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ELIMINATION OF *MICROCYSTIS* CYANOBACTERIA (BLUE-GREEN ALGAE) BY AN OZOFLOTATION PROCESS: A PILOT PLANT STUDY

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ABSTRACT

It is now known that since cyanobacteria (blue-green algae) occur in both swimming and drinking water supplies, and lakes and rivers, they represent an increasing hazard to animal life and human population. Moreover, high algal contents pose also a number of operation problems for water purification plants. The objective of the work is to study the elimination of a *Microcystis* strain of cyanobacateria by the use of an ozoflotation process which associates the oxidizing properties of ozone and the physical aspects of flotation. The functioning and the efficiency of a pilot unit is presented according to such parameters as: ozone dose, flow rate, coagulants and raw water quality. The use of ozone in pretreatment leads to an inactivation of the algal cells. Experiments let us calculate the specific ozone utilisation rate of *Microcystis* and the [C.t] (ozone concentration, contact time) curve is determined versus algal removal. Under real conditions, a previous coagulation stage is necessary; best results are obtained with ferric chloride. Preozonation is also of influence on the enhancement of the coagulation efficiency. Association of the ozoflotation process and bilayer filtration can solve the algae problems of waters presenting low turbidity and low organic content, and improve water quality.

KEYWORDS

Algae, blue-green algae, coagulation, cyanobacteria, flotation, *microsystis aeruginosa*, ozoflotation, ozone, treatment process.

INTRODUCTION

It has been realized for many years that the cyanobacteria (blue-green algae) which occur in freshwaters from May to September, present a potential toxic danger to the environment.

In retrospect, 25 countries of Europe, Asia, America and Australia have noted the occurrence of these blue-green algae in natural waters. Under favorable conditions of nutrient supply, particularly phosphorus, they form dense water blooms and dominate the ecology of the water. These blooms are frequently harmful to wildlife, domestic livestock and human consumers, causing animal poisoning and a range of human allergic

and gastroenteric reactions. This phenomenon has been studied by many researchers and the predominant poisonous algae that they reported were the types *Microcystis*, *Aphanizomenon*, *Anabaena*, *Oscillatoria*, *Gloeotrichia*, *Coelesphaeria* and *Nodularia* (Francis, 1878; Gorham, 1964; Schwimmer and Schwimmer, 1964, 1968; Collins, 1978; Gorham and Carmichael, 1979; Moore, 1981; Skulberg *et al.*, 1984; Codd, 1984; Codd and Bell, 1985). Moreover, recent research has shown that the main types of toxins produced by these algae in eutrophic waters are hepatotoxic peptides and neurotoxic alkaloides. These works suggest how to conduct a toxicity evaluation of drinking or swimming water by using mouse bioassays and other new biotests (Brooks and Codd, 1986, 1988; Carmichael, 1986; Codd *et al.*, 1989; Nakano *et al.*, 1989; Sivonen *et al.*, 1989; Repavich *et al.*, 1990; Lawton *et al.*, 1990).

At the present time, another important aspect of this high algal content is that it can cause several treatment problems for some drinking water purification plants:

Firstly, the algae cause taste, odour and colour problems which can be generated by metabolites releases in the water.

Secondly, the algal blooms lead frequently to many malfunctions of the plants like a high clogging index of the water, short filter runs and algal development inside the treatment works, necessitating expensive manual work to return them to full efficiency (Bourbigot and Faivre, 1991).

Finally, an oxidation pre-treatment of raw water containing cyanobacteria can make their toxins be released in the treated water.

Therefore, the objective of this work was to study the elimination of a *Microcystis* strain of cyanobacteria by the effect of an ozoflotation process in a pilot plant. This pre-treatment combining the oxidizing properties of ozone with the flotation process in particularly suitable for removing particles suspended in water (Betzer *et al.*, 1980; Adler *et al.*, 1985) Baetz *et al.*, 1986; Becker *et al.*, 1990). The algae are first coagulated to facilitate flotation. They are brought into close contact with fine bubbles of ozone that are swept off porous diffusion plates (through which they are injected into the pilot plant) by an additional stream of water (Van Vuuren *et al.*, 1965; Faivre *et al.*, 1987; Edzwald and Wingler, 1990; Smith *et al.*, 1991). thanks to these bubbles the flotation takes place and leads to froth formation at the water surface of the pilot plant.

In this study, the functioning and the efficiency of a pilot unit is presented accoridng to different parameters like ozine and coagulant doses, flow rates of gas or liquid and characteristics of raw river water doped with *Microcystis aeruginosa* strain. By using the ozoflotation process, we will be able to:

- eliminate a part of the algae and thus reduce clogging of the filters.
- reduce organic matter and turbidity.
- determine an optimum dose of ozone with a corresponding contact time of treatment.

To evaluate the efficiency of the process, several methods of analysis were carried out on water samples at different stages of the treatment.

MATERIALS AND METHODS

Ozoflotation process

The ozoflotation process is a combination of the pre-ozonation treatment and non-conventional flotation. Figure 1 is a schematic representation of this process for which a patent request was filed June 18, 1986 in France (Bourbigot and Faivre, 1986).

The contactor is divided in two cells. In the first, cell A (ozonation compartment), the water and air flows are counter-current. Ozonated air is diffused through porous plates which are located at the bottom of the

contactor. Diffusion is not conventional because the porous plates are swept by a water flow, in order to create very small bubbles. These bubbles adhere to flotable particles; they also improve ozone transfer efficiency. As the water flows from the top of the bottom, and as the water speed is very high only at the outlet of the ozonation compartment, it is possible to select very small bubbles and bring them into the second compartment B. In this cell, the combination of the water flow and of small bubbles enables to flotation of the particles. Larger bubbles stay in compartment A. In order to generate the size of bubbles needed, it is necessary to have the correct porosity of the diffusers, the correct air flow through the porous plates and the right water flow rate of the diffusers. The result is pre-ozonation and removal of flotable particles.

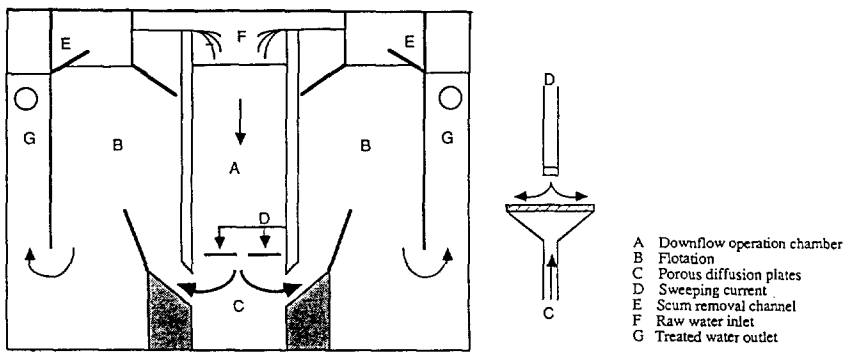

Fig. 1. The ozoflotation process.

The major advantages of this process are the following:

•mass transfer is enhanced by increasing considerably the interfacial area between the water and gas phases
•residence time of the bubbles inside the column is much longer
•ozone losses in the exhaust vents are reduced
•the porous plate is continuously cleaned by the water stream and its plugging is avoided
•the generated bubbles are quickly dispersed in the bulk of the water column.

Use of ozoflotation process for removal of algae

The ozoflotation process associates the physical aspect of flotation and oxidation effects of ozone. Ozone is a strong oxidant as well as a powerful disinfectant. Its chemical effect on algae is to inactivate them and stops their development in water works. Flotation is the most appropriate treatment process for the removal of algae due to their low density and, in some cases, natural tendency to float. Compared to dissolved air flotation (using pressurised water saturated with air) the number of fine bubbles per unit of volume in ozoflotation is smaller. But when it is combined with a previous coagulation, particle-bubbles contact is enhanced. Therefore, the effect of flocculation-flotation is a physical removal of both inactivated and living algae.

Description of pilot plant

We used the pilot plant unit described in Figure 2, with two compartments for ozone-flotation. In order to resemble a complete conventional treatment, the pilot set-up consisted of coagulation, ozoflotation and filtration processes.

The pilot plant worked continuously for at least one hour at a time and received raw water from a reservoir of the drinking water plant of Rennes-Villejean (France). The raw water, after receiving the coagulant and algae, was mixed rapidly and arrived at the top of the first compartment via an inlet channel. The ozone was

introduced via a porous diffuser placed at the bottom of the compartment, with a sweep water inlet placed directly above it to produce fine bubbles. In this compartment the raw water and the bigger ozone bubbles flowed in counter currents leading to more efficient pre-ozonation. The time the water took to flow down enabled further flocculation to occur. The passage between the two compartments was carried out at an initially very high rise rate which enabled the fine bubbles to be selected and dragged into the second compartment where flotation took place. Furthermore, an inclined plane provided the necessary velocity gradient to trap the fine bubbles. They enveloped the flocs containing the algae, lowering even further their specific gravity, and causing them to float. Then, ozofloted water left through the bottom of the second compartment and passed through a filtration column filled with sand and granular activated carbon.

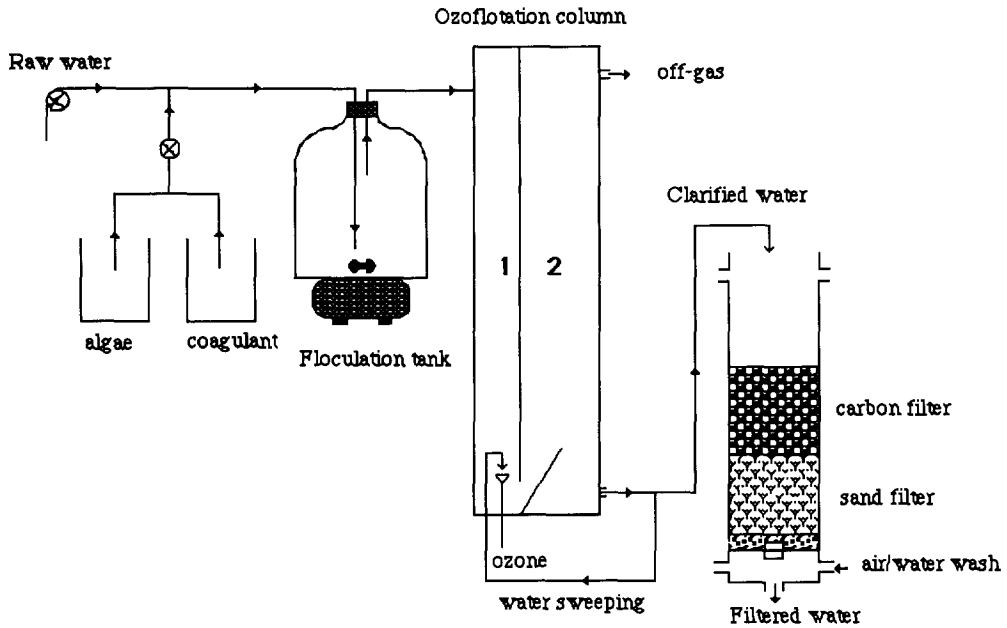

Fig. 2. Ozoflotation pilot set-up

The nominal characteristics of the pilot plant were:

Qc = coagulant flow rate = 2 l/h;
Qa - algae flow rate = 2 l/h;
Qb = sweeping water flow rate = 20 l/h (recycling about 10 to 20% of Ql).

The variable parameters were:

Ql = raw water flow rate (l/h)
Qg = ozone-air flow rate (l/h)
Cg = ozone-air concentration (mg/l)
Cd = dissolved ozone concentration in water (mg/l)
t = contact time
TR = treatment rate in ozone (mg/l)

Algal material

The raw water was doped with a *Microcystis aeruginosa* strain which came from a Culture Collection of Algae and Protozoa (CCAP). After the strain had reached a stationary phase of growth, about 10 days in batch flasks, laboratory algal production was carried out in a continuous sterile tank containing Jaworski's medium, enriched with vitamins. The medium was pumped in the reactor and an entry-exit movement was

created. The reactor was continuously stirred, aerated and maintained under constant light at the following conditions: temperature = 25°C
light level = 4 x 15 W
photoperiodic light of 12 h and 12 h darkness.

The density of the cells (algal number per litre) was evaluated by a microscopic numeration and the phase of growing was always controlled.

Coagulation-flocculation

It is will known that algae need preliminary coagulation to enhance the efficiency of flotation. So two mineral coagulants were tested, ferric chloride $FeCl_3$ and aluminium sulfate $Al_2(SO_4)_3$, 18 H_2O, at different doses from 10 to 50 mg/l. In some cases, anionic polyelectrolyte was added for flocculation to aid removal of the algae. The coagulant-algae contact time was about 2-3 minutes in a 5 litre rapid mixing flask. It appeared that slow flocculation took place in the second compartment of the pilot plant, thanks to the upward and downward currents of both water and bubbles, creating a turbulence zone in it.

Ozonation

A Trailigaz ozone generator was used for producing an ozone–air mixture which served as the flotation gas. The gas pressure leaving the ozone generator was 0.5 bar (relative) and the flow rate ranged from 1.5 to 5 l/h. The ozone content of the gas mixture entering the porous plate was determined by diverting the gas stream through a by-pass line leading to an ozone trap filled with potassium iodide solution through which the gas was bubbled. The titration of liberated iodine and the volume of ozone trapped let us determine the various concentrations. Ozone dissolved in water was measured by a spectrophotometric method at λ = 600 nm with carmine indigo solution.

Filtration

Continuous filtration of the water was conducted through a bilayer filter: 15 cm of sand and 15 cm of granular activated carbon. The filtration was used not only for its traditional role in taste and odour removal, but also for the removal of residual coagulated algae, organic matter or other micropollutants. In fact, this stage would have shown us the influence of ozoflotation on the filtration cycles. Nevertheless, the running periods of the pilot plant were insufficient (because of algal material limitation) and we have not been able to monitor filter head-loss during the treatment.

Measured parameters and analytical methods

Different analyses were carried out on the water samples taken at 3 stages of the treatment.

RW : Raw water (dopes and coagulated)
OW : Ozone floated water
FW : Filtered water.

The parameters monitored during the study were:

- Turbidity (NTU)
- Organics (UV at 254 nm)
- Oxidability (with permanganate)
- Total organic carbon (TOC)
- Chlorophyll-a (filtration on GF/C glass fibre filter paper, extraction with methanol and spectrophotometric method at λ=750 nm and 665 nm)
- Fluorescence (*in vivo*) emission (fluorimeter at λex = 350 nm and λem = 680nm)
- Ozone production gas
- Residual ozone dissolved in water

- Numeration of algae: on a Malassez cell (qualitative determination) with an epifluorescence microscopic method (quantitative determination).

RESULTS AND DISCUSSION

The effect of ozone on *Microcystis aeruginosa*

Before considering ozoflotation and bilayer filtration on the raw water, the chemical effect of ozone on *Microcystis* was previously studied in the laboratory.

The experiments were performed in Erlenmeyer flasks containing cultures of *Microcystis aeruginosa* diluted with distilled water, to which various volumes of ozone were added. The solution of ozone was obtained by bubbling ozone gas in water until its concentration became constant. Initial concentrations of algae ranged from 10^8 to 10^{10} algae/l/ Samples were observed and analysed after different times of ozonation and the results show that the algal cells were affected.

The qualitative effect of ozone on *Microcystis* was a deterioration of the components of their cells. Some of the chlorophyll-a disappeared, and some algal cells were damaged by ozone and their size decreased.

The result given in Figure 3 show a clear decrease of *in vivo* fluorescence emissions with time and with increasing doses of ozone.

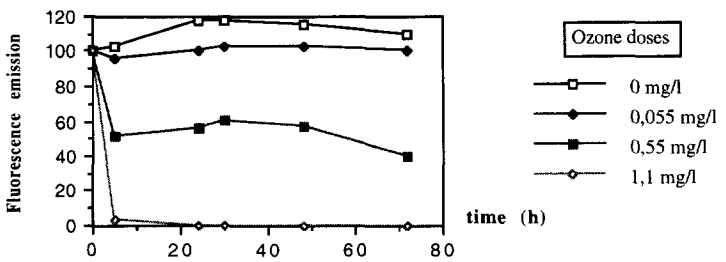

Fig. 3. Evolution of *in vivo* fluorescence of *Microcystis aeruginosa* after ozonation.

Furthermore, extinction of the red fluorescence emission was observed by epifluorescence microscopy and the algal cell seemed empty, which made counting very difficult. Thus, for example, a complete destruction of algae was achieved at a high dose of ozone (2 mg/l) and only some remains of them were observed. Moreover, in all the experiments, the number of algae didn't correlate with the chlotophyll-a values. This might be explained by persistence of the chlorophyll pigments in the destroyed algal fraction.

Ozone demand of *Microcystis aeruginosa*

This study was made in order to estimate the real ozone consumption of these algae in relation to their initial concentration. The experiments on ozonation were carried out under the same conditions as the previous ones and residual ozone concentrations were mentioned during at least one hour.

Figure 4 shows that the *Microcystis* algae have so great an oxidant demand that the added ozone consumed over time: The highest concentration of algae required the maximum dose of O_3 within 10 minutes. From the shape of this curve it is suggested that the consumption of ozone can be approximated as a first-order chemical reaction:

$$\mathrm{Ln}[O_3]/[O_3]_0=-W.Ca.t=W'.t \qquad (1)$$

in which:

$[O_3]$=ozone concentration at time t (mg/l) Ca=concentration of algae (algae/l)
$[O_3]_0$=ozone concentration at time zero (mg/l) t=time (min)
W=specific ozone utilisation rate of *Microcystis* W'=rate constant ($time^{-1}$).

The logarithms of the ratio $[O_3]/[O_3]_0$ are calculated for each concentration of *Microcystis* and then plotted versus the time. The results shown in Figure 5 can be used to determine directly the W' rate constant of each linear curve.

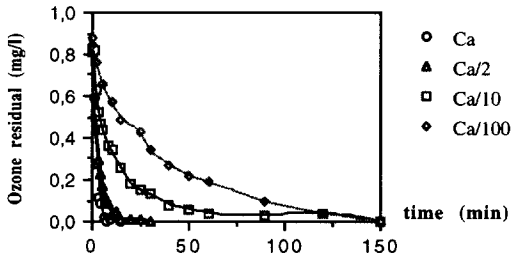

Fig. 4. Kinetics of ozone consumption by *Microcystis aeruginosa* (Ca=4.10+8 algae/l).

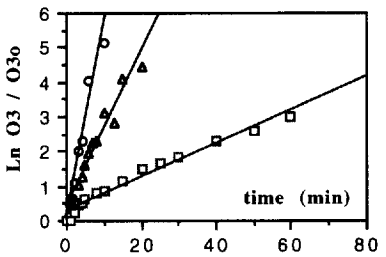

Fig. 5. Linear curves of ozone consumption.

For this series of experiments, W' is proportional to Ca and we therefore deduce the specific O_3 utilisation rate of *microcystis* algae so that: $W'=10^{-9}$ Ca(min^{-1}).

(At the lowest concentration, Ca/100, the algae were so dilute that it became impossible to separate their consumption from the natural ozone decomposition.)

Pilot flotation and filtration without ozone

The behaviour of the pilot unit was tested on coagulated algae without ozone diffusion. Table 1 gives the results with the coagulants $FeCl_3$ (30 mg/l) and $Al_2(SO_4)_3$ (50 mg/l).

TABLE 1. Percentage Reductions after Flotation-Filtration

Coagulant	$FeCl_3$		$Al_2(SO_4)_3$	
Reduction %	OW	FW	OW	FW
Turbidity	57	99,4	8	96,6
Algae	23	99,6	8	99,7
Fluorescence	15	88,5	10	96

In all experiments, the algal number represents the residual active cells observed by microscope. The removal efficiency is expressed as the ratio between the parameters analysed after flotation (or filtration) and that measured before treatment tests. In general, it is of interest to note the lesser effect of $Al_2(SO_4)_3$ flotation compared to that of $FeCl_3$: algal concentration was reduced by a maximum of 25% be ferric chloride, while aluminium sulfate resulted in only 8% reduction. Reduction in turbidity increased in the highest proportion when $FeCl_3$ was used. (The pH of the water would influence the coagulation efficiency.)

During this treatment stage, removal of algae was the sole benefit of a physical flotation intervention, and it can be inferred that ozone pre-treatment would be useful in enhancing flotation. After filtration, the values presented show that both coagulants brought about a minimum reduction of about 90%.

Removal of algae by ozonation:C.t graph determination

In the disinfection of 60% of US drinking water treatments, the product of concentration and time (C.t) is used to link treatment conditions to specific degrees of virus and cyst inactivation. Tables of C.t values are recommended by the US Environmental Protection Agency for various water quality conditions. In general, the concentration of the disinfectant (C) is mg/l and the time (t) is in minutes during which the disinfectant is in contact with the water. In support of this concept, investigations were carried out on the chemical removal of *Microcystis* in our ozoflotation plant, without coagulant. In our experiments, the variation of C.t values was monitored according to variation of the parameters Ql (different contact times) and both Qg and Cg (different ozone doses in water).

C.t values were calculated according to:
in which: i = compartment number
Ci = average of two measures of dissolved ozone inside each compartment
ti = residence time of the raw water in the reactor

In fact, ti was the simple ratio Vi/Ql in which: Vi = real volume of the compartment.

It can be noted that the second compartment was characterised by a great back mixing and Ci gradient along this part of the reactor was not important (verification was made on seven other points). The C.t graphical determination versus the removal percentage of algae is represented in Figure 6.

The algal number represents the residual cells that still fluoresce under the epifluorescence microscope, and here, the elimination of algae is clearly the result of their chemical inactivation by ozone.

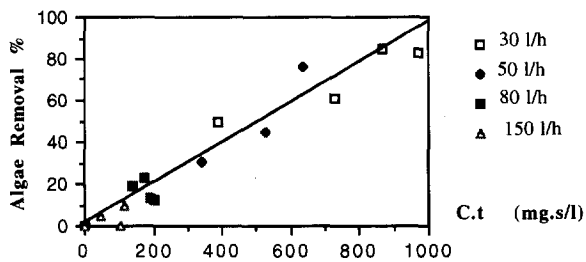

Fig. 6. Ozone (concentration contact time) versus algae removal.

The overall impression from Figure 6 is of a linear increase in algal removal with rising C.t product, but more detailed investigations, the results must be examined separately:

For flow rates (e.g. 30 l/h and 50 l/h), and when the contact time is fixed, good correlation is achieved when both C and algal removal increase, reaching a yield of about 85%.

For high flow rates (e.g. 80 l/h and 150 l/h) the poor correlation obtained may be explained by "short circuit" problems in the pilot plant, leading to less contact of O_3 with water. In this case, removal increases rather with time than with ozone concentration , and maximum percentages are about 20–30%.

Briefly, the C.t graph determination would have let us chose an optimum value of C.t for inactivation at a given algal concentration. However, low flow rates or high ozone doses are not applied to real conditions of water treatment for economic reasons. In support of this view, the usual C.t are not sufficient to remove algae only be chemical inactivation. It therefore seems that a combination of pre-ozonation and coagulation-flotation would improve the efficiency of the treatment.

Ozoflotation and bilayer filtration with ferric chloride

In this case, a complete run of the pilot plant was tested on algae with both coagulant and ozone. Let us remember that the ozoflotation process removes algae thanks to the combination of chemical ozonation and physical flotation. The results presented in this section are a graphical representation of those obtained throughout the pilot tests by varying the water flow rates. The optimum $FeCl_3$ dose chosen for these experiments was 30 mg/l. For a fixed value of Ql the plant was run with various ozone treatment rates obtained by either increasing ozone-air concentration or flow rate Qg, so as to treat from 0.1 to 2 mg/l. The initial algal number was about 10^7 algae/l. The characteristics of the raw water were:

pH = 7.4 TOC = 6.3 g/l
UV 254 nm = 0.15 Turbidity = 3.0

The performance of ozoflotation for each situation in terms of algae, turbidity, UV 254 and chlorophyll-a removal can be seen in the following cases.

Low water flow rate. For Ql = 50 l/h, Figure 7 shows increasing algal removal with rising ozone treatment rates, like in the correlated zone of C.t presented above. However, if we compare the results obtained with and without coagulation, in Figure 8, it is interesting to note that similar removal can be reached by ozoflotation using low ozone doses.

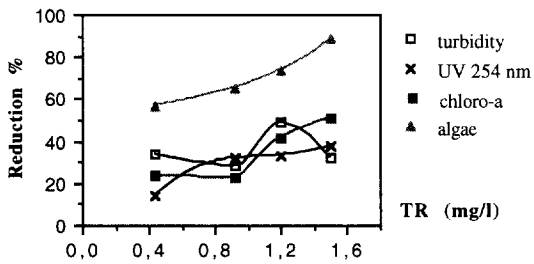

Fig.7. Percentage reduction after ozoflotation with Ql=50 l/h.

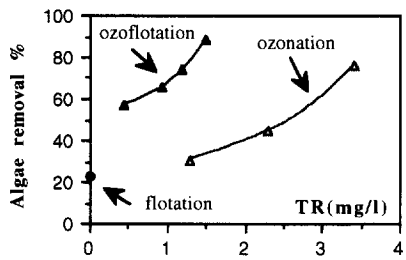

Fig.8. Comparison of the performances of ozoflotation and simple ozonation.

High water flow rate. In terms of algae removal, Figures 9 and 10 show average reductions of 80% and 50% for respective flow rates 80 l/h and 150 l/h, instead of about 20% and 10% without $FeCl_3$.

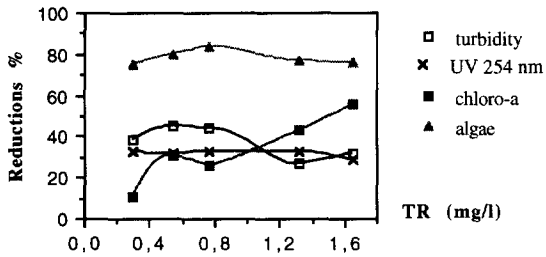

Fig. 9. Percentage reduction after ozoflotation with Ql=80 l/h.

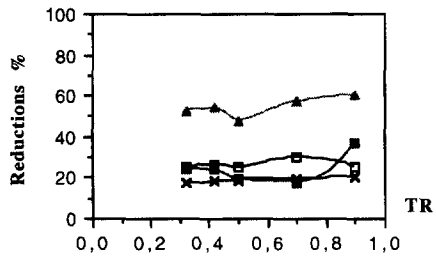

Fig. 10. Percentage reduction after ozoflotation with Ql=150 l/h.

The results confirm the great necessity to combine both physical and chemical effects on the algae to improve their removal from raw water. Turbidity removal remains low, reaching a maximum of 40%. Removal differences between the two flow rates are due not only to the contact times, but also to competition between the upward flow of flocs-bubbles and the downward current of water causing a considerable settling of particles, especially for Ql=150 l/h.

In general, the results show that when a low ozone dose is applied, the % reduction of each parameter reaches a level that remains constant despite increasing O_3 treatment rates.

Firstly, these observations are related to the previous C.t values for which no clear correlation between ozone and % algae removals has been found for high flow rates (due to short circuit problems).

Secondly, the coagulation effect of $FeCl_3$ on algae must be stronger than their inactivation by ozone, which explains why ozone increases are not of great influence on algal removal.

However, on the other hand, ozone would have an effect on floc charge density, enhancing the coagulation process.

Filtration. The results of the filtration study are shown in Figure 11.

In both cases, filtration produced good water quality, achieving more than 96% algal removal. Satisfactory results were also obtained for reductions of all the other parameters.

Influence of raw water quality

The previous data were compared under the same conditions over the test period with $FeCl_3$ but, due to the variable quality of the raw water, experimental conditions cannot be considered always constant. That is

who other experiments were carried out to compare the influence of initial raw water quality on ozoflotation performances.

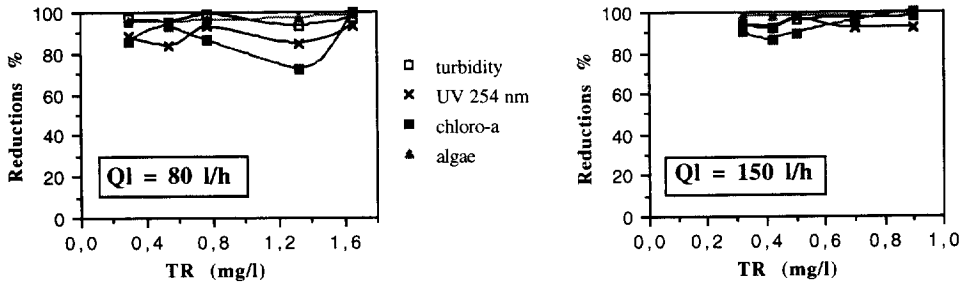

Fig.11. Percentage reductions after ozoflotation and bilayer filtration.

Organic charge (UV 254 nm) was the variable parameter as follows:

RW, high charge: UV 254 = 0.27; Ca = $2x10^7$ algae/l
RW, low charge: UV 254 = 0.15; Ca = $5x10^6$ algae/l

The results obtained are shown in the table below:

TABLE 2. Influence of the Organic Content of Raw Water on Ozoflotation Performance

	Percentage reductions after ozoflotation with $FeCl_3$			
Ql	80 l/h		150 l/h	
Parameters	high charge	low charge	high charge	low charge
UV 254 nm	17,8 %	33 %	12,3 %	18,2 %
Turbidity	44 %	44,5 %	6,6 %	26,3 %
Algae	32 %	84 %	38,2 %	54 %

The experiments show greater efficiency with low charged water than with high. It is evident that when the ozone demand of the raw water increases, there is less residual ozone available to inactivate algae, and their removal becomes only the effect of a slight ozonation added to flotation.

Comparison between $FeCl_3$ and $Al_2(SO_4)_3$ coagulants

With either high or low charged raw water, the table below shows less efficiency of ozoflotation process with $Al_2(SO_4)_3$ than with $FeCl_3$:

TABLE 3. Ozoflotation Efficiency with $Al_2(SO_4)_3$ Coagulant

	Percentage reductions after ozoflotation with Al2(SO4)3			
Ql	80 l/h		150 l/h	
Parameters	high charge	low charge	high charge	low charge
UV 254 nm	8,8 %	13,5 %	4 %	14,5 %
Turbidity	0	12 %	0	7,3 %
Algae	13,1 %	26,9 %	11 %	20,9 %

This difference can be explained by the better capacity of ferric hydroxide flocs to coagulate *Microcystis* algae and enhance their flotation. Another explanation is that algae could have been protected by aluminium

flocs and then made O_3-inactive. This may explain the relatively low % reductions in chlorophyll-a and UV 254 obtained after filtration.

CONCLUSIONS

The series of experiments described in this work was performed to show that the ozoflotation process can solve the algae problems and improve the water quality.

From the results presented in this article several conclusions can be made:

• The chemical effect of ozone on *Microcystis* (*aeruginosa* strain) is an inactivation of the cells. The consumption of O_3 is characterised by a first-order reaction from which the specific ozone utilisation rate is deduced, and related to initial algae concentrations.

• The C.t determination shows an overall linear increase with algal removal, but in real conditions of water treatment, the usual C.t are not sufficient to remove algae by chemical inactivation alone.

• To facilitate flotation, previous coagulation of algae is necessary to enhance their contact with fine bubbles of ozone. The effect of flotation is physical removal of both inactivated and living algae.

• The combination of pre-ozonation and coagulation-flotation improves markedly the efficiency of the raw water treatment.

• In terms of algal elimination, physical coagulation-flotation triumphs over chemical inactivation by increasing ozone. However, ozone pre-treatment is of influence on the enhancement of flocculation efficiency.

• Ferric chloride coagulant gives a better performance than aluminium sulfate.

• For raw water presenting high organic content, the efficiency of both ozonation and flotation is considerably reduced.

• After ozoflotation, bilayer filtration is necessary to obtain good water quality.

The major advantage of the ozoflotation process lies in the fact that it combines flocculation, flotation and ozonation into a single treatment stage.

Ozoflotation is particularly adapted for algal removal from waters presenting low tubidity and low organic content.

The combination of ozoflotation and bilayer filtration can improve the treatment of waters whose major problems derive from the presence of high algal numbers.

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