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Invertebrate colonisation of GAC filters in a potabilisation plant treating groundwater

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ABSTRACT

Invertebrate colonisation of granular activated carbon (GAC) filters is one of the most frequently occurring and less studied biological problems in the process of water potabilisation. In this study we monitored invertebrate presence in the GAC filters of a potabilisation plant located in the province of Ferrara (Northern Italy), treating groundwater only. In particular, we studied the temporal evolution from November 1999 to January 2001 in relation to the duration of backwashing procedures used to cleanse the filters. The study focused on two separate GAC filter lines at the same time which work in identical conditions. The results showed that the community was dominated by nematodes and, with lower densities, gastrotrichs, rotifers and anellids. Invertebrate density did not follow a clear time pattern in either line, in relation to abiotic factors. It seems to depend on plant management practices, such as backwashing effluent recycling within the plant. Nematode generation time, in combination with the time span between two backwashings, is apparently the principal factor in controlling filter colonisation, while backwashing duration did not seem to have a significant effect.

Key words | backwashing, biological filters, GAC filters, groundwater, invertebrates, nematodes, potabilisation

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INTRODUCTION

Riverwater and groundwater, which are used as drinking water sources, contain many kinds of organic substances that have a wide distribution of molecular weights and cannot be removed by conventional water treatment processes, such as coagulation–sedimentation, sand filtration and chlorination disinfection.

In the last few decades, research started to focus on advanced treatment processes in combination with GAC filtration, in order to help remove various organic substances (Symons 1984; Weisner *et al.* 1987; Lykins *et al.* 1988; Adams & Clark 1989; Urfer *et al.* 1997), as well as ammonium and metals such as manganese and iron (Chartrain & Rizet 1983; Vandenabeele *et al.* 1995a, b).

Enhanced microbial growth on the filters was observed and considered a hygienic problem at first. Subsequently, the positive and necessary function of micro-organisms in filtration processes was acknowledged (Eberhardt *et al.* 1974). Nevertheless, one of the major problems concerning the application of these filters for drinking water production is to control biofilm on the granules (Scholz & Martin 1997). In particular, the main objective of the operators in establishing backwashing procedures is to prevent clogging of the sand and GAC filters.

In hygienic terms, the presence of invertebrates, mostly represented by nematodes, gastrotrichs, rotifers and anellids, has to be considered in relation to the presence/absence of faecal indicators, enteric pathogens or pathogen germs (*Standard Methods* 1992). Anyway, even if bacteria and viruses are found in adhesion or ingested by invertebrates (Levi *et al.* 1986; Lupi *et al.* 1995), there is no evidence of pathologies associated with their recovery (Gray 1994). In practice, the limit is fixed at about 3–4 nematodes/l for drinkable water and 20 nematodes/l for water to be treated. If this limit is exceeded, it is useful to implement engineering contention measures (Chang *et al.* 1960).

Although sand and GAC filters are colonised by numerous protozoa and metazoans, little is known about these organisms and their dynamics in these artificial substrates (Husmann 1982; Schreiber *et al.* 1997). Nematodes are the most frequent and abundant colonisers (Gray 1994), found in 80% of Italian potabilisation plants (Volterra *et al.* 1996) treating both groundwater or spring water (Volterra *et al.* 1993).

Previous studies mainly focus on factors causing and controlling the presence and abundance of nematodes and other invertebrates in water treatment plants and drinking water, thus showing the existence of a direct relationship between rainfall, flow and turbidity on the one hand, and the density of invertebrates on the other (Tombes *et al.* 1979; Mott *et al.* 1981).

The main objective of this study is to identify the causes of the presence and abundance of nematodes, ciliate protozoa and other micro-organisms colonising biologically activated GAC filters in a potabilisation plant treating groundwater only.

METHODS

Sampling sites

Samples were taken at waterworks located in the province of Ferrara (Northern Italy) from November 1999 to January 2001. The selected waterworks treated groundwater (Table 1) pumped from 19 wells ($550\,l\,s^{-1}$). In this plant two lines of 12 GAC filters each, indicated as B1 and B2, are the last step before disinfecting; filters within each line are in series. A description of the water treatment plant is given in Table 2. Before the experiment, in the everyday management of the GAC filters' lines, each filter was backwashed without a predefined frequency and according to acquired practical experience, only in order to avoid clogging phenomena.

Sampling procedure

The two separate GAC filter lines, treating the same water but at different flow rates, higher in line B2, were monitored on the same days and, when testing the effect of the different backwashing durations (30 min, 1, 2, 3, 8 and 16 h), the same treatment was applied to one filter per line at the same time. Treated water was taken after flushing for a few minutes to obtain representative samples (Prèvost *et al.* 1997) from preinstalled taps, one of which was positioned after the last filter, to monitor the whole line during ordinary functioning, while the other was located at the single filter outlet, in case of backwashing. Physical parameters were directly measured in the filtrate, sampled for chemical and microbiological determinations, carried out in the laboratory of the plant. Ten litres of liquor were filtered through a 5 μm diameter polycarbonate fibre filter. Filters were immediately dried at 37°C for two hours and microscopic observations of organisms were performed under phase contrast at 200 × magnification. Invertebrate densities were reported in ind. m^{-3}. In particular, we searched for multicellular organisms such as nematodes, gastrotrichs, rotifers and anellids, included in the meiofauna, which can enter into water treatment plants and settle and develop mainly in sand and GAC filters (Schreiber *et al.* 1997; Madoni *et al.* 2000).

Statistical analyses

One-way ANOVA was used to test the differences between the two GAC filter lines, taking into account the nominal flow measured before backwashing and the monthly average presence of invertebrates as a whole, and as nematodes, gastrotrichs, rotifers and anellids.

A two-way MANOVA was used to test differences between applied "backwashing time duration" and the existence of a post-treatment "temporal evolution" throughout the study period. The following parameters were considered: total invertebrates, nematodes, gastrotrichs, rotifers and anellids as changes of density calculated before and after the treatment.

All *post hoc* comparisons were made using the Tukey test and the homogeneity of variances were previously determined by the Cochran test (Cochran & Cox 1957).

Moreover, to stress the similarities/dissimilarities among the backwashing procedures and between the two filter lines, an MDS (multi-dimensional scaling) was performed using total invertebrates, nematodes, gastrotrichs, rotifers and anellids as changes of density.

Table 1 | Major parameters of the groundwater treated by the plant (mean, standard deviation, minimum and maximum), during the study period, November 1999–January 2001; n.d. = not detectable

Parameter	Mean	St. dev.	Min	Max
pH	7.64	0.10	7.32	7.93
Conductivity (μS)	565	95	42	837
Chloride (mg/l)	67.25	36.69	22.17	546.00
Fe (μg/l)	891	143	775	1256
Ca (mg/l)	65	3	57	70
Mg (mg/l)	23.9	49.5	11.9	295.0
BOD_5 (mg O_2/l)	n.d.	–	–	–
COD (mg O_2/l)	n.d.	–	–	–
NH_4^+ (mg/l)	1.96	0.36	1.12	3.50
NO_3^- (mg/l)	n.d.	–	–	–
NO_2^- (mg/l)	n.d.	–	–	–
P_2O_5 (μg/l)	336	186	150	983
Cu (μg/l)	2.4	0.5	1.9	3.4
Zn (μg/l)	n.d.	–	–	–
Cd (μg/l)	n.d.	–	–	–
Hg (μg/l)	n.d.	–	–	–
Pb (μg/l)	n.d.	–	–	–
Total coliforms (FCU/100 ml)	n.d.	–	–	–
Faecal coliforms (FCU/100 ml)	n.d.	–	–	–

A simple correlation test was used to assess the relation between invertebrate density and water flow in the two filter lines.

RESULTS AND DISCUSSION

GAC filter invertebrate colonisation in ordinary functioning

The invertebrate community was composed, both in line B1 and B2, by nematodes, rotifers, gastrotrichs and anellids, listed in order of decreasing quantity. Nematodes were the dominant group, accounting for 94% and 91% of the total on average, in line B1 and B2 respectively, with mean densities significantly higher ($P < 0.01$) in line B1 (6000 ind. m^{-3}) compared to line B2 (2200 ind. m^{-3}) over the entire study period. *Monystera*, *Ironus* and *Anaplectus* were the most frequently found genera.

Gastrotrichs tended to be more abundant in line B1 (4.5% of the total), while rotifers were more common in line B2 (7.8% of the total). However, the differences are not significant.

Table 2 | Water treatment plant description

Steps	Technical equipment
Water collection	19 wells (550 $l\,s^{-1}$)
Sedimentation	2 tanks (5 m diameter)
Disinfection (sodium hypochlorite)	4 lines
Oxidation–flocculation	4 lines
Sand filters	21 filters – granulometry: 1.2–2 mm
GAC filters	2 lines (12 filers each) – granulometry: 1.2–1.7 mm
Drinkable water storage	1 basin (3600 m^3)
Chloration (dioxychloride)	Before distribution

Monthly average values of total invertebrate density in both lines followed an irregular temporal evolution (Figure 1), without significant variation from month to month ($P > 0.05$) in both GAC filter lines and rare significant differences were shown considering separately the dominant taxa.

In particular, in line B1, nematodes ranged from 900–15 800 ind. m^{-3}, while in line B2 their quantity was less variable, with nematode density varying between 200–2600 ind. m^{-3} from the beginning of the study period to August 2000. In September 2000, line B2 registered a rapid increase in nematode density, reaching the highest value of 71,000 ind. m^{-3}, significantly different ($P < 0.01$) from any monthly average registered for this line, with the exception of August and October of the same year, as well as from all monthly means of line B1, except January, February and June 2000 ($P > 0.05$). Immediately after this maximum peak, nematode density decreased rapidly to the previous level.

The two lines were significantly different ($P < 0.01$) in flowrate (Figure 2). Flux ranged respectively from $0.016\,m^3\,s^{-1}$ to $0.242\,m^3\,s^{-1}$ in line B1 and from $0.02\,m^3\,s^{-1}$ to $0.352\,m^3\,s^{-1}$ in line B2. Moreover, a significant negative correlation was identified between nematode abundance and flux magnitude in line B1 ($r = -0.44$, d.f. $= 27$, $P < 0.05$), while in line B2 the correlation coefficient was close to the limit of significance ($r = -0.35$, d.f. $= 28$, $P > 0.05$).

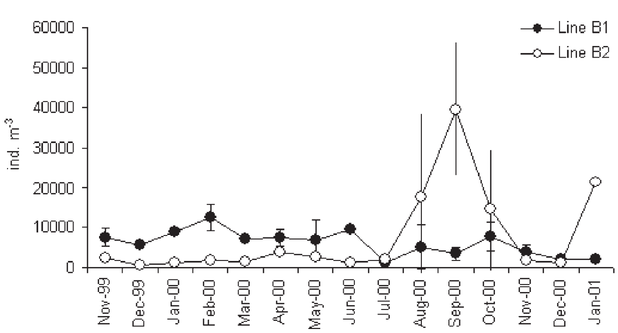

Figure 1 | Monthly means (n = 5) of total invertebrate density (ind. m^{-3}) measured at the outlets of the two GAC filter lines, throughout the study period (Nov. 1999–Jan. 2001).

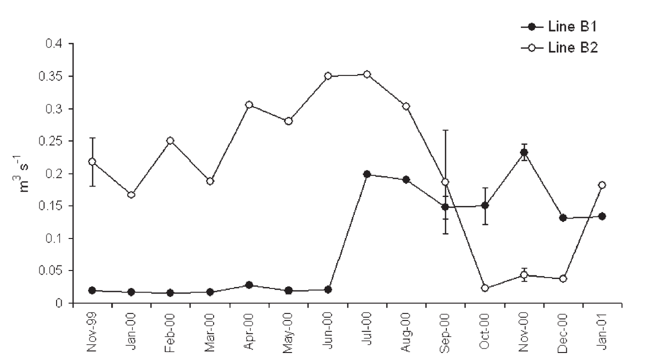

Figure 2 | Monthly means (n = 5) of flowrate ($m^3\,s^{-1}$) for line B1 and B2 throughout the study period (Nov. 1999–Jan. 2001).

Backwashing procedures to control invertebrate colonisation of GAC filters

To evaluate the effect of the different backwashing procedures, differences in density were calculated before and after the treatment for nematodes, rotifers, gastrotrichs, anellids and total invertebrates. Filtrates were sampled from backwashed filters every day just after the treatment for 15 d. Using the changes rather than the absolute values made it possible to skip the differences in density registered from filter to filter and throughout the whole period of experimentation. Half of the filters in each of the two lines were tested, for a total of twelve filters. Results for the shortest (30 min) and the longest (16 h) treatments are shown in Figure 3. Considering all the applied procedures (30 min, 1 h, 2 h, 3 h, 8 h and 16 h), in the first day after backwashing a rapid increase (200–900% of the starting value) in invertebrate density was registered, although not statistically significant. From the second to the sixth day, the density decreased, seldom above 80% of the starting value, rapidly recovering within 15 d and reaching similar or higher levels in comparison with the value preceding the treatment. This temporal evolution of changes (0–15 d) did not show any significant difference ($P > 0.05$), both considering total invertebrates and single taxa alone.

In contrast, testing the backwashing duration, highly significant effects ($P < 0.01$) on the changes emerged. Nematode density in both filter lines, and gastrotrich and rotifer density in line B1 or B2 respectively, showed significant differences; no significant effect was registered for anellids (Table 3).

MDS, run on changes of densities as graphical representations of similarities among the applied backwashing procedures, showed the existence of three clusters in line B1 (Figure 4(a)), corresponding to 1 h and 30 min, 2 h and 16 h, and 3 h and 8 h, respectively. Line B2 (Figure 4(b)) showed a cluster of the shortest (30 min) and the longest times (8 and 16 h) and another cluster with 2 h and 3 h, while the 1 h treatment appeared separated from all the other treatments.

As a result, a clear relationship between backwashing duration and the reduction of invertebrate density in the filtrate could not be assessed in either line.

Since the occurrence of invertebrates in drinking water can cause complaints from consumers (*Manual of Water Supply Practices* 1995) and not all critical aspects concerning the microbiological safety of drinkable water can be dismissed (Chang *et al.* 1960; Levi *et al.* 1986), an extensive removal of invertebrates by treatment processes should be achieved.

The waterworks which were the object of this study treat only groundwater, in which no significant presence of invertebrates was ever registered (data not shown).

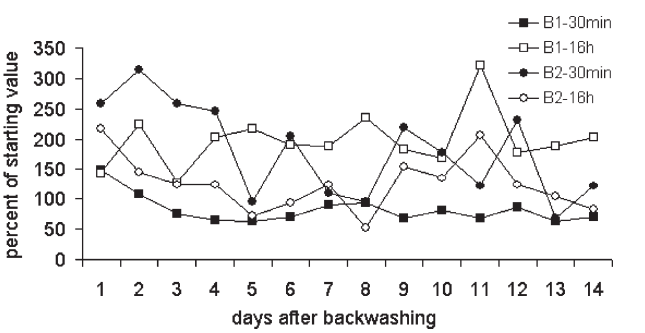

Figure 3 | Total invertebrate density (percentage of the starting value), during the two weeks following the washing procedures. The 30 min. and the 16 h backwashings are reported as examples for line B1 and B2.

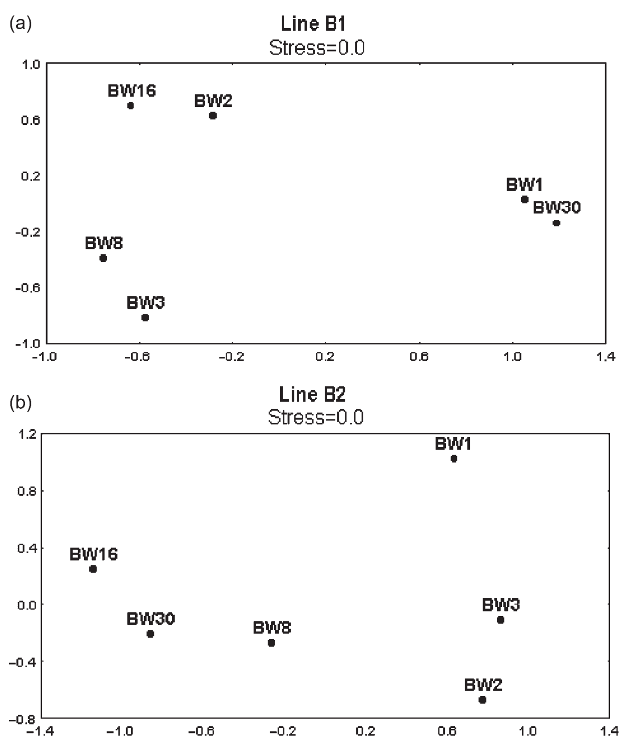

Figure 4 | MDS for line B1 (a) and B2 (b); labels represent the different backwashing time durations (BW30 = 30 min; BW1 = 1 h; BW2 = 2 h; BW3 = 3 h; BW8 = 8 h; BW16 = 16 h).

Table 3 | *Post hoc* comparisons for the factor "backwashing time duration" in line B1 and B2. Significant ($P < 0.05$) and highly significant ($P < 0.01$; in bold letters) differences are reported for nematodes, gastrotrichs, rotifers and anellids, as changes of density calculated before and after the treatment (n.s. = not significant)

Line B1	Nematodes	Gastrotrichs	Rotifers	Anellids
30 min	**2 h, 3 h, 8 h, 16 h**	**1 h, 2 h, 16 h**	n.s.	n.s.
1 h	**2 h, 3 h**, 8 h, **16 h**	**30 min, 2 h, 16 h**	n.s.	n.s.
2 h	**30 min**, 8 h	**30 min, 1 h, 3 h, 8 h**	n.s.	n.s.
3 h	**30 min, 1 h**	**2 h, 16 h**	n.s.	n.s.
8 h	**30 min**, 1 h, 2 h	**1 h, 16 h**	n.s.	n.s.
16 h	**30 min, 1 h**	**30 min, 1 h, 3 h, 8 h**	n.s.	n.s.
Line B2				
30 min	2 h	n.s.	1 h	n.s.
1 h	16 h	n.s.	30 min, **2 h, 8 h**, 16 h	n.s.
2 h	30 min, **16 h**	n.s.	**1 h**	n.s.
3 h	**16 h**	n.s.	n.s.	n.s.
8 h	n.s.	n.s.	**1 h**	n.s.
16 h	1 h, **2 h, 3 h**	n.s.	1 h	n.s.

A stable invertebrate colonisation of the two GAC filter lines was shown by the relatively constant density found throughout the study period and confirmed by the routine control data and density peaks, i.e. the explosion of nematodes in line B2 could not be related to any variation of abiotic parameters or managing practices, such as water flux.

Moreover, there was no significant difference between before/after treatment density changes, independently from their being calculated over a hourly or weekly period. Finally, even in the case of strong intervention on a single filter, using hyper saline solutions (NaCl 35% solution, 1 h time of contact for each carbon layer) for the complete removal of invertebrates, the cleaned filter, once reconnected in series with the others, was re-colonised in a few days (data not shown).

Since unpredictable sources of contamination can be excluded, raw water being always pumped from wells, and routine analysis never showing the presence of invertebrates since the opening of the plant, attention was focused on other parts of the plant as possible sources of contamination. In particular, two sedimentation tanks were studied, which had been designed to receive backwashing treatment water before driving it back to the head of the plant where it is mixed with water pumped from the well net. Owing to gravity these sedimentation tanks remove large debris, detached from GAC filters during backwashing, and no coagulant is added at this stage. Because of their small size (6 m diameter, ratio of diameter to depth about 3:1) and low loads applied, the sedimentation tanks were not equipped with continuous scraper blades and were designed with tank bases sloping from the periphery inwards, by as much as 30°, encouraging the sludge into a central collection hopper, from where it can be withdrawn by a pump and sent to sludge treatment.

Moreover, the backwashing procedure was not continuous, determining the presence of intermittent hydraulic and particulate loads in the sedimentation tanks. This particular hydraulic regime, not constant throughout the year, recurrently caused almost complete sedimentation and the persistence of good transparency. In these conditions periphyton developed on the tank slopes, offering a suitable environment for the settlement of a stable invertebrate community within the plant.

From this, it is evident that every treatment of GAC filters to eliminate invertebrates becomes useless owing to the continuous re-colonisation from the sedimentation tanks (Cobb 1918; Lupi *et al.* 1994).

CONCLUSIONS

This study shows that applied backwashing procedures are only apparently effective. In fact, immediately after the treatment, the microscopic quality of the outflow water decreased owing to the presence of more invertebrates. However, considering the short re-colonisation time within 15 d after treatment (Figure 3), it is clear that only a few organisms are removed by the treatment and the backwashing effect is always temporary.

From a practical point of view, in order to face invertebrate colonisation, sedimentation tanks were physically cleaned, scraping away the algal mats and applying a strong disinfectant. The GAC filter cleaning procedure was modified by reducing backwashing time duration (1–2 h) and increasing the number of interventions.

The adoption of this strategy during the four years following this experiment definitely reduced the number of invertebrates colonising both GAC filter lines to about 1000 ind. m^{-3} without the reoccurrence of peaks, as was previously shown. This further positive and temporarily constant effect clearly indicated that a most effective control of invertebrate colonisation could be achieved mainly through increasing the backwashing frequency rather than prolonging its duration. This evidence could be related to the interference of more frequent backwashing with the short life cycle, from hours to days, of rotifers, gastrotrichs (Rici & Balsamo 2000) and nematodes (Traunspurger 2000).

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