Bulking control with ozonation in a nutrient removal activated sludge system

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Abstract

The control of sludge bulking by ozonation was studied on four parallel pilot-scale (110 ℓ/d) biological nutrient removal systems. Bulking was caused by filamentous organisms which typically occur in nutrient removal systems, i.e. Type 0092, Type 0041 and *Microthrix parvicella.* Continuous dosing of ozone, at 1; 2 and 4 g O_3/kg mixed liquor suspended solids (MLSS).d resulted in a diluted sludge volume index of about 50 mℓ/g less than the unozonated control. Ozonation was more effective in the sludge cycle than directly into the aeration basin. Nitrification-denitrification was not affected, not even at dosages of 30 g O_3/kg MLSS.d. Biological phosphate removal was not affected by any of the ozone dosages either. The removal of COD was improved, as was colour and suspended solids.

Introduction

Filamentous bulking is a problem in most nutrient removal activated sludge plants. According to a survey by Blackbeard *et al.* (1986) about three quarters of these plants as operated in South Africa had diluted sludge volume indices (DSVI) > 150 mℓ/g. As most South African plants have settling tanks designed for an overflow rate of 1 m/h at peak wet weather flow, these settlers will become inadequate at DSVI values above 150 mℓ/g (Ekama and Marais, 1986). This leads to solids carry-over and difficult operation of the settlers due to sludge build-up. Sludge bulking also results in poorer sludge dewaterability and consequent increases in sludge disposal costs (Osborn *et al.*, 1986).

At the root of the bulking problem is the excessive growth of filamentous bacteria. These organisms proliferate under low food to microorganism ratios, septic influent, low dissolved oxygen concentrations in the aeration basin or nutrient deficiencies (Jenkins *et al.*, 1986). Lakay *et al.* (1988) recommend that remedial and preventative measures be investigated using

- specific bulking control measures, i.e. the "selector reactor" approach; and
- non-specific bulking control measures, i.e. the use of chemicals which are toxic to the filaments. According to Ekama (1988) the specific control measures are often only partially effective, and particularly on existing plants, the only reliable measure at this stage remains the use of disinfectants. The most popular and effective of these is chlorine.

Chlorine has been used for bulking control for over half a century (Smith and Purdy, 1936) and has recently again been propagated and promoted by Jenkins and co-workers (Jenkins *et al.*, 1982 and 1986 and Neethling *et al.*, 1985). Although it is very effective in bulking control, it also creates additional problems, i.e.

- interference with nitrification (Eisenhauer *et al.*, 1976 and Thirion, 1982);
- increased turbidity and COD of the effluent (Smith and Purdy, 1936; Frenzel and Sarfert, 1971; Frenzel, 1977; Lakay *et al.*, 1988);
- reduced biological phosphate removal (Lakay *et al.*, 1988); and
- the formation of chlorinated hydrocarbons, particularly trihalomethanes (Van Leeuwen *et al.*, 1988).

Ozone is an alternative oxidant and disinfectant in many water and waste-water purification applications (Miller *et al.*, 1978; Sierka, 1984 and Stover *et al.*, 1985). More powerful than chlorine, ozone does not contribute to the salinity nor does it normally form toxic residuals (Rice and Browning, 1981). Its benefits in bulking control (Van Leeuwen and Pretorius, 1988) and the improvement of activated sludge effluent quality (Van Leeuwen, 1988) have already been demonstrated for domestic waste water. The research described in this paper serves to prove that the earlier results also apply to combined domestic and industrial waste water and to accurately determine ozone requirements in terms of more fundamental dosage descriptions. The pilot plant was also designed to avoid artefacts causing the growth of organisms not normally encountered in sewage treatment plants.

Experimental

Most of the experimental work was conducted on a small pilot-plant scale at the Rooiwal Sewage Works of the Municipality of Pretoria. The sewage originates in the eastern parts of Pretoria and the Rosslyn industrial area. Sludge characterisation tests, feed and effluent analyses were done at the laboratories of the Municipality of Pretoria.

Activated sludge units

The pilot plant comprised four parallel activated sludge units of 80 ℓ each which were each fed settled sewage at a rate of 110 ℓ/d. Each unit operated on the Phoredox principle having an anaerobic, anoxic and aerobic zone with retention times of 5, 3 and 9 h respectively (based on influent flow rate) followed by a settler (Fig. 1).

Sludge was recycled from the settler to the anaerobic zone of each unit at a rate of 1:1 to the feed rate. Sludge was also recycled internally from the aerobic to the anoxic zone at a rate of 4:1 to the feed rate. Sludge was wasted from the aerobic zone by withdrawing 2 ℓ of mixed liquor every day in order to maintain a sludge age of 20 d.

The effluent of each unit overflowed from the settler into a tank of 80 ℓ from which 15 h compound samples could be drawn.

The feed and external recycles were moved by peristaltic pumps. Air lift pumps actuated the internal recycles. Porous diffusers, connected to the main blowers of the sewage works, were used for aeration. The oxygen concentration in the aerobic zones was maintained at between 1 and 3 mg/ℓ by regulating the air flow with hand valves.

Ozone was generated from desiccated air in a high voltage discharge tube and introduced into the sludge by porous diffusers. Three experiments on the effect of ozone were conducted:

- the effect of different ozone dosages was studied by introducing 10; 20 and 40 g O_3/h respectively into the aerobic compartments of three of the units. This provided an overall

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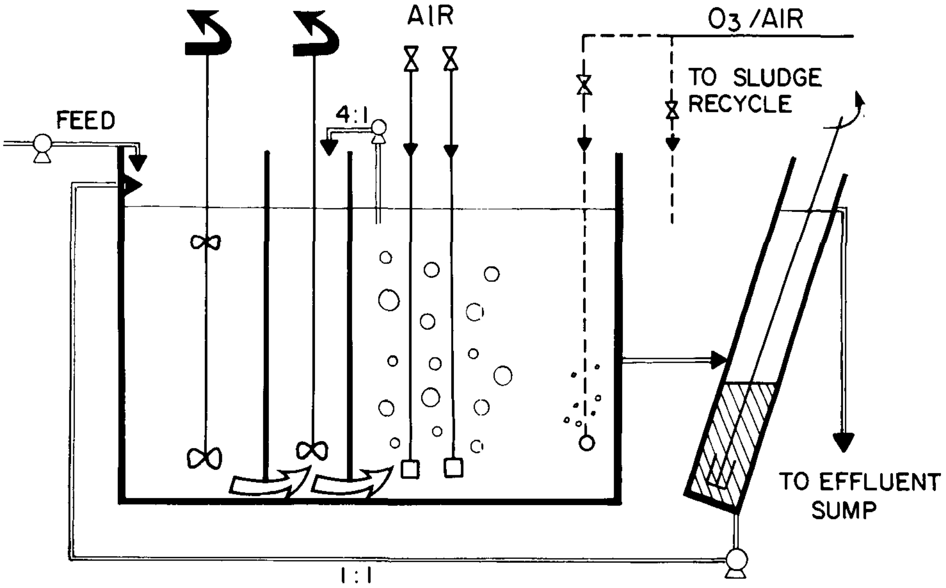


Figure 1
Activated sludge pilot plant.

mass dose rate of 1; 2 and 4 g O_3/kg mixed liquor suspended solids (MLSS). d, based on the unit volume of 80 ℓ and a MLSS concentration of 3 g/ℓ;

- the effect of maintaining a higher local concentration of ozone was studied by introducing ozone at a rate of 2 g /kg MLSS.d into a cylindrical column of 1,1 m height and 2 ℓ volume through which the external sludge recycle passed; and
- the effect of higher ozone dosages on nitrification and phosphate removal was studied by steadily increasing the ozone dosage to up to 30 g O_3/kg MLSS.d.

The ozone dosage in each case was calculated by measuring the total quantities of ozone entering and exiting the activated sludge system as a function of time. This value, divided by the total quantity of MLSS in the system, provided the dosage. Ozone concentrations in air were determined by reacting ozonated air with a potassium iodide solution as described in Standard Methods (1980).

Sludge characterisation tests

MLSS values were measured by filtering 100 mℓ of mixed liquor through a glassfibre filter and determining the mass of the residue after drying at 103°C. Diluted sludge volume index (DSVI) was determined by the ATV (1973) method. This involves measuring the volume occupied by the diluted sludge after settling for 30 min. Dilution should be effected to ensure that the sludge occupies a volume of 20 % or just less after 30 min settling. The sludge volume per gram of MLSS under these conditions is known as the DSVI.

Microscope studies

A Zeiss microscope with phase contrast was used at 400 times magnification for sludge microphotography and identification of microorganisms. Identification was done according to the guidelines by Eikelboom and Van Buijsen (1983).

Feed and effluent quality analyses

The settled sewage feed quality was determined weekly on a 24 h compound sample. The effluent analyses were performed four or five times per week on 15 h compound samples.

Chemical oxygen demand (COD) and oxygen absorbed (OA) were determined as described in Standard Methods (1980).

Ammonia, nitrate and phosphate concentrations were determined by automated procedures adapted from Standard Methods (1980).

Effluent suspended solids were measured by determining the mass of solids dried at 103°C after filtering 500 mℓ of effluent through a glassfibre filter.

Colour was measured using Nessler tubes and a Hazen comparator disk.

Results

The results of the physical and microbiological sludge characterisation and of the feed and effluent analyses are presented below.

The effect of ozonation on sludge settleability

The effect of different ozone dosages within the aerobic zone of the activated sludge plants is shown in Fig. 2.

A comparison between the effect of ozonation in the aerobic zone and ozonation in a 2ℓ column in the sludge recycle stream is shown in Fig. 3.

The effect of ozonation on sludge microbiology

The control sludge contained large numbers of filaments, mainly as a backbone to the flocs but also extending outwards. Bridging of flocks by filaments often caused open structures. The dominant forms of filaments were Types 0041 and 0092 (or 0803 according to Eikelboom, 1988) with *Microthrix parvicella* occurring commonly. *Nostocoida limicola* was found occasionally.

The ozonated sludge samples contained the same filaments but usually in smaller numbers. The reduction in extending filaments and bridging was notable. The flocs were more compact. Amorphous *zooglea* structures were absent in contrast with those found in the control.

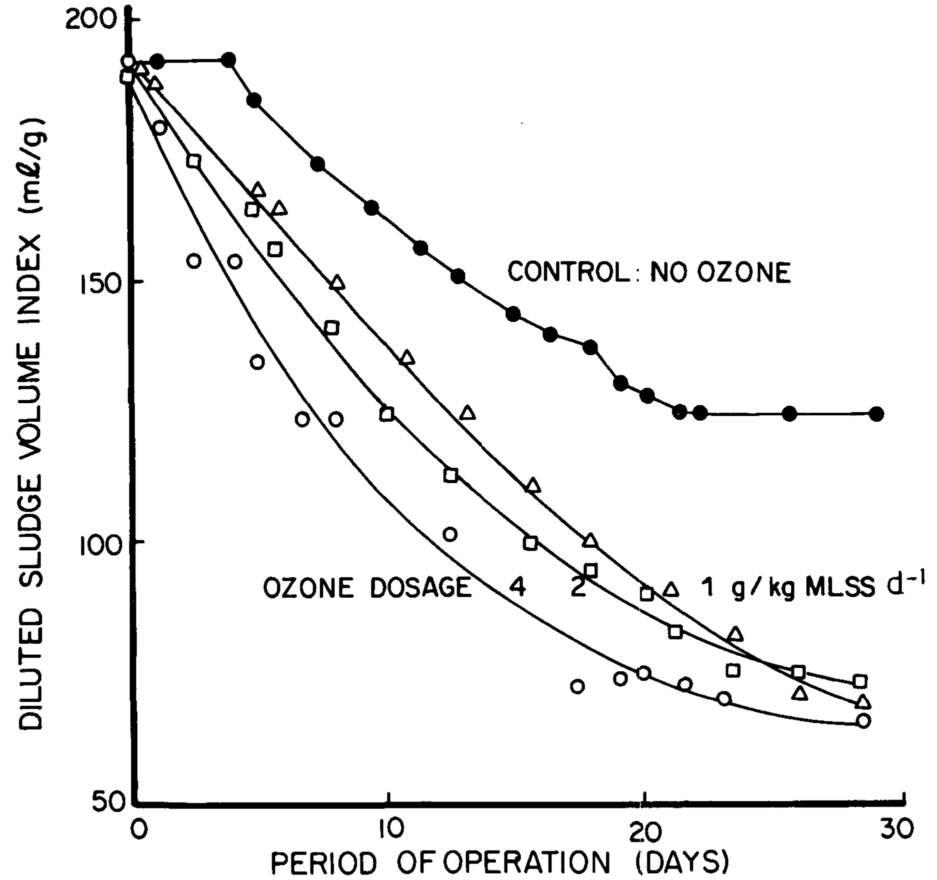


Figure 2
The effect of different ozone dosages in the aerobic zone on settleability.

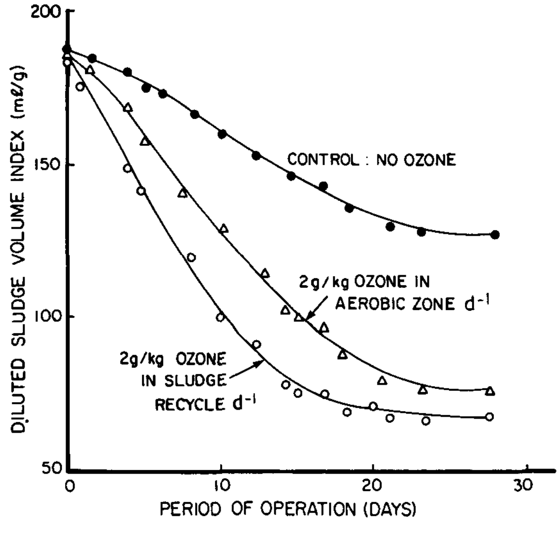


Figure 3
The effect of ozonation position on sludge settleability.

Protozoa of the same type were encountered with more or less equal frequency in both the control and ozonated sludges. Amoeba, attached ciliates, spirochaetes, crawling ciliates and also rotifers were found in all the sludge samples (Melmed, 1987).

Typical examples of microscope photographs are shown in Fig. 4.

Feed quality

The average composition of the settled sewage fed to the pilot plant (based on 24 determinations) was as shown in Table 1.

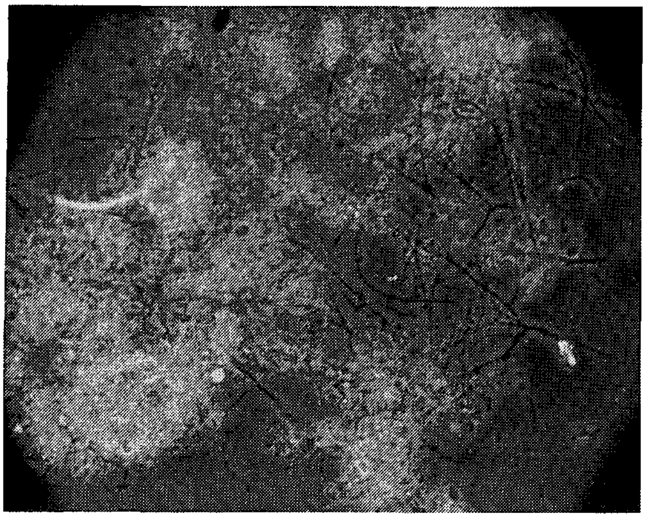
TABLE 1
AVERAGE COMPOSITION OF SETTLED SEWAGE FEED (mg/ℓ)

COD	568
OA	39
NH_3-N	30
NO_3-N	0,2
O-PO_4	10,8
Suspendid solids	85
Total dissolved solids	588
pH	7,1

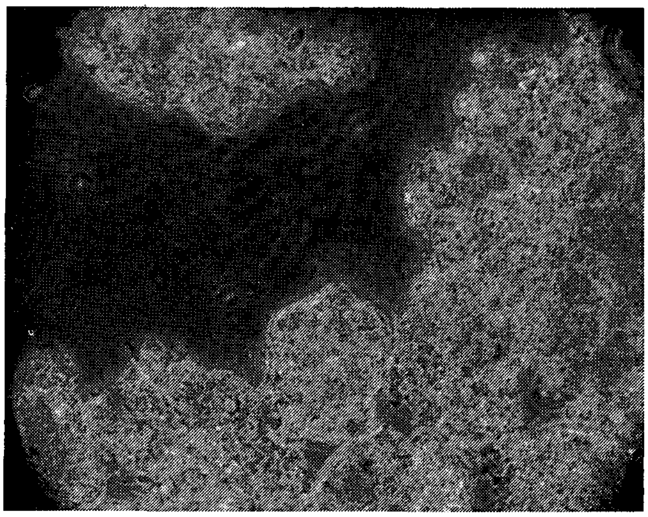
Effluent quality

Organic substances

The effect of ozonation within the activated sludge on the removal of organic substances as typified by COD and OA is shown in Fig. 5. The figure only shows the values during ozonation at 4 and 30 g/kg MLSS.d. The average effluent COD values during a twelve-week operational period were 65; 49; 53 and 48 mg/ℓ for ozone dosages of zero (control), 1, 2 and 4 g/kg MLSS.d respectively. The corresponding OA values were 7,6; 6,7; 6,1 and 5,7 mg/ℓ respectively.



(a) Control



(b) Ozonated activated sludge

Figure 4
The effect of ozonation on filamentous bacteria in activated sludge.

Nitrification

The effect of ozonation on nitrification is shown in Fig. 6. The average ammonia concentration of the control effluent was 1,7 mg/ℓ compared with the 0,9 mg/ℓ of the ozonated (4 g/kg MLSS.d) activated sludge unit. The corresponding nitrate concentrations were 4,0 and 4,6 mg/ℓ respectively. There was a marginal increase in nitrification at this ozone dosage and also at a dosage of 30 g/kg MLSS.d. At dosages of 1 and 2 g/kg MLSS.d there was no significant difference in the ammonia or nitrate values compared with the control.

Phosphate removal

The average orthophosphate concentrations of the effluents as a function of ozone dosage is shown in Table 2.

TABLE 2
EFFLUENT PHOSPHATE CONCENTRATIONS (AVERAGE OVER 12-WEEK PERIOD)

Ozone dosage	o-P concentration (mg/ℓ)
(g/kg MLSS.d)	
0	2,2
1	2,2
2	1,9
4	2,0

During the separate six-week test at an ozone dosage of 30 g/kg MLSS.d, the average effluent phosphate was 1,9 mg/ℓ against the control of 2,4 mg/ℓ.

Suspended solids

Suspended solids levels in the effluent were influenced by the ozone dosage as shown in Table 3. The values are each based on the average of 53 determinations, except the last value, which is based on 22 determinations.

TABLE 3
THE EFFECT OF OZONATION ON SUSPENDED SOLIDS IN THE EFFLUENT

Ozone dosage	Suspended solids (mg/ℓ)
g O_3/kg MLSS.d	
0 (control)	13,2
1	7,7
2	6,4
4	5,1
30	5,5

Colour

The colour of the effluent was affected as shown in Table 4. The values are based on the average of 14 determinations.

TABLE 4
THE EFFECT OF OZONATION ON THE COLOUR OF THE EFFLUENT

Ozone dosage	Colour
(g O_3/kg MLSS.d)	(Hazen)
0	45
1	36
2	22
4	12
30	8

Discussion

There was a general trend towards a decrease in the sludge volume index of all the sludges, even in the control. This phenomenon can be explained by the operational conditions on the pilot plant. Firstly, to ensure sufficient dissolved oxygen levels at all times in the aerobic zone without automatic control, periodic over-aeration was inevitable. This could have led to the depression of growth of some filaments, particularly *M. parvicella* (Blackbeard *et al*., 1986). Secondly, gradual and occasional sludge losses occurred, particularly in the control. The sludge par-

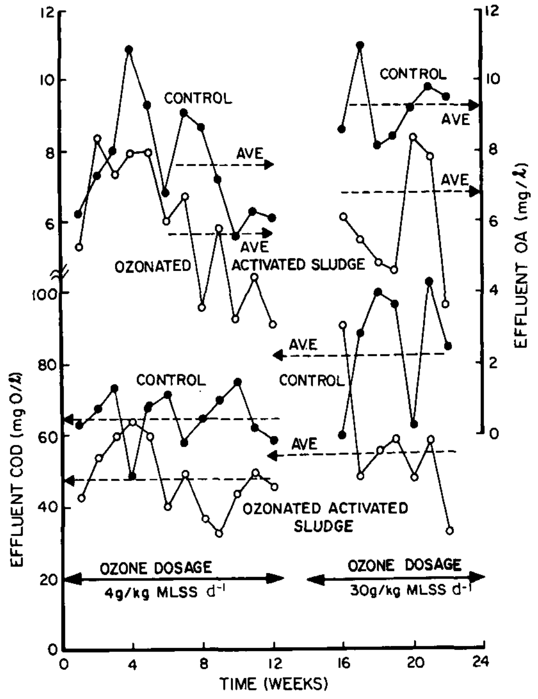


Figure 5
The removal of organic compounds by ozonated activated sludge.

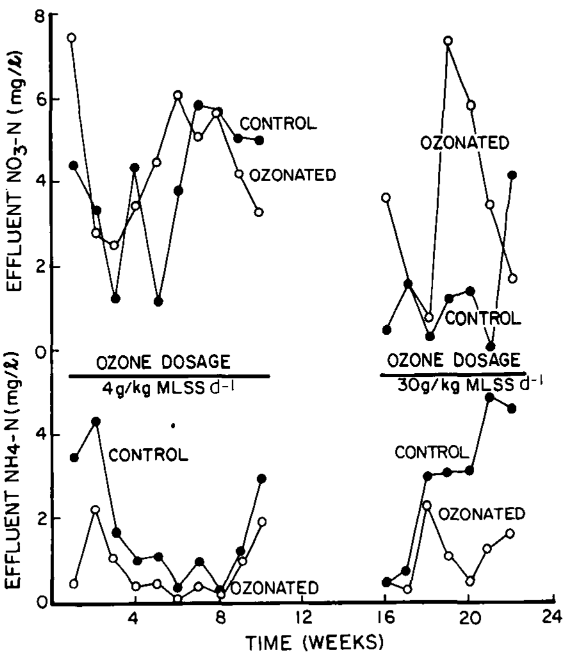


Figure 6
Nitrogen removal in ozonated activated sludge.

ticles lost had a higher volume index than those remaining, a selection leading to a gradual increase in settleability.

Ozonation led to an immediate and lasting improvement in sludge settleability. Increasing ozone dosages above 1 or 2 g/kg MLSS.d. resulted in further improvements in settleability but at a declining rate of return. Ozonation at the same overall mass dose rate was more effective in the return activated sludge stream than directly in the aerobic zone. The explanation for this cannot be found in the local mass dose rate (Jenkins *et al.*, 1982) which is the daily rate of ozone dosage divided by the daily mass flow rate of sludge passing the dosage point — in the aerobic zone of the one unit this was:

$$\frac{20 \times 24 \text{ mg/d}}{220\ell/\text{d}.\ 3 \text{ g}/\ell} = 0{,}73 \text{ g/kg}$$

and in the return activated sludge stream of the other it was:

$$\frac{20 \times 24 \text{ mg/d}}{110\ \ell/\text{d}.\ 6 \text{ g}/\ell} = 0{,}73 \text{ g/kg}.$$

The frequency of exposure of the MLSS inventory (Jenkins *et al.*, 1982) to the ozone remained:

$$\frac{220\ \ell/\text{d}.\ 3 \text{ g}/\ell}{80\ \ell\ .\ 3\text{g}/\ell} = 2{,}8/\text{d}$$

OR

$$\frac{110\ \ell/\text{d}.\ 6 \text{ g}/\ell}{80\ \ell\ .\ 3 \text{ g}/\ell} = 2{,}8/\text{d}$$

in both cases.

This is low in comparison to the recommendation by Neethling *et al.* (1985) of a frequency of exposure to chlorine of 3 d^{-1}. The answer must therefore be sought in the higher local dose concentration of

$$\frac{20 \times 24 \text{ mg/d}}{110\ \ell/\text{d}} = 4{,}4 \text{ mg}/\ell \text{ in the return activated sludge}$$

compared with the

$$\frac{20 \times 24 \text{ mg/d}}{220\ \ell/\text{d}} = 2{,}2 \text{ mg}/\ell \text{ in the case of the dosage in the}$$

aerobic zone. The higher volumetric ozone dosage can provide a larger driving force for ozone transfer through the bacterial slime and provide a larger excess to satisfy parasitic reactions with reducing agents such as nitrites.

The improvement in sludge settleability was clearly due to the reduction in filament numbers and lengths. This resulted in more compact sludge particles. No significant alteration in the population composition could otherwise be observed. The sensitive phosphate removers and nitrifiers were not inhibited by the ozone at any practical ozone level.

Contrary to the effect of chlorine, ozone did not lead to a deterioration in effluent quality. Ozonation actually improved the effluent quality with respect to the COD, OA, turbidity and colour. The improved COD removal may be linked to the lower turbidity and to the oxidation of organic material. It should be pointed out however, that a dosage of 2 mg O_3/ℓ influent (the prevailing dosage at an overall mass dose rate of 1 g/kg. d) could not explain a decrease in the effluent COD from 65 mg/ℓ for the control to 49 mg/ℓ in the ozonated activated sludge by chemical oxidation nor by the decrease of 5,5 mg/ℓ in suspended solids alone. It is possible that improved biodegradability of organic substances after ozonation and subsequent biodegradation may also have contributed to the COD removal (Van Leeuwen *et al.*, 1985, Stover *et al.*, 1985).

Conclusions

Ozone is an effective deterrent against the filamentous growths causing poor settleability in activated sludge. Higher local concentrations of ozone are more effective in improving sludge settleability than longer exposure to lower ozone dosages.

Ozonation in activated sludge does not impair nitrification and phosphate removal and improves the removal of organic and suspended substances and colour leading to a better effluent quality.

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