

Operational Paper

Rapid start-up of biofilters for removal of ammonium, iron and manganese from ground water

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ABSTRACT

Spontaneous formation of the active layer in biological filters for removal of iron, manganese and ammonium from ground water usually takes a few months. Inoculation of the new filters with well-established filter material is a common start-up procedure. An operational approach for inoculation of new filters using backwash sludge, instead of filter material, is elaborated here. The sludge is obtained from an already well-established biofilter used for removal of iron, manganese and ammonium. This procedure reduces the start-up time of the filters to 2 weeks only. The successful application of the described start-up procedure was demonstrated in two new plants treating ground water of different qualities. In one of these plants, the ground water contained increased concentrations of iron, manganese and ammonium, and in the other, only manganese concentration was increased.

Key words | ammonium removal, biofilters, ground water, iron removal, manganese removal, start-up procedure

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INTRODUCTION

Ground waters frequently contain iron, manganese and ammonium above the allowed concentration levels for drinking water. When using such ground water for water supplies, these species must be removed. Taking into consideration that iron and manganese appear in ground water as soluble $\text{Fe}(2+)$ and $\text{Mn}(2+)$ ions, their removal is based, as a rule, on their oxidation into $\text{Fe}(3+)$ and $\text{Mn}(4+)$, states characterized by low solubility, and therefore a form in which they can easily be removed by sedimentation and filtration. On the other hand, ammonium is removed from ground water by oxidation to N_2 , or into less harmful NO_3^- ions. All of these processes can be carried out by chemical and/or biological methods.

Chemical oxidation methods for the removal of iron and manganese from ground water include oxidation with atmospheric oxygen assisted by aeration, and oxidation by various chemical substances such as potassium permanganate, chlorine, sodium hypochlorite, chlorine dioxide

and ozone. Chemical oxidation is generally followed by filtration. Moreover, filtration through a catalyst, for example manganese greensand, zeolites of volcanic origin or sand coated, naturally or artificially, by a layer of manganese dioxide, can be used as well (Kothari 1988; Mouchet 1992).

While several chemical oxidation processes can efficiently remove iron and manganese, ammonium can be removed only by chemical oxidation with chlorine (Cl_2). The use of chlorine for this purpose, however, is not recommended because of the high costs involved, and the formation of undesirable products of the chlorine reaction with humic substances usually present in water.

An alternative to the chemical approach is the biological removal of ammonium. In the biological process, ammonium is removed by a two-stage nitrification process, which transforms it to the less harmful nitrate ion. The first nitrification stage includes the oxidation of

ammonium into nitrites using bacteria from the *Nitrosomonas* genus, and the second stage uses bacteria from the *Nitrobacter* genus to oxidize these nitrites into nitrates (Stumm & Morgan 1996). A characteristic feature of the nitrification bacteria is their low growth rate, which can be problematic in biological systems for water treatment (Bitton 1994; Liu & Capdeville 1996). The growth rate of the bacteria from the *Nitrobacter* genus is higher than those of the *Nitrosomonas* genus. Thus, the transformation of ammonium into nitrites is the rate-determining step of nitrification, and nitrites are not normally found in high concentrations in the nitrification process under stable conditions. The appearance of nitrites is thus only temporary (Powell 1986; Bitton 1994; Focht & Verstraete 1977).

It is well known that iron and manganese can be removed from ground water by applying biological processes, instead of chemical ones (Korać 1985). Many bacteria oxidize iron, producing insoluble iron oxides or hydroxides, which can be easily removed. Microorganisms are responsible, directly or indirectly, for the circulation of manganese in the environment, too (Gounot 1994). Biological removal of manganese is usually carried out in 'rapid' quartz sand filters coated with a catalytic layer of manganese oxides, MnO_2 . The oxide layer is formed spontaneously by treating ground water that contains manganese. It is assumed that Mn^{2+} is adsorbed first onto the MnO_2 and is then oxidized catalytically and/or bacteriologically. This process is often described as bioadsorption (Gouzinis *et al.* 1998). The process of formation of the catalytic layer takes 1–2 months (Frischhertz *et al.* 1985; Mouchet *et al.* 1985). If water contains ammonium, manganese is removed biologically only after the complete nitrification process is established. In this case, the formation of the active layer on the quartz sand surface takes 3–4 months (Rittman & Snoeyink 1984; Frischhertz *et al.* 1985; Mouchet 1992; Vandenabeele *et al.* 1995).

This research was performed in the attempt to define a procedure that would reduce the start-up time of the biological filter from the usual few months to only several weeks. The reduction of start-up time was achieved by applying a special inoculation start-up procedure to a new filter, using microbe biomass produced in an already

well-established biological process for removal of iron, manganese and ammonium, working under natural environmental conditions (temperature, pH, dissolved oxygen concentration, etc.). The successful application of the described start-up procedure was demonstrated in two new plants treating ground water of different qualities. In one of these plants, the ground water contained increased concentrations of iron, manganese and ammonium, and in the other, only manganese concentration was increased.

MATERIALS AND METHODS

Ground water characteristics

The rapid start-up procedure for biofilters was tested with ground waters of two different origins and compositions. Their basic chemical composition is given in Table 1. The ground water in Bjelovar region contained an increased concentration of iron ($\gamma(Fe) = 1.04 \text{ mg l}^{-1}$), manganese ($\gamma(Mn) = 0.147 \text{ mg l}^{-1}$) and ammonium ($\gamma(NH_3) = 0.84 \text{ mg l}^{-1}$), which is typical for most of northern Croatia. The ground water from Dragalić, in the vicinity of Nova Gradiška, is unusual because of its relatively high concentration of manganese ($\gamma(Mn) = 0.42 \text{ mg l}^{-1}$), but the concentration of iron is only slightly increased ($\gamma(Fe) = 0.40 \text{ mg l}^{-1}$) and practically no ammonium is present. The waters differ in their macro components as well. While the Bjelovar ground water is characterized by high values of alkalinity and hardness as well as values of $pH > 7$, the Dragalić ground water appears to have relatively low alkalinity, hardness and $pH < 7$.

Water treatment plants

Since the ground waters differed considerably in their composition, the treatment plants applied were different, as shown in Figure 1. For the ground water treatment in Bjelovar, closed aeration and filtration units with a capacity of 15 l s^{-1} (Figure 1a) were used. An elevated pressure of 1.5 bar was applied in order to provide sufficient oxygen

Table 1 | Basic chemical parameters of the investigated ground waters

	Bjelovar	Dragalić	MCL (CR/EEC)
Temperature, °C	16.50	12.9	
pH	7.30	6.27	
Conductivity, $\mu\text{S cm}^{-1}$	718	345	
CO ₂ , mg l ⁻¹	45	91	
Dissolved oxygen, O ₂ mg l ⁻¹	< 0.5	< 0.5	
Alkalinity, CaCO ₃ mg l ⁻¹	382	140	
Total hardness, CaCO ₃ mg l ⁻¹	363	178	
Calcium hardness, CaCO ₃ mg l ⁻¹	249	106	
Magnesium hardness, CaCO ₃ mg l ⁻¹	114	72	
Oxidizability with KMnO ₄ , O ₂ mg l ⁻¹	0.88	0.60	3/5
Humic substances, A ₂₅₄ /10 mm	0.016	0.012	
Ammonium, N mg l ⁻¹	0.840	0.018	0.10/0.50
Nitrite, N mg l ⁻¹	0.007	0.010	0.03/0.5
Nitrate, N mg l ⁻¹	0.04	0.05	10.0/50.0
Iron, Fe mg l ⁻¹	1.04	0.40	0.30/0.20
Manganese, Mn mg l ⁻¹	0.147	0.425	0.05/0.05

MCL, maximum contaminant level; CR, Croatian standards (1994); EEC (1998)

(13–14 mg l⁻¹ O₂) for the nitrification process, that is, the biological oxidation of ammonium into nitrates. Conversely, open aeration systems and a closed filtration unit, both with 5 l s⁻¹ capacity, were applied in Dragalić (Figure 1b). The open aeration system was used as the first treatment step primarily for removal of free CO₂, in order to increase the pH of the water. The second treatment step in the process, the biofiltration, was practically identical in Bjelovar and Dragalić. In both cases, the biofilters were filled to a height of 1.5 m with quartz sand, with a granulation of 0.5/2 mm. Because of the different capacities of the treatment plants, the filters in Bjelovar consisted of

three identical cylindrical filter units, 2 m in diameter, whilst in Dragalić only one unit, also 2 m in diameter, was used.

Analytical methods

The general chemical parameters of the waters, such as alkalinity, total hardness, calcium and manganese, were determined by standard analytical methods (*Standard Methods* 1995). The iron concentration was determined by the spectrophotometric method with 1,10-phenantroline

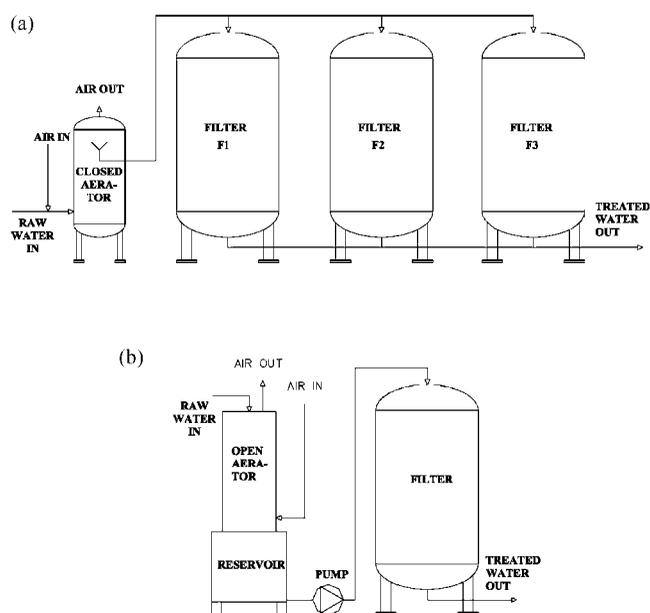


Figure 1 | Schematic of the drinking water treatment plants in Bjelovar (a) and Dragalić (b).

(Standard Methods 1995); manganese concentration was determined by the spectrophotometric method using PAN (Goto *et al.* 1977); ammonium according to Wagner (International Standard 1984); nitrites by the method with sulfanilic acid and α -naphthylamine; and nitrates by dimethylphenol (Höll 1979). The values of pH, electrical conductivity and oxygen concentration were determined using instruments from the ISKRA Company.

Microbiological analyses

Microbiological analyses of the sand particles from the filter were made to confirm the presence of microorganisms immobilized on the surface capable of oxidizing iron, manganese and ammonia. A suspension of the bacteria was obtained by mixing 10 g of sand particles in 100 ml of sterile demineralized water with a magnetic stirrer. Glass tubes containing Winogradsky liquid medium (0.5 g NH_4NO_3 , 0.5 g NaNO_3 , 0.5 g K_2HPO_4 , 0.5 g $\text{MgSO}_4 \times 7\text{H}_2\text{O}$, 0.2 g $\text{CaCl}_2 \times 6\text{H}_2\text{O}$ and 10 g ferric ammonium citrate in 1000 ml demineralized water) for culturing iron bacteria and liquid media (0.1 g $\text{Mn}(\text{CH}_3\text{COO})_2$ in 1000 ml demineralized water) for

culturing manganese bacteria were inoculated with the suspension and incubated at 17°C (Rodina 1972). Solid media were prepared by adding 1.5% of agar to the above-mentioned liquid media. After 7 days, flocs formed in the liquid media were examined by light microscopy.

Separate analyses were run for phase I nitrifying bacteria, that is, those forms that oxidize ammonium to nitrites, and for phase II nitrifying bacteria, which oxidize nitrites to nitrates. The previously prepared bacterial suspension was transferred into Winogradsky liquid media for culturing nitrifying bacteria of phase I (2 g $(\text{NH}_4)_2\text{SO}_4$, 1 g K_2HPO_4 , 0.5 g $\text{MgSO}_4 \times 7\text{H}_2\text{O}$, 2 g NaCl , 0.4 g $\text{FeSO}_4 \times 7\text{H}_2\text{O}$ and chalk in 1000 ml demineralized water) and of phase II (1 g NaNO_2 , 1 g Na_2CO_3 , 0.5 g NaCl , 0.5 g K_2HPO_4 , 0.3 g $\text{MgSO}_4 \times 7\text{H}_2\text{O}$ and 0.4 g $\text{FeSO}_4 \times 7\text{H}_2\text{O}$ in 1000 ml demineralized water). Solid media were prepared by adding 1.5% of agar to the liquid media (Rodina 1972). Four days after the inoculation of media I and II, the presence of nitrite and nitrate was regularly determined by chemical assay. Nitrites were detected in liquid cultures with the addition of dilute sulfanilic acid and α -naphthylamine. Nitrates were detected by reaction with pyrogallol (Rodina 1972). A detailed description of these culturing and identification procedures is given elsewhere (Štembal 2000). Subsequently, one loopful of bacterial suspension from each liquid media was transferred to the surface of an appropriate solid media, and incubated at 17°C and 25°C for iron/manganese and nitrifying bacteria, respectively. When surface colonies appeared on the agar media, cultures were distinguished according to their form, and also by optical microscopy after differential staining. Iron and manganese bacteria were stained using a method suggested by Meyers, and nitrifying bacteria were stained using the Gram method (Rodina 1972).

Inoculation procedure

The new filters were inoculated with the suspension of the biomass obtained by backwashing the biofilters of the water treatment plant in Ravnik, near Popovača. This water plant operates successfully using well-established biological processes for the removal of iron, manganese

and ammonium. The backwashed water contained 30–100 ml l⁻¹ of sludge and 1–3 g l⁻¹ of suspended solids, with typically 30–40% biomass, expressed as volatile suspended solid. The suspension was applied to the biofilter within 2–3 hours. For inoculation of the filter in Bjelovar (capacity of 15 l s⁻¹), the suspension was dosed at a flow rate of 2.5 l h⁻¹ for 24 h. The suspension was continuously mixed with compressed air in a 60-litre container. For filter inoculation in Dragalić (capacity of 5 l s⁻¹), 20 l of the suspension was added directly to the container (2 m³) with the aerated water at the intake of the filtration unit. The inoculation was repeated after 6 and 12 days in Dragalić and Bjelovar, respectively. During the start-up period, the filters were operating at only half of their designed capacity, and were backwashed with treated but non-chlorinated water at a hydraulic load of 20 (m³ m⁻²) h⁻¹, every 48 h. Compressed air was never applied for the backwash.

RESULTS AND DISCUSSION

Rapid start-up of filter in Bjelovar

The ground water treatment plant in Bjelovar was originally designed for the removal of iron and manganese by chemical oxidation with H₂O₂. This process, however, did not produce water of satisfactory quality. There were many difficulties regarding the dosage of chemicals and the plant was unable to remove ammonium as well. Thus, it was decided to adapt the plant for the more efficient biological removal of iron, manganese and ammonium. Consequently, the plant was equipped with an appropriate aeration system (Figure 1a). Moreover, it was necessary to apply a rapid start-up procedure, since the spontaneous start-up process of the biological filters takes 3–4 months (Rittman & Snoeyink 1984; Frischhertz *et al.* 1985; Mouchet 1992; Vandenabeele *et al.* 1995). Although the ground water contains microorganisms with the ability to oxidize iron, manganese and ammonium, their concentration in ground water is extremely low for establishing a useful biofilter operation in a reasonably short period of time.

The problem of slow start-up can be solved by making use of an established biofilter medium from another treatment plant (Štembal 2000). However, this approach can suffer from a range of different problems and complications. Therefore, we made an attempt to accelerate the process of immobilisation and creation of active biomass on the new filter.

Instead of adopting the common approach of inoculating new filters using previously established filter mass, the inoculation here was performed using sludge obtained by backwashing one of the filters of the ground water treatment plant in Ravnik. This water treatment plant has been in operation for several years and possesses well-established filter material with immobilized microorganisms for oxidation and removal of iron ($\gamma(\text{Fe}) = 2.45 \text{ mg l}^{-1}$), manganese ($\gamma(\text{Mn}) = 0.22 \text{ mg l}^{-1}$) and ammonium ($\gamma(\text{NH}_4^+ - \text{N}) = 1.0 \text{ mg l}^{-1}$) from ground water. Thus, its backwash sludge contains a high concentration of active microorganisms obtained by scaling off the surface of the quartz sand during the intensive filter backwash. The sludge produced in this process was of constant composition, containing always the same amounts of removed iron and manganese, incorporated in the form of insoluble compounds within the mixture of corresponding biomass. The backwashed water containing 30–100 ml l⁻¹ of sludge, corresponding to 1–3 g l⁻¹ of suspended solids, with typically 30–40% biomass, was efficient enough for inoculation and no more detailed characterization of the biomass was necessary.

Approximately 60 l of sludge, dosed continually during 24 hours, was found to be sufficient for the initial inoculation of the filters of the water treatment plant in Bjelovar with a capacity of 15 l s⁻¹. The inoculation of the filter by the backwashed water containing sludge was repeated after 12 days.

The efficiency of the start-up process was monitored and evaluated by periodic measurement of the concentration of iron, manganese and ammonium before and after filtration. The results are shown in Figures 2, 3 and 4. No significant changes in concentration of the total iron, manganese and ammonium in raw water were noticed before and after the short aeration step preceding the filtration. Also, at this step, the oxidation of iron(II) into iron(III) was found to be relatively low (10–20%). Thus,

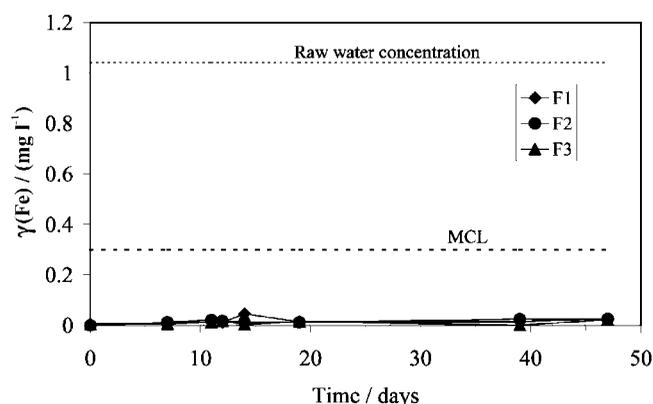


Figure 2 | Iron concentrations in the effluent (filters F1, F2 and F3) of the water treatment plant Bjelovar during start-up.

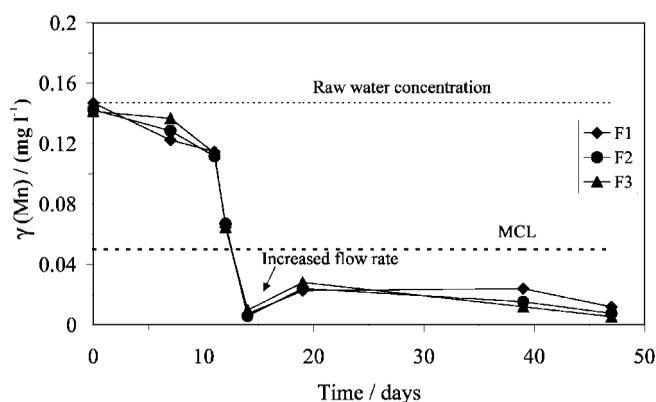


Figure 3 | Manganese concentrations in the effluent of the water treatment plant Bjelovar during start-up.

the raw water concentrations, presented in the figures, represent the total concentrations of iron, manganese and ammonium at the inlet to the filter.

The complete removal of iron in the filter was achieved immediately after the treatment plant was put into operation (Figure 2). Evidently, the process of removal of iron does not require any start-up time. That means that the oxidation of iron was not caused by the activity of the microorganisms. It seems more likely that the oxidation of iron was achieved in the filter chemically by oxygen supplied during the aeration step. This is in agreement with results published previously where the high oxidation rate of iron with oxygen in the absence of humic substances and at values of $\text{pH} > 6$ was reported (Robinson 1967; Robinson and Dixon 1968; Nealson 1982; Michalacos *et al.* 1997). Since the organic content of the ground water in Bjelovar is relatively low, this finding additionally explains our results.

The removal of manganese began approximately 2 weeks after the initial inoculation of the filter (Figure 3). In this case this is certainly due to a biological removal process because significant oxidation of manganese with oxygen takes place only in solutions of $\text{pH} > 8.5$ (Cleasby 1975; Aziz & Smith 1992). Since the average pH value of the ground water in Bjelovar is 7.3, this suggests that the dominant oxidation process is biological and not chemical. Biological water treatment processes enable the oxidation and removal of manganese even at low pH

values, without the addition of any chemicals. The main disadvantage of this approach, according to the literature data, is that a start-up period of as long as 3–4 months is needed for establishment of an efficient biofilter (Rittman & Snoeyink 1984; Frischhertz *et al.* 1985; Mouchet *et al.* 1985; Mouchet 1992; Vandenabeele *et al.* 1995). However, the results of the experiments presented in this paper confirm unambiguously that it is possible to significantly reduce the start-up period. As shown in Figure 3, the adaptation and the propagation phase of the manganese-oxidizing microorganisms within the filter layer took only 2 weeks after the inoculation.

During the first 14 days of the start-up only 50% of the designed hydraulic load of 15 l s^{-1} was applied. After the capacity was doubled, the effluent manganese concentration increased slightly. However, the filter recovered quickly, improving the quality of the effluent, obviously because of the adaptation of the microorganisms to the new hydraulic conditions.

Figure 4 shows the efficiency of the biological filters for ammonium removal during the investigations. In the first 7 days after the initial inoculation of the filter, ammonium removal was practically negligible. However, after 14 days the complete elimination of ammonium occurs. Simultaneously with the elimination of ammonium, and as a result of the activity of the bacteria of genus *Nitrosomonas*, nitrites appear in the effluent (Figure 5). Twelve days after the initial inoculation the nitrite concentration

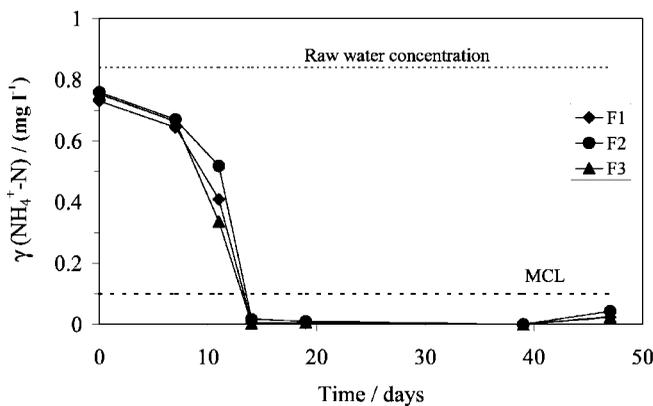


Figure 4 | Ammonium concentrations in the effluent of the water treatment plant Bjelovar during start-up.

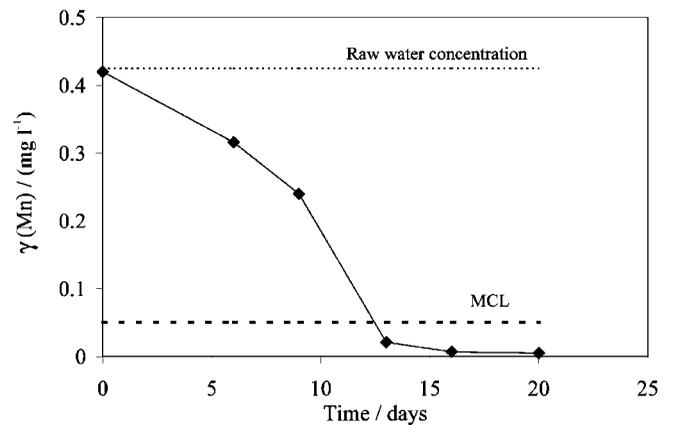


Figure 6 | Manganese concentrations in the effluent of the water treatment plant Dragalić during start-up.

reached its maximum value ($\gamma(\text{NO}_2^- - \text{N}) = 0.4 \text{ mg l}^{-1}$). The increasing nitrite concentration in the effluent was the sign to begin the second inoculation procedure, in order to accelerate the biological removal processes of nitrites. Since nitrites, the substrates for the growth of the bacteria of genus *Nitrobacter*, were not present before, neither the reproduction of these bacteria nor the oxidation of the nitrites could have occurred to any significant extent after the first inoculation stage. Therefore, accumulation of nitrites in the system occurred (Figure 5). The aim of the second inoculation of the filter was to accelerate the nitrite removal process by additionally sup-

plying bacteria of the genus *Nitrobacter*. When the critical concentration of these bacteria was reached, nitrites completely disappeared from the effluent. This happens because the oxidation rate of nitrite is higher than its rate of production from ammonium.

Rapid filter start-up in Dragalić

The second rapid start-up experiment was performed in Dragalić, in the vicinity of Nova Gradiška. The Dragalić ground water is unusual because of its high manganese content ($\gamma(\text{Mn}) = 0.425 \text{ mg l}^{-1}$) and, together with its macro constituents, is atypical of north Croatian ground waters. It is also unusual because of its low alkalinity and hardness. Furthermore, owing to the excess of free CO_2 , the water has an exceptionally low pH of 6.27. Accordingly, it was necessary to reduce the free CO_2 content by aeration prior to filtration, in order to increase the pH. With intensive aeration a value of pH 7.6 was achieved. After the initial inoculation of the filter, a second inoculation was performed at 6 days.

The results of monitoring the manganese removal start-up process are shown in Figure 6. It is obvious that after 14 days of start-up the manganese concentration in the effluent decreased significantly, below the permitted concentration of 0.05 mg l^{-1} Mn in drinking water.

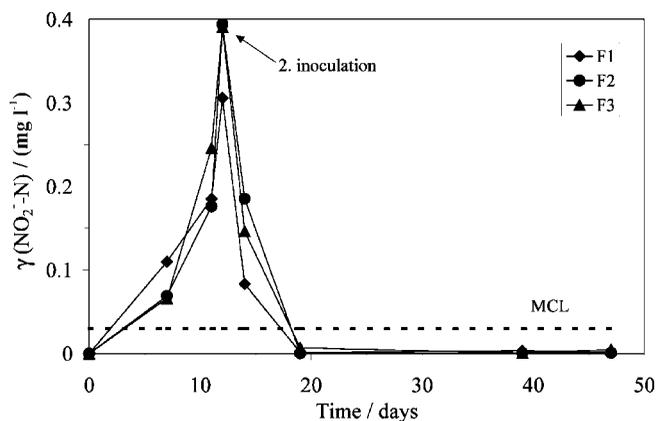


Figure 5 | Nitrite concentrations in the effluent of the water treatment plant Bjelovar during start-up.

The results of these experiments prove, without a doubt, that even atypical ground waters, such as those in Dragalić, can be efficiently treated by a biological manganese removal process established in only 2 weeks, according to the start-up procedure suggested and described in this paper.

Biomass characterization

After the start-up of the iron, manganese and ammonium removal process in Bjelovar, the quartz sand from the filters underwent a microbiological analysis in order to prove the presence of the microorganisms and determine their genus. The tests confirmed the activity of microorganisms and their ability to oxidize iron, manganese and ammonium.

In the liquid medium for the nitrification bacteria culturing, inoculated with the suspension of microorganisms, nitrite and nitrate formation was controlled. After 8 days, when positive reactions for nitrite and nitrate were recorded, cultures were spread on solid media. After 48 hours' incubation at 25°C, microscopic examination and staining by Gram revealed the presence of the bacteria from the *Nitrosomonas* and *Nitrobacter* genera. Isolated bacteria were Gram-negative, straight rods and cell size was $0.34 \times 1.3 \mu\text{m}$. However, recent investigations based on modern molecular biological techniques indicate that, instead of *Nitrosomonas* and *Nitrobacter*, species like *Nitrospira* are more important nitrifying bacteria. The cultivation-independent molecular techniques including rRNA gene surveys (Ward *et al.* 1990), fluorescent *in-situ* hybridization (Amann *et al.* 1995) and denaturing gradient gel electrophoresis (Muyzer *et al.* 1993), confirmed that *Nitrospira* is the dominant nitrifying bacteria. However, the precise differentiation of the nitrifying bacteria operating in biological filters was beyond the scope of this paper.

In the inoculated liquid medium for culturing iron bacteria, after 7 days of incubation a cotton-like accumulation of the iron precipitate appeared on the bottom of the test tube as a result of bacterial activity. On the solid medium, after 7 days of culturing, bacterial colonies with a visible metal shine of iron-oxidizing bacteria appeared.

Microscopic examination of the unstained culture revealed the spherical cells of the bacteria belonging to the genus *Siderocapsa*. Stained slides showed red coloured bacterial cells and blue coloured iron deposits. The bacteria cells from the Siderocapsaceae family differ morphologically and show different capsule formation. Their cells represent the centres for the accumulation of iron and manganese (Bergey 1994). It is well known that the usual habitat of the bacteria of the *Siderocapsa* genus is natural and clean water, which includes ground water. By a microscopic examination of the native substrates, some olive green and rusty-brown colouring was observed. The rusty-brown colour of the capsule material is the consequence of the oxidation of iron present in the ground water, while the olive-green colour is caused by manganese oxidation. According to the literature data (Frischhertz *et al.* 1985; Dempsey 1992; Bergey 1994; Durakovi 1996), the role of the capsule is to enable the bacteria to bind to different surfaces.

In this study the role of the bacteria that oxidize iron was not investigated since the complete removal of iron occurs before the creation of the microbial layer. Michalakos *et al.* (1997) showed, when comparing biological and chemical iron oxidation by filtration, that the presence of bacteria in the filter can significantly improve the filter performance under the same working conditions. It is possible that the presence of microorganisms affects the structure of the emerging sludge, and therefore, further research in this field is required.

CONCLUSIONS

The results of the investigations performed demonstrate that the time necessary for start-up of a biofilter for removing iron, manganese and ammonium from ground water can be significantly reduced by inoculation of the filter with sludge obtained from the backwash of an already established filter. Sludge obtained in this way contains active biomass, which is relatively easily immobilized on the quartz sand surface. Using this procedure the start-up time of a biofilter can be reduced to 2 weeks compared with the natural spontaneous process of several months.

Microbiological analysis of the established biomass on the surface of the quartz sand filter material confirms the presence of bacteria of the *Siderocapsa* genus, responsible for oxidation and removal of Fe^{2+} and Mn^{2+} , as well as bacteria of the genera *Nitrosomonas* and *Nitrobacter*, both involved in the biological removal processes of ammonium from ground water.

The rapid start-up procedure, described in this paper, is applicable for putting into operation water treatment plants for treating ground waters of different quality containing diverse concentrations of iron, manganese and ammonium.

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