Bulking control with ozonation in a nutrient removal activated sludge system

J van Leeuwen
Department of Chemical Engineering, University of Pretoria, Pretoria 0002, South Africa

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 parvica. Continuous dosing of ozone, at 1; 2 and 4 g O₃/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 O₃/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 Rooival Sewage Works of the Municipality of Pretoria. The sewage originates in the eastern parts of Pretoria and the Roslynn 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 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 O₃/h respectively into the aerobic compartments of three of the units. This provided an overall

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