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INFLUENCE OF ALGAL SPECIES AND CULTIVATION CONDITIONS ON ALGAL REMOVAL IN DIRECT FILTRATION

B. Petruševski*,**, A. Vlaški*, A. N. van Breeman** and G. J. Alaerts*

* *IHE (International Institute for Hydraulic and Environmental Engineering), P.O. Box 3015, 2601 DA Delft, The Netherlands*
** *Department of Civil Engineering, Delft University of Technology, P.O. Box 5048, 2600 GA Delft, The Netherlands*

ABSTRACT

The influence of growth media on the behaviour of cultured algae in direct filtration was examined. Cultured *Chlorella vulgaris* and *Selenastrum capricornutum* on Jaworski and Z-8 media are used for model water preparation. It was found that the same algal species in the same growth phase had different responses under identical treatment conditions. Also, difference in growth phase influenced their behaviour. Therefore. assuming similarity between cultured algae and algae from natural waters is highly questionable.
The efficiency of the direct filtration treatment process for the removal of dominant algal species present in Biesbosch Water Storage Reservoirs was investigated. Different removal patterns were found for various algal species. The most difficult to be removed were *Rhodomonas minuta* and *μ-algae*. High removal efficiency was found for *Stephanodiscus hantzschii* and other cylindrical diatoms. An overall algal biomass removal of 90 % was achieved. Algal penetration through filters is a consequence of algal size and inefficient agglomeration during coagulation. It was found that the application of oxidants (ozone and potassium permanganate) prior to coagulant addition improves the efficiency of direct filtration . The use of H_2O_2 did not enhance algal removal under the conditions investigated.

KEYWORDS

Direct filtration; Algae; Algal removal; Algal cultivation media; Preoxidation; Ozone; Potassium permanganate.

INTRODUCTION

Numerous problems are associated with the production of drinking water from eutrophic waters with a high algal content. As far as direct filtration is concerned, problems caused by algae may be grouped into three categories: algal penetration through filters, interference of coagulation and flocculation processes caused by extra-cellular organic matter (EOM) produced by algae, and short filter runs with an associated increased use of backwash water. Direct filtration is in principle capable of removing most algal species relatively efficiently. However, this requires careful optimisation of the direct filtration procedure. Due to algal penetration through filters, and rapid filter clogging, it is not advisable to apply direct filtration to raw

waters with very high algal concentration. According to the AWWA filtration committee report (1980), waters with algae counts of up to 2000 ASU/ml are suitable for direct filtration. Very eutrophic reservoirs and lakes with higher concentrations may be more efficiently treated with flotation. If large algae, exceeding the size of commonly applied microsieve fabric, are abundant, application of mechanical pre-treatment like microstraining, may diminish filter clogging problems and permit direct filtration application. Although no standards are set specifically for algal concentration in drinking water, the algal count should be kept as low as possible for numerous reasons such as increased chlorine demand, presence of haloform precursors and other organic compounds, biological aftergrowth of bacteria and zooplankton in activated carbon filters and distribution mains and introduction of natural toxins.
Generally, two approaches exist to study algal removal efficiency. In the first, and most frequent one, small scale laboratory experiments use reproducible, controlled model water with a mono-algal culture. The second entails more representative simulation experiments on a larger scale, with natural water incorporating particle and algae heterogeneity. When the algae from natural waters are used, their concentration fluctuates over the year and, in the case of water sources suitable for direct filtration, is often too low, with the exception of short bloom periods.

This paper discusses algal removal efficiency in direct filtration. Basically, this study focuses less on the issue of turbidity removal, but more on prevention of occurrence of organic material in the tap water. As algae removal in water treatment is extremely complex, the study was not intended to fully resolve the optimisation question, but rather to identify the main factors influencing algal removal in direct filtration. The influence of key factors such as algal species, their growth phase and growth media, filter media and pre-oxidation were investigated. An additional research goal was to validate the routine approach in laboratory investigations dealing with algal removal, based on the use of model water with algae from pure cultures. The findings reported are part of a comprehensive ongoing research programme aimed at assessing the applicability of direct filtration to Biesbosch reservoir water, characterised by a seasonally high algal load. Water from these reservoirs is used as a raw water source for city of Rotterdam. In addition, it partly covers the requirements of Dordrecht city and the water works of the provinces of North-West Brabant and South-West Netherlands. Natural water from Biesbosch storage reservoirs was used for filter runs with an automatic mobile and bench scale direct filtration pilot plant installed at the water treatment plant "Kralingen" - Rotterdam. Removal efficiency for different algal species was examined. Also, removal of different types of green algae (*Chlorella vulgaris* and *Selenastrum capricornutum*) and blue-green algae (*Microcystis aeruginosa*) from model waters was studied in modified jar test experiments.

EXPERIMENTAL PROCEDURES

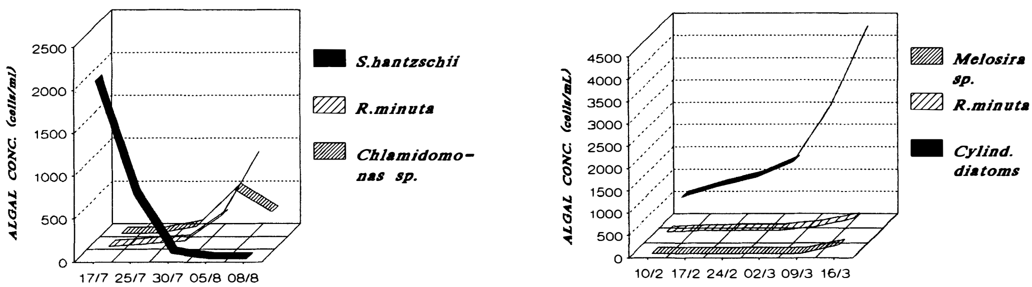
Three types of experimental set-up were used for direct filtration studies:
(1) a modified jar test procedure, consisting of a jar test apparatus connected to small scale filters (diameter 60 mm, height 400 mm), with sand as the filtration medium (commercial fraction 0.80-1.25 mm, bed thickness 200 mm). The procedure consists of the addition of a coagulant, 30 seconds rapid mixing at the $G=1000\ s^{-1}$, seven minutes slow mixing at the $G=10\ s^{-1}$ and filtration at the constant filtration rate of 10 m/h. Model water with algal cultures and preconcentrated natural water were used in these experiments. This simplified technique was found to provide reliable and reproducible indications of changes in response due to different treatment conditions.
(2) a bench-scale direct filtration pilot plant developed in order to overcome some of the modified jar test apparatus limitations (e.g. effect of the filter bed ripening, of dual and multi media, etc.). The plant consists of four parallel filter columns, 100 mm in diameter with associated flow-measuring and regulating devices, and chemical dosing equipment. Filter columns were constructed of segments (100 and 200 mm) allowing a variation of bed thickness and composition. Natural water from the Biesbosch storage reservoirs was used in these experiments.
(3) a mobile fully automated direct filtration plant, developed at the Sanitary Engineering Laboratory (TU Delft), also used in experiments with natural water. This installation allows assessment of algal removal on a larger scale. The plant consists of two filter columns (190 mm in diameter), a chemical dosing unit and process control, measuring and regulating equipment. Application of up to three different chemicals is

possible, with automatic plant operation and continuous measurements of filtrate turbidity and head loss development. Dual (anthracite/sand) and multi-media (anthracite/sand/garnet) beds were used in the experiments.

Ferric chloride at a dosage of 1 mg Fe(III)/L, a value selected after preliminary optimisation experiments, was used as coagulant, unless otherwise mentioned.

For ozonation experiments a bench scale ozone reactor (as developed by KIWA - The Netherlands Waterworks' Testing and Research Institute) was utilized.

Raw water from Biesbosch reservoirs used in the experiments is characterised by seasonal and even monthly cycles of a limited number of dominant algal genera and species. Figure 1 shows the typical distribution pattern for the summer and early spring periods. In addition to species presented on the graphs, small green, so-called μ-algae were consistently present in a considerable number (a few thousand cells /mL). Chlorophyll-a yearly average level is about 5 μg/L, with the spring peaks reaching values as high as 50 μg/L. In addition, Biesbosch water is characterized by low turbidity, less than 4 FTU (most frequently below 1 FTU) and TOC levels between 3 and 4 mg/L.



a. b.

Fig. 1. Variation of algal concentration in Biesbosch water, for the periods summer 1991 (a), and spring 1992 (b).

In the investigation, removal efficiency for different algal species belonging to different groups e.g.*Bacillariophyceae-Stephanodiscus hantzschii*, *Cryptophyceae-Rhodomonas minuta*, *Chlorophyceae-Chlamydomonas sp.*, colonies and single cells of *μ-algae* was examined. During the early spring period diatoms *S. hantzschii*, *S. astraea* and *Cyclotella sp.* were enumerated under the common name of "cylindrical diatoms". However, the dominating species was *S. hantzschii*. In order to obtain a more pronounced response in the treatment, during the study the algal concentration in natural water during the period of low algal count was increased with the help of a tangential flow filtration system. It was found that the high concentration factors of up to 20 may be applied without affecting algal viability and cell recovery rates (Petruševski et al. in preparation).

The removal of large algae, exceeding the size of commonly applied micro-mesh fabric (35 μm), was not investigated. It was assumed that their efficient removal may be obtained more easily by raw water pre-treatment (microstraining).

Cultured green (*C. vulgaris* and *S. capricornutum*) and blue-green (*M. aeruginosa*) algae were used for preparing model water. *C. vulgaris* was selected because it is the most frequently used in laboratory investigations. *S. capricornutum* was chosen as an alternative representative of green algae. *M. aeruginosa* was selected as a common blue-green alga, frequently responsible for unpleasant taste and odour of treated water. In order to assess the influence of the growth phase and growth media, the first two were cultured as semi-continuous cultures on Jaworski (Thompson et al. 1988) and Z-8 media (Skulberg 1964). When selecting suitable growth media, it was found that difference in these particular media influenced algal filterability over membrane filters. Hence, the Z-8 and Jaworski solutions were selected as growth substrates.

Particle agglomeration and removal were evaluated by Mini-Magic Scan (IAS 25/ IV25 from Joice-Loebl

Ltd), an image analysis system, in the form of statistically elaborated binary image data expressed as cumulative particle size distributions. An inverted microscope providing up to 600 magnification was used for plankton counting. Standard Netherlands Water Works practice for algal enumeration was followed (minimum 50 fields or 400 counted units-cells per sample). Turbidity was measured with a high precision Sigrist turbidimeter.

RESULTS AND DISCUSSION

Influence of Growth Media on Algal Removal in Direct Filtration

A routine approach in investigation of algal response to different treatment conditions is to use model water with algae from cultivated, mono-algal cultures. In order to study the validity of the approach, a series of experiments was conducted using model waters with representative species *C. vulgaris* and *S. capricornutum* cultured on two different growth media as semi-continuous cultures. All model waters were exposed to the modified jar test. Experimental results were expressed as cumulative particle size distribution curves for model water and filtrate (Fig. 2 and 3).

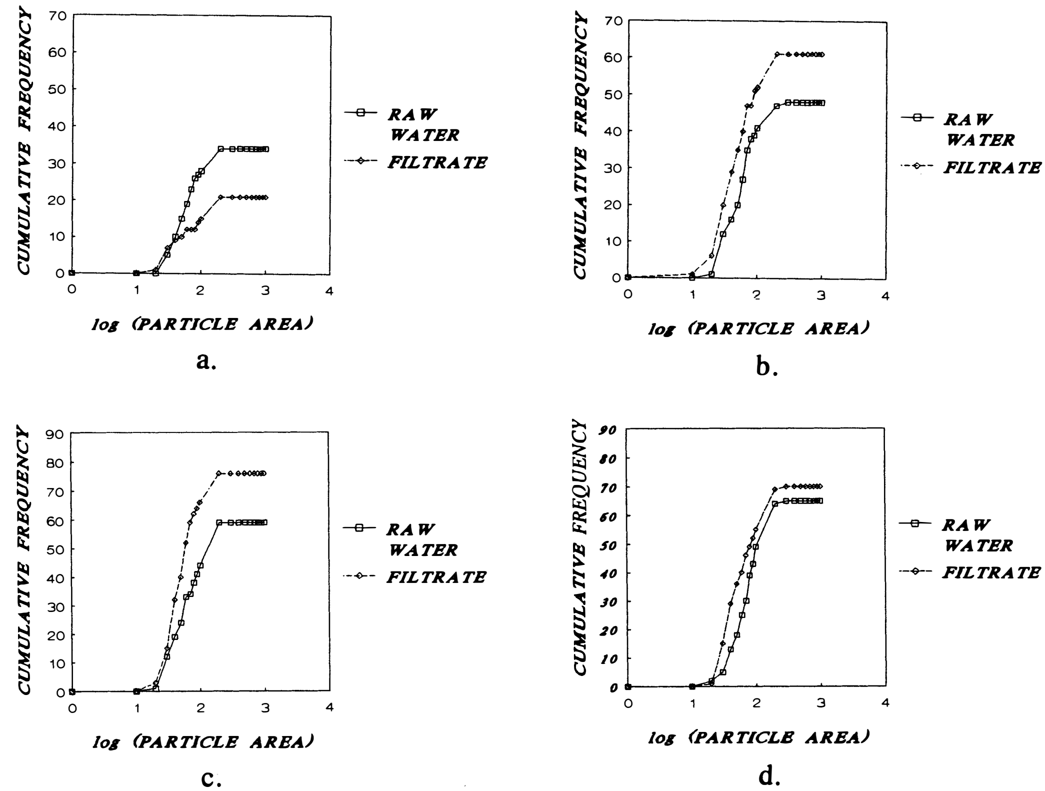


Fig. 2. Particle size, expressed as logarithm of the horizontally projected area in μm^2, distribution before and after experiments with modified jar test apparatus. *Chlorella vulgaris* in stationary (a, b) and logarithmic (c, d) growth stage, cultured on Z-8 (a, c) and Jaworski (b, d) media.

The horizontally projected particle area was employed as a size indicator . The efficiency of the treatment process is judged by a decrease in the number of scanned particles in the filtrate. Results show that the same algal species in the same growth phase, but grown on a different medium, respond differently to identical treatment conditions. Typically, comparison of Fig.2 a and b shows that the Z-8 medium produced *C. vulgaris* in a stationary growth phase yields better filtrate quality. However, this discrepancy was not observed during their logarithmic growth stage (Fig.2 c, d). In order to verify the general validity of these outcomes, the same set of experiments was repeated with another type of green algae, *S. capricornutum* (Fig. 3). In this case both model waters, with Jaworski and Z-8 medium cultured algae, led to a higher quality of filtrate than raw water. However, the overall reduction in the number of scanned particles was much higher with Z-8 medium grown algae. During the logarithmic growth stage a value of 50 % reduction was reached for Z-8 medium, compared to 25 % for Jaworski medium grown algae. The difference was even more pronounced in the stationary growth phase, in which a 40 % particle reduction was accomplished for Z-8 medium grown algae, compared with a mere 3 % reduction obtained for model water with algae grown on Jaworski substrate. In general the Jaworski medium grown algae led to poorer direct filtration performance.

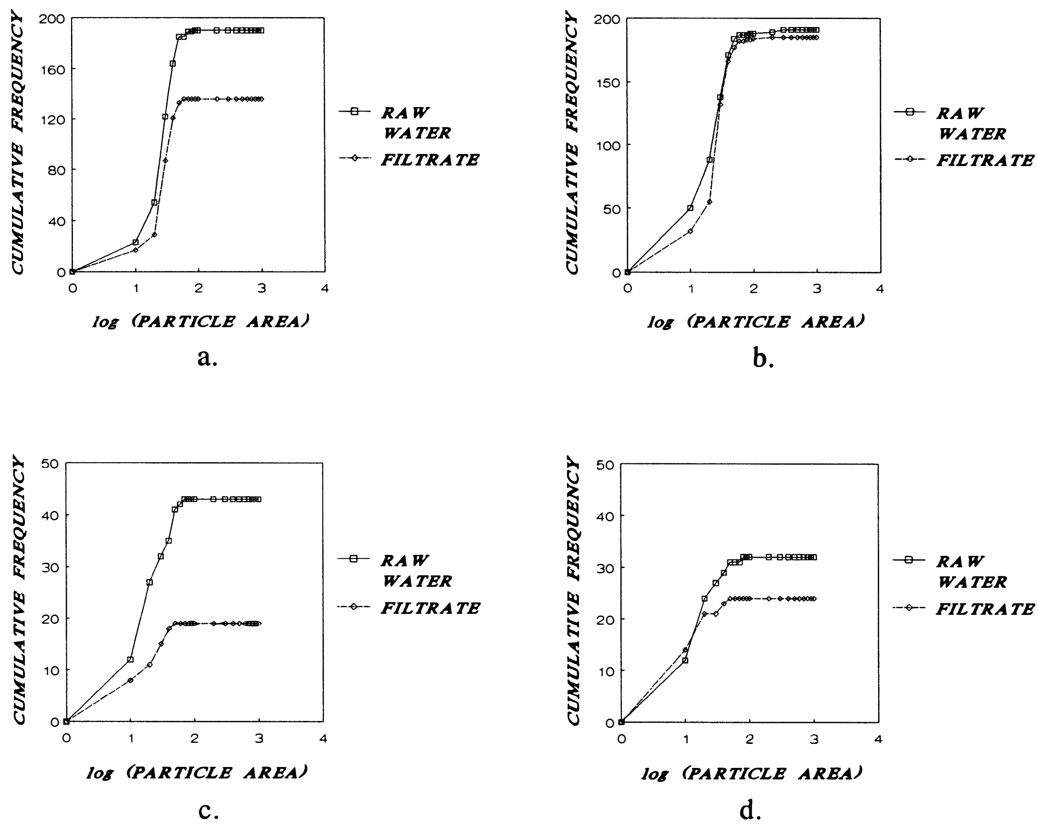


Fig. 3. Particle size, expressed as logarithm of the horizontally projected area in μm^2, distribution before and after experiments with modified jar test apparatus. *Selenastrum capricornutum* in stationary (a, b) and logarithmic (c, d) growth stage, cultured on Z-8 (a, c) and Jaworski (b, d) media.

The observed phenomenon is most likely correlated to a difference in the medium's composition. A considerable difference exists in major and trace elements, vitamin concentration, and the composition and concentration of complexing agents which are applied to maintain elements mobilized. Complexing agents, however, are able to solubilize Fe by complex formation, thus making less Fe available for floc formation. In the Z-8 medium, a significant part of the complexing agent is likely to be already bound by the high concentration of numerous micronutrients. That is less the case with the Jaworski medium, characterized by low micronutrient level. Consequently, the amount of iron coagulant available for algal flocculation is considerably higher in the case of Z-8 medium, producing more favourable agglomeration conditions. Apart from the direct relationship between medium composition and the available amount of hydrolysable iron, the growth medium may also be responsible for biochemical differences in the algal cell wall structure. This was partly confirmed by the measurement of electrophoretic mobility for the algae grown on these media, which were found to be different. Although the underlying phenomena are not yet completely clear, they reflect a general tendency of algae to vary surface and other properties with a change of environmental conditions. It can be concluded that the extrapolation of results obtained from earlier artificial model studies, applying algal cultures to natural waters, is questionable.

An additional set of modified jar test experiments was conducted with natural and model *M. aeruginosa* dominated water (Fig.4). Natural water was taken from the Biesbosch reservoirs during a late summer *M. aeruginosa* bloom. Model water was prepared from the cultured *M. aeruginosa*, grown as a batch culture at the Microbiological Department of the University of Amsterdam. In natural water, algal cells were found to be grouped in three-dimensional colonies, while the algae in the cultures were in the form of single cells, probably as a consequence of continuous mixing conditions during culturing.

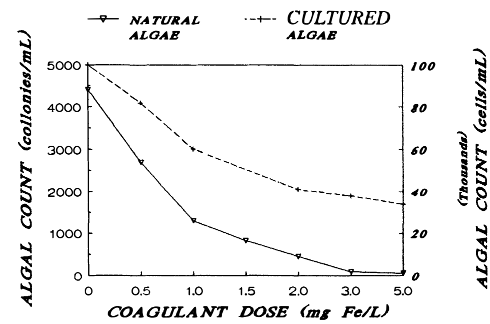


Fig. 4. Concentration of *M.aeruginosa* in the modified jar test effluent, as a function of coagulant dose.

Results show that a straightforward use of model water with cultured algae may lead to erroneous conclusions if results are extrapolated to natural conditions. On the other hand, a comparison of the results confirms the practical experience of waterworks that *M. aeruginosa* causes poor filtration performance when colonies break up and algal cells appear in the individual form. This phenomenon again emphasizes the importance of adequate floc formation or agglomeration, by natural or chemical flocculation, as a prerequisite for efficient filtration.

Removal of Dominant Algal Species from Biesbosch Reservoirs

As a consequence of the applied softening technique in Biesbosch reservoirs, a considerable number of calcite particles, of a size similar to algal dimensions, were present in the raw water. Complete elimination of calcite particles was systematically achieved suggesting that the flocculation and filtration conditions in the pilot plant are appropriate for removal of common inorganic particles.

The experiments with natural as well as model water, have shown that algal removal efficiency strongly varies with algal species and growth phase. It was also noticed that the removal efficiency may differ significantly for algal species with similar sizes and shapes, pointing out that other algal properties also play an important role. Figure 5 shows typical algal removal patterns achieved with the mobile direct filtration plant, during the summer and early spring. Removal efficiency as low as 5% was found for *R. minuta* during the summer period, making it the most difficult algal species to be eliminated. This alga, 5-10 μm long, is equipped with flagella allowing easy and fast swimming, possibly permitting it to escape from formed flocs. The movement of flagellated algae at speeds of 50 to 300 μm/s have been reported (Brokaw 1962). Significantly higher removal efficiency, typically about 60 %, of *Chlamidomonas sp.*, also a flagellated alga, was found. The difference in behaviour of *R. minuta* and *Chlamidomonas sp.* may be due to a difference in size and possibly cell surface properties, as well as the distinctive pattern of *R. minuta*'s flagellar movement. In the pilot plant experiments high removal efficiency (94-100%) was found for *S. hantzschii*, though it is generally reported to be difficult to agglomerate. This discrepancy is likely related to absence of long needles, reported by Bernhardt and Clasen (1991) to be the main agglomeration inhibitor. In our experiments, we found diatoms in Biesbosch water to lack needles during summer and early spring period. Small spherical green algae, *Chlorophyceae*, (less than 3 μm in diameter), also called μ-algae are almost continuously present in Biesbosch water. Their presence in raw water goes frequently undetected, since the commonly applied inverted microscopes with magnification of up to 400x are not sufficient for their proper identification and enumeration. Removal efficiency of μ-algae was found here to be less than 50 %, with somewhat higher removal of their colonies in a three layer filter. These results may be correlated with (1) their inefficient flocculation, and (2) results from filtration studies revealing that minimum removal efficiency may be expected for particles of size 1-3 μm (Westerhoff and Tobiason, 1991).

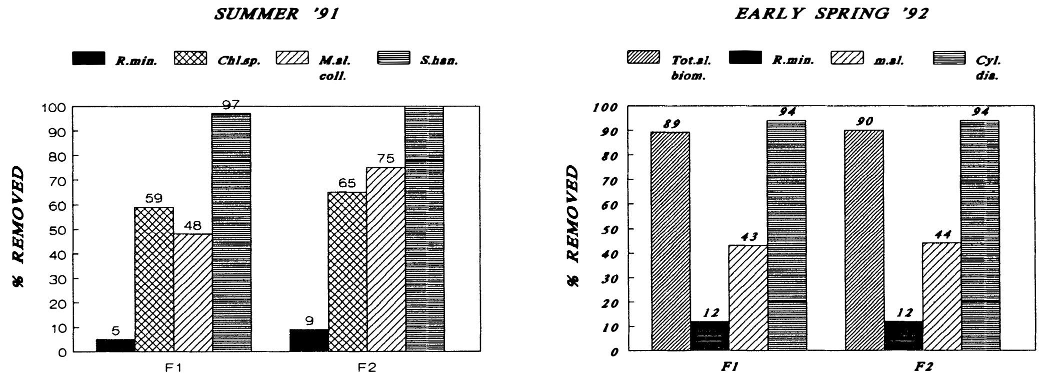


Fig. 5. Removal of different algal species obtained in the mobile direct filtration plant, during the summer and early spring period. Coagulant: ferric sulphate, 1.0 mg Fe(III)/l, F1-dual media filter (anth./sand), F2-three layer filter (anth./sand/garnet), filtr.rate 10 m/h. Algal species: R.min - *Rhodomonas minuta*, Chl.sp.- *Chlamidomonas sp.*, M.al.coll. and m.al. colonies and single cells of μ-algae, S.han. - *Stephanodiscus hantzschii*, cyl. dia. - cylindrical diatoms.

The problem of inefficient removal of these algal species is frequently neglected, partly because their concentration in reservoir water is relatively low compared with other species. However, Figure 6 indicates that the contribution of these algae to the total algal biomass in Biesbosch water during the spring period increased from approximately 6 % in raw water to over 47 % in the filtrate. Consequently, the issue of their efficient removal should be carefully addressed.

Microscopic examination (magnification 600X) revealed that the algae in the filtrate were present almost exclusively in the form of single cells. It was also observed that the coagulated raw water, before entering filter media, contains a mixture of iron hydroxide microflocs without algae, larger flocs (40-60 μm) with several algae trapped inside, and a large

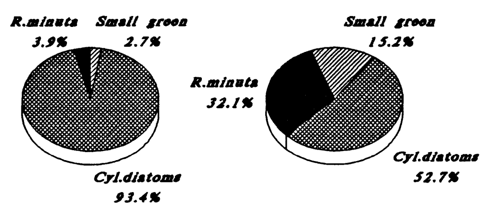


Fig. 6. Contribution of different algal species to total algal biomass in the raw water and filtrate.

number of single algal cells. This strongly suggests that where algal removal in direct filtration is poor, it is mainly related to inefficient algae-flocs interaction and agglomeration (low collision efficiency during coagulation and filtration stage). Algal properties that may cause this are complex and related notably to algal motility, wall composition, algal cell form and in particular the presence of the outer mucilaginous layer.

In comparison with dual filter media, the three layer filter, consistently featured equal or slightly higher algal removal efficiency, at the expense of somewhat shorter filter runs. Typically, filter run lengths were 50 hours for dual filter media and 40 hours for the three layer filter. Filter runs were terminated when the maximum allowable head loss of 2.5 m was reached. Improvement is also noticeable on the other water quality parameters followed in the experiments (turbidity and UV-extinction at 254 nm).

Pretreatment by Oxidation

Algal agglomeration and subsequent removal in the filter bed may be improved if the algal surface and other coagulation related properties are altered. Use of oxidants before coagulant addition is reported to result in enhanced algal agglomeration under certain conditions. Ginocchio (1981) reported that the algal removal efficiency in a direct filtration pilot plant was significantly improved with preozonation (dosage 2.0 mg/l). Jodlowski (1990) found that the application of ozone dosages (0.8-2.9 mg/l) before coagulant addition diminished the number of individual algal cells. Janssens et al. (1987) found that preozonation and prechlorination have strong positive effects on direct filtration performance. Experience with the use of other oxidants in combination with direct filtration, and understanding of the mechanisms involved, are rare.

In order to study the influence of oxidants on Biesbosch reservoir water, experiments with ozone, potassium permanganate and hydrogen peroxide were performed (the chlorine option was discarded to prevent THM formation). Raw Biesbosch water, during late winter and 5 to 10 times concentrated, was used in the experiments in which the modified jar test apparatus was employed. In addition, selected filter runs with a bench scale direct filtration pilot unit were conducted using raw Biesbosch water, to study pretreatment with potassium permanganate and hydrogen peroxide. Dominant algal species were cylindrical diatoms, μ-algae and *R. minuta*. Applied oxidant doses were: ozone 1.3-2.4 mg O_3 consumed/l, potassium permanganate 1.0 - 5.0 mg/l, hydrogen peroxide 10 - 80 mg/l.

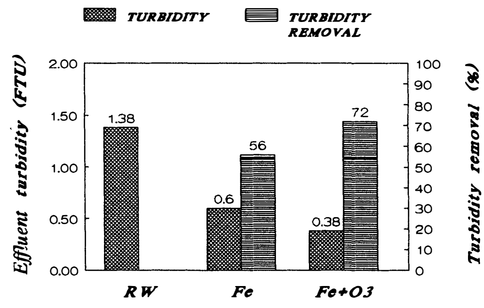


Fig. 7. Turbidity removal with modified jar test apparatus; coagulant FeCl*6H$_2$O , 1.0 mg Fe(III)/l; RW-raw water, Fe-sample without O_3; Fe+O_3 sample with 1.8 mg O_3/l.

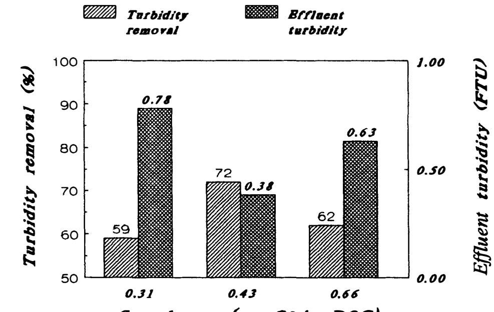


Fig. 8. Effect of specific ozone dosage on turbidity removal in modified jar test experiments; coagulant $FeCl_3$*6H$_2$O, 1.0 mg Fe(III)/l.

The results, found to be representative for longer periods (several months), (Figure 7) show the improvement of treatment efficiency, expressed as turbidity removal (from 56% to over 70%) with the application of ozone; the same was found with potassium permanganate. This effect could not be observed with hydrogen peroxide, however. The observation that preozonation significantly improves turbidity removal could not be documented by algal count, because practically all algae found in the preozonated filtrate were entrapped in flocs making proper algal enumeration impossible. The modified jar test, featuring only short, clean beds, does not guarantee complete flocs removal. Aggregates of the kind found in the filtrate would be retained in a ripened filter of normal depth. This shows that for the algal population under consideration, preozonation promotes efficient flocculation and hence filtration efficiency. A relation between specific ozone dosage, (mg O_3/mg DOC), and treatment efficiency was observed (Fig. 8). The optimum turbidity removal was observed for a specific ozone dosage of app. 0.4, confirming values from full scale plants successfully applying ozone as a preoxidant. The process mechanisms of ozone acting as an algal agglomeration promoter are still unknown. The likely beneficial effect may be attributed to a combination of such factors as: reaction with the adsorbed organic coating on the algal surface (Singer 1990), destruction of the algal EOM present in the raw water and attack on the algal cell wall structure (Sukenik et al. 1987), formation of biopolymers that can assist in the coagulation of particular matter (Singer 1990, Sukenik 1987) and immobilization or killing of motile algal species.

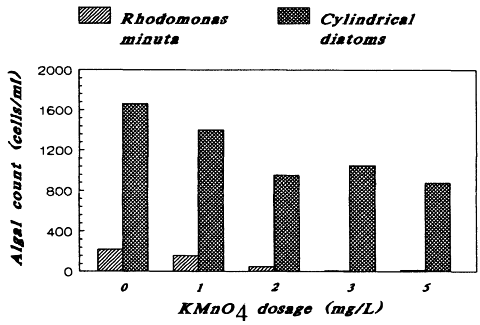


Fig. 9. Effect of potassium permanganate on algal removal with modified jar test apparatus (rearranged from Nalubega, in preparation).

Enhanced algal removal in the experiments with potassium permanganate applied as a preoxidant, should probably be attributed to different mechanisms. In addition to the above mentioned mechanism of immobilization or killing of motile algal species, precipitation of manganese oxides on the algal surface and enhanced perikinetic flocculation could also play an important role. However, additional experiments are required to assess the observed phenomenon comprehensively.

CONCLUSIONS

The results presented show that the same algal species, in the same growth phase cultured on different media, tend to respond differently to identical direct filtration treatment conditions. Also, direct filtration removal efficiency of algal species is influenced by their growth stage. Consequently, extrapolation of the results from model studies, applying algal cultures to natural conditions is highly questionable. Conceivably the better approach is to use natural algae, from water bodies intended to be used as water sources. Experimental difficulties caused by the low algal concentration in natural waters over long periods of the year, and typical for raw water sources suitable for application of direct filtration, may be resolved by concentration of algae. Results obtained with a tangential flow membrane filtration system reflect that high concentration factors, of up to 20 may be applied without affecting algal viability and cell recovery rates. Algal removal efficiency strongly varies with different algal species. High removal efficiencies, over 94 %, were found for cylindrical diatoms, the dominant algal species in Biesbosch reservoirs. The most troublesome algal species to be eliminated were found to be *R. minuta* and μ-algae. Their poor removal may be mainly related with inefficient agglomeration. Although contribution of μ-algae and *R. minuta* to total algal biomass in raw water is small, they represent almost half of the algal biomass in the filtrate.
Preoxidation with ozone and potassium permanganate, under the conditions investigated, improved direct filtration performance in the terms of turbidity and algal removal. Hydrogen peroxide on the contrary, did not yield similar improvement. A strong correlation between specific ozone dose and treatment efficiency exists.

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REFERENCES

AWWA Committee Report (1980). The status of direct filtration. J. AWWA, 72, pp 405-411.

Bernhardt, H. and Clasen J. (1991).Flocculation of micro-organisms. J. Water SRT-Aqua, 40, No 2, pp 76-87.

Brokaw, C.J. (1962). Flagella. In: Phycology and Biochemistry of Algae, R.A. Lewin (Ed.). Academic Press, pp 595-601.

Ginocchio, J.C. (1981). Effect of ozone on the elimination of various algae by filtration. In: Ozonization Manual for Water and Wastewater Treatment, W.J.Masschelein (Ed). John Wiley and Sons, pp 69-72.

Janssens, J.G., van Hoof, F. and Dirickx, J.J. (1987), AWWA Annual Conference Proceedings, Kansas City, MO June 14-18.

Jodlowski, A. (1990). Preoxidation effect on algae coagulation related to direct filtration water treatment. Internal communication, Delft University of Technology.

Nalubega, M. (in preparation). Algae and Direct Filtration of Biesbosch Water. Master of science report, IHE, Delft

Petruševski, B., Nalubega, M., A.N.van Breemen, Alaerts, G.J., Bolier, G. and Koopman, M. (in preparation). A procedure to concentrate live freshwater algae.

Singer, P.C. (1990). Assessing ozonation research needs in water treatment. J. AWWA, 82, pp 78-88.

Skulberg, O.M. (1964).Algal problems related to the eutrophication of European water supplies, and a bioassay method to assess fertilizing influences of pollution on inland waters. In: Algae and Man, D.F.Jackson (Ed.), New York, Plenum Press, pp 262-299.

Sukenik, A., Teltch, B., Wachs, A.W., Shelef, G., Nir, I. and Levanon, D. (1987). Effect of oxidation on microalgal flocculation. Wat. Res. 21, No. 5, pp 533-539.

Thompson,A.S., Rhodes, J.C. and Pettman, I. (1988). Culture Collection of Algae and Protozoa; Catalogue of Strains. Natural Environment Research Council.

Westerhoff, P.K. and Tobiason, J. E. (1991).Effects of flocculation on direct filtration. J. NEWWA, 105, No 2, pp 95-109.