Denitrification of trickling filter effluents using external carbon sources*

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Abstract

In order to upgrade existing trickling filter systems to comply not only with the orthophosphate effluent standard of 1,0 mg/ℓ as P but also with future pending nitrogen standards, a comprehensive system comprising chemical treatment for phosphate removal and biological treatment for nitrogen removal was considered. Pilot plant experiments were carried out to study the suitability of primary sludge and raw and settled sewage as carbon and energy sources for biological denitrification in such schemes. Using settled sewage from the Daspoort Sewage Works, an average of 15 mg/ℓ NO_3-N could be removed from biological filter effluent. The denitrification rate was 17 mg NO_3-N per g VSS per h, but all systems suffered from poor sludge settleability. This problem is considered inconsequential in terms of full-scale application, where chemical addition should ensure good settleability.

Introduction

According to figures obtained from Barnard (1975), 50% of all sewage treatment plants operated by municipalities in South Africa make use of trickling filters. Although not all of these plants are located in controlled areas, where orthophosphate concentrations are limited by the effluent specifications promulgated in 1980, there are nevertheless several areas in which there is a need for upgrading existing systems with the objective of producing higher quality effluent. To date much attention has been focused on effluent phosphate, which should not exceed 1 mg/ℓ (as P) in defined areas. This limit generally cannot be achieved by conventional trickling filter systems and additional treatment is required. Apart from phosphate, stricter limits for nitrogenous compounds are also in the offing, at least for selected areas in the country. The only nitrogen limit generally in force allows a maximum effluent ammonia concentration of 10 mg/ℓ (as N). During winter, when nitrification rates are depressed, even this limit is often exceeded.

In a recent move the Rand Water Board has suggested imposing nitrogen control measures on treatment works discharging into rivers upstream of certain freshwater intake points in the Vaal River (Van der Merwe, 1983). In response to this, attempts are being made at the Vereeniging Wastewater Treatment Plant, (on a three-month trial basis) to reach an average total nitrogen concentration in the effluent of 3,0 mg/ℓ (as N) or less with a maximum concentration of 4,0 mg/ℓ (Engels, 1983). There is thus a need for developing nitrogen removal capabilities at trickling filter systems even though the requirement may be less than the need for phosphate removal.

The removal of chemical oxygen demand (COD) to the general standard of 75 mg/ℓ is another objective which is difficult to achieve in many trickling filter plants, especially those which are organically overloaded. Upgrading measures aimed at nutrient removal should ideally also cater for improved reduction of influent organics.

While problems associated with poor phosphorus and COD removal can be alleviated or overcome by chemical treatment in conjunction with biological filtration, the need remains for the development of feasible methods of nitrogen removal in areas where highly nitrified effluents are unacceptable. In view of this the National Institute for Water Research has investigated the biological denitrification of trickling filter effluent in conjunction with the Municipality of Pretoria and the Water Research Commission, as part of a joint project on nutrient removal in existing trickling filter plants. It has been assumed that biological removal is the only feasible way of achieving nitrate reduction in full-scale municipal wastewater treatment schemes. The conceptual treatment system comprised the combination of a chemical dosage component for phosphorus and COD removal, and a denitrification unit for nitrogen removal.

Biological denitrification requires carbonaceous energy, which is a limiting substrate in most local wastewaters. This condition may be aggravated by prefiltration chemical treatment, which removes influent organics. Energy sources such as methanol or molasses may be unavailable or uneconomical to use. For this reason the use of carbon sources available at sewage treatment plants, such as primary sludge and raw and settled sewage have been considered. Based on a survey carried out at Rooiwal Sewage Works (Pretoria) and the equation of MacCarty *et al.* (1969) to calculate the energy requirements for biological denitrification, it was concluded that these materials were suitable energy sources and that they were available in sufficient quantities to reduce typical nitrate levels in trickling filter effluents to levels in the range 0 to 10 mg/ℓ (as N). It was assumed that these electron donors would be contacted with recycled humus tank effluent (HTE) in a denitrification reactor preceding the biological filter. A possible layout of such a treatment sequence for practical application is given in Figure 1.

This paper describes pilot plant studies which were carried out to confirm the above-mentioned conclusions regarding the availability and suitability of various carbon and energy sources for denitrification, to gain experience of problems likely to occur in practical applications.

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*Revised paper, originally presented at the biennial conference of the Southern African Branch of the Institute of Water Pollution Control, East London, May 1983.

Original paper was published in the September 1984 issue of IMIESA without the permission of the authors.

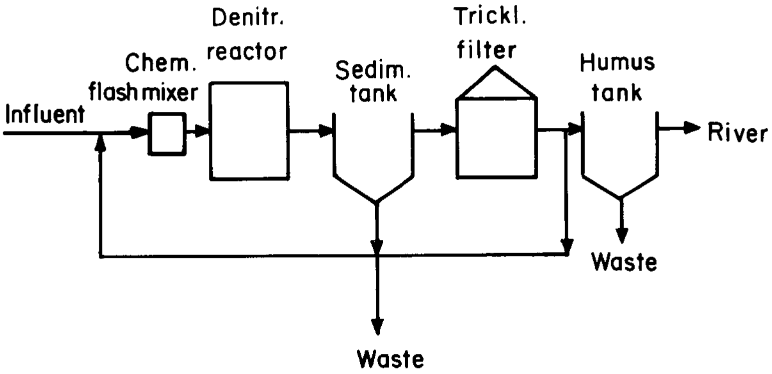


Figure 1
Schematic layout of plant for chemical phosphate removal and biological denitrification in trickling filter effluents.

Experimental

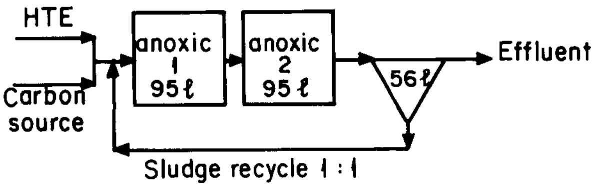
The small-scale pilot study was performed at the Daspoort Sewage Works, Pretoria. Attention was focused on the evaluation of a denitrification reactor *per se* and it was not possible to simulate full-scale operation because of the problems associated with the operation of pilot-scale trickling filter units.

The specifications of the denitrification unit are given in Table 1. In the course of evaluating four modes of operation the layout and operation of the unit were modified to suit changed requirements. The two configurations investigated are shown in Figure 2.

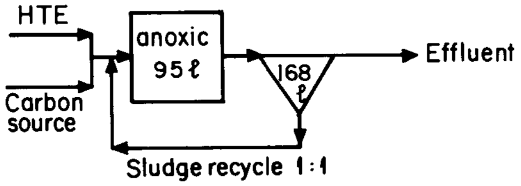
All samples for chemical analyses were preserved using $HgCl_2$. Chemical oxygen demand, total Kjeldahl nitrogen (TKN), ammonia (NH_4^+) and total phosphate (TP) were determined manually according to the NIWR Analytical Guide (1974) using unfiltered samples. Orthophosphate (PO_4^{3-}) and nitrite-nitrate ($NO_2^- - NO_3^-$) of filtered samples were determined automatically using a Technicon AutoAnalyzer (NIWR Analytical Guide, 1974).

TABLE 1
PILOT PLANT SPECIFICATIONS

Parameters	Raw sludge feed	Screened raw sewage and settled sewage feed
Total volume, ℓ	190	95
Anoxic volume, ℓ	2 x 95	95
Clarifier, ℓ	56	168
Clarifier surface area, m²	0,15	0,38
Total feed flow, m³/day	1,2	1,2
Sludge age, days	20	about 1



Carbon source : raw sludge



Carbon source : Screened raw sewage,
settled sewage,
settled sewage enriched with $NaNO_3$

Figure 2
Schematic layout of denitrification unit during different modes of operation.

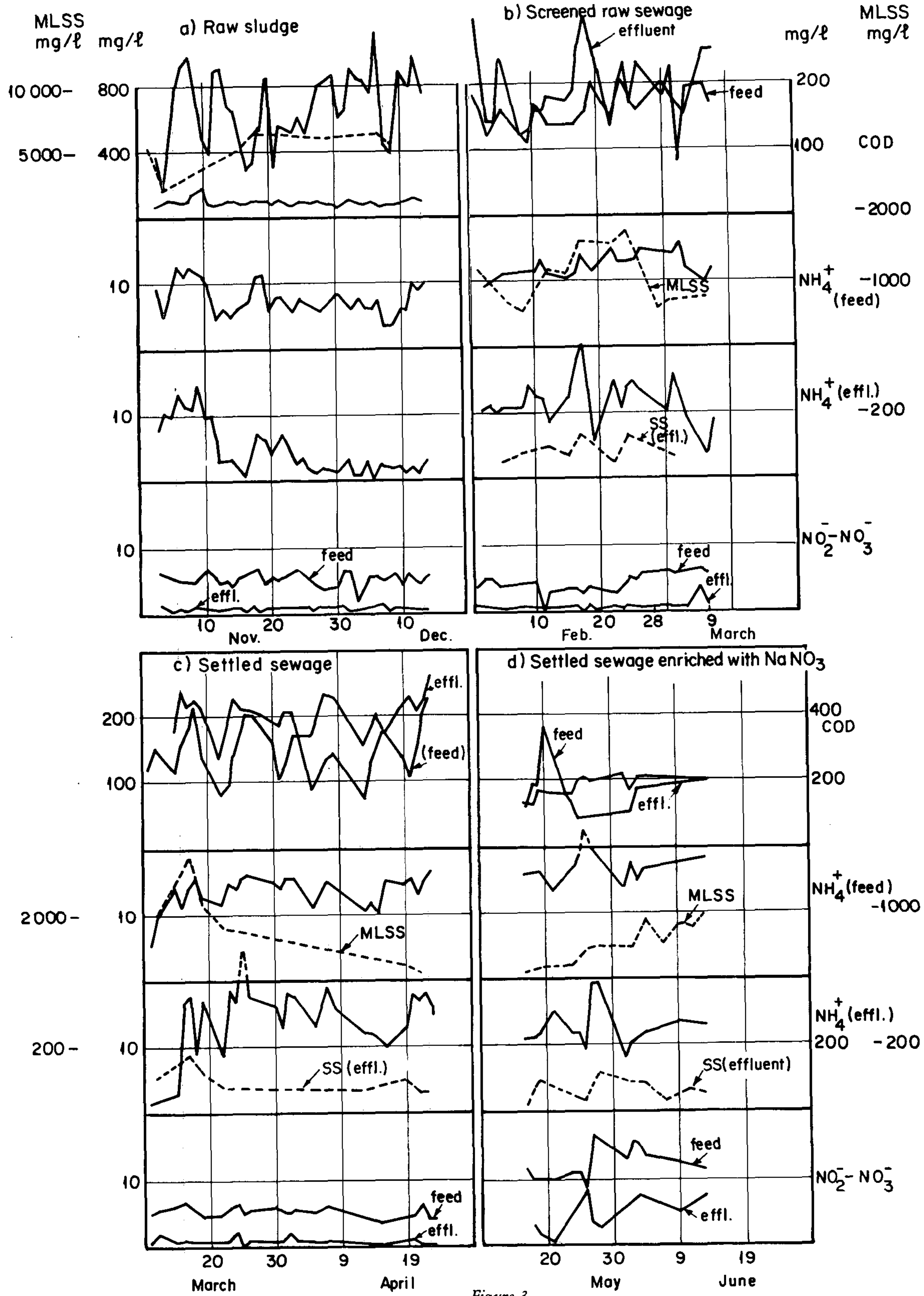


Figure 3
Temporal performance of denitrification reactor during different modes of operation.

Results and Discussion

Raw sludge as carbon source

In the first mode of operation an amount of raw sluge equivalent to that produced by settling raw sewage of a volume equivalent to the effluent treated was mixed with humus tank effluent, resulting in a COD:TKN ratio of 25:1 in the pilot plant. Performance results are shown in Figure 3a, while average values of parameters of interest are given in Table 2. Effluent nitrate concentrations of 0,7 mg/ℓ (as N) were achieved, which practically amounts to complete denitrification. The settling properties of

TABLE 2
AVERAGE PERFORMANCE OF A DENITRIFICATION UNIT RECEIVING HUMUS TANK EFFLUENT WHEN USING RAW SLUDGE AS A CARBON AND ENERGY SOURCE (CONCENTRATION IN mg/ℓ)

	COD (unfiltered)	NH_4^+ (filtered)	$NO_2^- - NO_3^-$ (filtered)	PO_4^{3-} (filtered)
Raw sludge	83 179	nd	nd	nd
Humus tank effluent	35	3,1	10,8	8,4
Feed entering pilot plant	674	7,7	5,4	nd
Pilot plant effluent	90	4,6	0,7	9,8

nd = not determined

the sludge in the clarifier, however, left much to be desired as indicated by the relatively high unfiltered effluent COD values of 90 mg/ℓ.

Screened raw sewage as carbon source

Subsequent to studying raw sludge as a carbon source, the anoxic capacity of the unit was halved and a larger clarifier installed in an attempt to reduce solids carry over in the final effluent. Screened raw sewage was then fed in a 1:1 dilution with humus tank effluent, resulting in a COD:TKN ratio of 10:1. Screening was necessary to make the raw sewage more readily pumpable and was achieved by passing the sewage through a screen with 6 mm by 11 mm openings.

The mixed liquor suspended solids concentration (MLSS) decreased to an average of about 1 500 mg/ℓ during this period, while the settling properties of the sludge deteriorated further. Nevertheless, the unit was still functioning well as indicated by the influent nitrate concentration of about 5,0 mg/ℓ (as N) being reduced to an average 0,8 mg/ℓ in the effluent (Table 3 and Figure 3b). Sludge was continuously lost in the effluent, the average suspended solids concentration being about 90 mg/ℓ and consequently the sludge age could no longer be controlled positively and was reduced to an effective average of about 1 day only.

TABLE 3
AVERAGE PERFORMANCE OF A DENITRIFICATION UNIT RECEIVING HUMUS TANK EFFLUENT WHEN USING SCREENED RAW SEWAGE AS CARBON AND ENERGY SOURCE (CONCENTRATION IN mg/ℓ)

	COD (unfiltered)	TKN (unfiltered)	NH_4^- (filtered)	$NO_3^- - NO_2^-$ (filtered)	PO_4^{3-} (filtered)	TP (unfiltered)	MLSS	VSS
Screened raw sewage	289	29,2	19,4	nd	nd	7,8	nd	nd
Humus tank effluent	45	nd	2,4	9,5	6,9	nd	nd	nd
Feed entering pilot plant	167	nd	10,9	4,8	nd	nd	nd	nd
Denitrification reactor	nd	nd	10,8	0,7	6,6	nd	1465	1330
Pilot plant effluent	182	nd	12,1	0,8	6,3	nd	89	81

nd = not determined

TABLE 4
AVERAGE PERFORMANCE OF A DENITRIFICATION UNIT RECEIVING HUMUS TANK EFFLUENT WHEN USING SETTLED SEWAGE AS CARBON AND ENERGY SOURCE (CONCENTRATION IN mg/ℓ)

	COD (unfiltered)	TKN (unfiltered)	NH_4^- (filtered)	$NO_3^- - NO_2^-$ (filtered)	PO_4^{3-} (filtered)	MLSS	VSS
Settled sewage	230	33,3	21,4	nd	nd	nd	nd
Humus tank effluent	36	nd	2,8	10,8	7,2	nd	nd
Feed entering pilot plant	133	nd	12,1	5,4	nd	nd	nd
Denitrification reactor	nd	nd	14,0	0,7	6,7	1734	1498
Pilot plant effluent	183	nd	13,2	0,7	6,7	118	105

nd = not determined

TABLE 5
AVERAGE PERFORMANCE OF A DENITRIFICATION UNIT RECEIVING HUMUS TANK EFFLUENT WHEN USING NITRATE-ENRICHED SETTLED SEWAGE AS CARBON AND ENERGY SOURCE (CONCENTRATION IN mg/ℓ)

	COD (unfiltered)	TKN (unfiltered)	NH_4^- (filtered)	$NO_3^- - NO_2^-$ (filtered)	PO_4^{3-} (filtered)	TP (unfiltered)	MLSS	VSS
Settled sewage	345	34,4	24,8	nd	nd	6,9	nd	nd
Humus tank effluent	60	8,0	6,7	6,5 47,6 after spiking	7,0	7,3	nd	nd
Feed entering pilot plant	202	21,2	15,8	24,0	nd	7,0	nd	nd
Denitrification reactor	nd	nd	13,1	8,8	6,8	nd	618	502
Pilot plant effluent	193	21,6	16,3	9,2	6,5	6,9	71	54

nd = not determined

Settled sewage as carbon source

During this leg of the study settled instead of screened raw sewage was introduced into the denitrification reactor, using a 1:1 ratio with humus tank effluent. Even at feed COD values as low as 133 mg/ℓ practically complete denitrification was achieved, resulting in effluent nitrate concentrations of 0,7 mg/ℓ (as N) (Table 4 and Figure 3c). However, sludge was still being lost as indicated by average suspended solids concentrations of 118 mg/ℓ in the effluent. The average MLSS during this period was 1 700 mg/ℓ.

The denitrification rate in the reactor was determined by continuing to feed settled sewage but by adding sodium nitrate to the feed, to an average influent concentration of 24,0 mg/ℓ (as N) (Table 5, Figure 3d). The denitrification capacity of the system was extended to the full by this addition, as indicated by an average effluent nitrate concentration of 9,2 mg/ℓ as N. The net denitrification rate was calculated to be 17 mg NO_3-N per g VSS per h. This rate was achieved at an average MLSS concentration of about 600 mg/ℓ and an effective sludge age of only about 1 day. Most of the biomass may thus be assumed as having been in a very active state. This is expressed by the small difference between MLSS and VSS.

Practical application

The results presented above indicate that denitrification of humus tank effluent proceeds in a straightforward manner. The most important problem area which should be considered in the design of a slurry denitrification reactor, appears to be the loss of suspended solids in the effluent and its effect upon the maintenance of the proper mean cell residence time. In situations where upgrading with respect to phosphorus removal is required as well, this is unlikely to be a point of major concern. In such applications the denitrification reactor would be located prior to the filter but following chemical dosage for phosphate removal, with humus tank effluent being recycled in this point (Figure 1).

Settling properties of the biological sludge can be expected to be much improved under those conditions due to the presence of chemical coagulant. This has been shown by Van Vuuren (1981) in applications of the LFB process as well as by preliminary results obtained from a full-scale trial of a pre-denitrification unit at Daspoort Sewage Works (Pretoria), where phosphate was removed chemically by pre-treatment with ferric chloride. The SVI of sludge in the latter study is about 50 mg/ℓ (Thirion, 1983).

Conclusions

Pilot plant studies showed that complete denitrification of humus tank effluent such as that at the Daspoort Sewage Works can be achieved using local primary sludge and raw or settled sewage as carbon sources. The extent of denitrification in a practical situation in which humus tank effluent is recycled to a pre-denitrification reactor will thus be determined by hydraulic considerations, which limit the maximum recycle rate that can be imposed. Using settled sewage the average denitrification rate was 17 mg NO_3-N as g VSS per h.

The major problem experienced during the study concerned was the formation of pin-point floc, which resulted in poor settling of the sludge and typical suspended solids concentrations in the effluent of 71 to 118 mg/ℓ. This aspect is, however, not considered to be a significant factor in full-scale applications in which chemicals are added for phosphate removal. It is recommended that biological denitrification of trickling filter effluent should be considered only as one part of a comprehensive upgrading system comprising chemical treatment for phosphorus and biological treatment for nitrogen removal.

Acknowledgements

This paper is published with the permission of the Chief Director of the National Institute for Water Research and the Water Research Commission who sponsored the research.

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