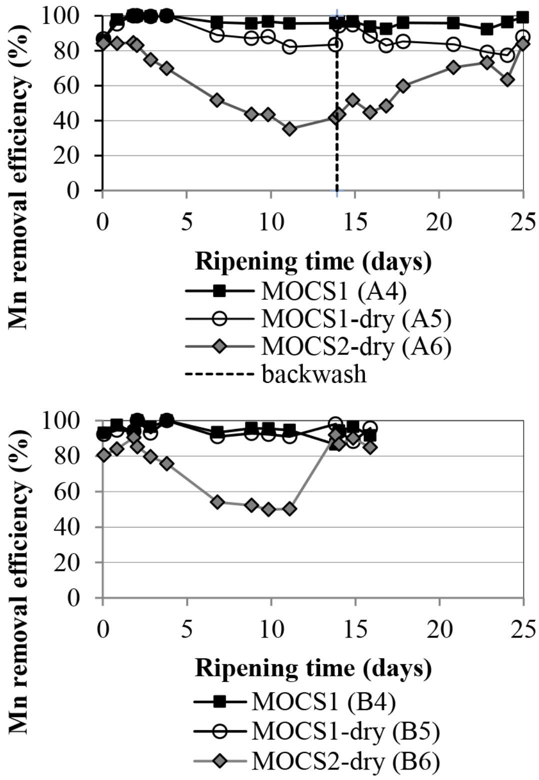

Fig. 7. The Mn removal efficiency as a function of filter run time for pilot filters containing layers of dried or fresh MOCS; feed water without (left) and with UF (right) pre-treatment.

coated media could eliminate the ripening time of manganese removal filters.

Fig. 6 also shows that the manganese removal efficiency of fresh MOCA and $MOCS_1$ was almost identical, as expected based on the Freundlich adsorption isotherm constants (Table 2). Use of fresh MOCA or MOCS, from well performing manganese filters (even with different physical properties and chemical composition) can consequently reduce, or even eliminate the long filter ripening period.

Results obtained (Fig 6, left) also confirmed that backwashing has rather limited effect on manganese removal for filters media with well developed (birnessite) coating.

Fig. 7 shows the manganese removal during initial 2–3 weeks of operation of pilot filter columns with virgin sand and a layer of dry $MOCS_1$ and $MOCS_2$, or a layer of fresh $MOCS_1$. Feed water without (Fig. 7, left) and with UF pre-treatment (Fig. 7, right) was used in these filter runs.

Fig. 7 shows that the performance of the filters containing a layer of dry manganese coated media was not as efficient as the filters with a layer of a fresh manganese coated media. The difference was more pronounced when no UF pre-treatment was applied (Fig 7, left). Compared to the fresh material, the removal of manganese was less efficient from the start of the filter run of the pilot filters with a layer of $MOCS_2$-dry, while for pilot filters with $MOCS_1$-dry showed only during the initial 5 d of operation very effective Mn removal (>95%), that was subsequently reduced to approximately 80% and 90% for feed water without and with UF pre-treatment, respectively. For $MOCS_2$-dry the Mn removal efficiency started strongly decreasing from the 3rd day of filter run.

Dry MOCS is less effective for manganese removal due to several reasons. Firstly, MOCS during drying process may have lost part of its adsorptive capacity, presumably due to oxidation of autocatalytic active MnO_X (birnessite) into less autocatalytic active MnO_X (pyrolusite). As a result, the number of available adsorptive sites decreases [27]. Secondly, drying the MOCS can have negative effect on the structure of the manganese oxide. The auto-catalytically active birnessite, consisting of plates [27], may irreversibly collapse during drying, subsequently additionally limiting the number of available adsorption sites. Finally, filter media drying might cause a loss of the biological activity on the media surface due to manganese oxidizing bacteria die-off. These bacteria likely play an important role in the process of manganese oxidation and removal [9–13].

Fig. 7 also shows that dry $MOCS_2$ removed manganese less effectively than dry $MOCS_1$-dry. The differences between the two MOCS media could be likely attributed to difference in manganese content and associated available adsorptive sites (e.g. $MOCS_2$-dry that was less effective for manganese removal contained 12.8 mg Mn/g, while $MOCS_1$-dry contained 30.4 mg Mn/g). Another explanation for the differences in removal capacities of the two dry MOCS media might be the storage time of two materials; $MOCS_1$-dry was stored for 2 months, whereas $MOCS_2$-dry was stored for 6 mo before their use in this study. Longer storage (in a dry air) presumably resulted in more pronounced loss of auto-catalytic properties through mechanisms earlier discussed.

Backwashing of the pilot filter with a layer of dry $MOCS_1$ and $MOCS_2$ had a short positive effect on manganese removal, that could be likely explained by removal of iron precipitates that physically blocked adsorption sites on filter media.

In both pilot filters with dry manganese coated media, irrespective of the UF pre-treatment, manganese removal efficiency started to improve after 12 d of pilot filter operation. At approximately the same time manganese removal started increasing in pilot filters with virgin sand or anthracite (Fig. 3). The coinciding ripening times indicate that dry manganese coated media behaved similar to virgin filter media, likely due to formation of manganese oxides and a biologically active layer that were required to facilitate effective manganese removal.

The findings of this research can be used in practice: addition of a layer (≥0.3 m) of fresh manganese coated media, strongly reduces or completely eliminates the filter ripening time. Manganese coated media can easily be taken from a well-operating manganese removal filter and transferred to a filter with virgin media. This procedure has to be done only once, and there is no need for follow up replacements of manganese coated filter media.

Filters are immediately ready for operating after using a fresh layer of MOCS or MOCA. As a consequence of this fast filter media ripening procedure, a water company saves operational costs (saving water, labor, costs for analysis, no need for extra filters, etc.). Savings are strongly depending on the original ripening time, without the use of manganese coated filter media.

If no fresh layer of manganese oxide coated filter media from a well-operating manganese removal filter can be used in practice, the long ripening period of manganese removal filters with virgin filter media can be reduced by operating filters, temporarily, at a lower filtration rate during the ripening period, consequently reducing the iron loading and thus limiting the backwashing frequency. Although in this situation the water production capacity of the filter is, temporarily, also reduced, possible advantages are more pronounced.

4. Conclusions

Findings emerging from this study focussed on the investigation of key factors controlling the ripening period of manganese removal filters with virgin media in conventional aeration-filtration treatment lead to the following conclusions:

- Despite different physical properties, virgin sand and virgin anthracite will have similar ripening time required to achieve very effective manganese removal, assuming that the feed water quality and operational conditions are identical.
- Filter backwashing prolongs the ripening time of a virgin filter. The influence of backwashing becomes less pronounced with the progress of filter media coating, due to development of thicker layer of biomass and/or auto-catalytically active birnessite on adsorption media surface.
- Backwashing has no, or only limited influence, on manganese removal when a layer of fresh manganese oxide coated filter media from well performing manganese removal filters, is added to a filter bed with virgin media.
- Ripening of manganese removal filters with virgin filter media can be shortened by temporarily operating filters at lower filtration rate with associated less frequent backwashing cycles.
- Addition of a layer (≥0.3 m) of fresh manganese coated media, from a well-operating manganese removal filter, to a filter with virgin media, strongly reduces or completely eliminates the filter ripening time.
- Compared to fresh-, dry MOCS has inferior manganese removal properties due to lower adsorption capacity and likely very limited potential for catalytic Mn^{2+} adsorption-oxidation.
- Time required to create a new (bio-active) auto-catalytically layer of birnessite on the surface of dry manganese coated or virgin filter media is similar.
- The long ripening period of manganese removal filters with virgin filter media in practice, can be reduced or even eliminated by (1) addition of a layer of fresh MOCA or MOCS from a well-functioning manganese removal filters, and (2) operating filters at lower filtration rate during the ripening period consequently reducing the iron loading and the backwashing frequency.

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