

# Upgrading of biological filter sewage purification processes for phosphate and nitrogen removal

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## Abstract

A three year investigation was undertaken on the Boksburg and Pretoria, Republic of South Africa (RSA) biological filter sewage purification works to evaluate and further develop existing techniques for phosphate and nitrogen removal. It was demonstrated that the upgrading of this type of works to meet the RSA regulatory effluent phosphate standard of 1 mg/l dissolved orthophosphate (as P), is practically feasible under local conditions. It was also shown that by relatively minor process additions and modifications an effluent with a nitrogenous matter content of less than 10 mg/l (as N) can be produced.

## Introduction

In the Republic of South Africa (RSA) 53 per cent (on a volumetric basis) of the sewage generated in eutrophication sensitive river catchments is treated by biological filter processes (Davidson and Howarth, 1983). The main reason for the popularity of biological filter sewage treatment is the reliability and stability of the process in meeting effluent standards for BOD, COD, ammonia and suspended solids, as well as its low maintenance and energy requirements. However, the effluent from this process still contains high concentrations of nitrogenous compounds, typically 10-30 mg/l (as N) and orthophosphate, typically 5-10 mg/l (as P). Discharge of effluents with such a high nutrient content to the water environment has resulted in over-fertilization (eutrophication) of recipient water bodies. As a consequence, prolific growth of water plants and algae has taken place in river courses, lakes and impoundments downstream of effluent discharges, which in turn has resulted in the deterioration of water quality, as well as giving rise to health and aesthetic problems, all with significant economic implications. Furthermore, although phosphates are not considered toxic, free ammonia has a high toxicity towards aquatic life, while nitrates can cause fatal methemoglobinemia in infants (Kempster *et al.*, 1980).

In order to minimize and control eutrophication as well as overcome the other deleterious effects of high nutrient concentrations, a world-wide trend has developed, i.e. to limit the discharge of nutrients to the water environment. Considerable research and development work was undertaken on chemical phosphate removal in the late sixties and early seventies in the USA, Scandinavia and Europe, the results of which have been widely published and applied (US EPA, 1976; and Wiechers and Van Vuuren, 1979). Nitrogen removal by physical, chemical and

biological means has also been widely researched (US EPA, 1975; and Wiechers and Van Vuuren, 1979), but has not been applied extensively.

In the RSA eutrophication has been increasing steadily, particularly since the introduction of the Water Act in 1956, which requires the return of all treated effluents to their stream of origin, a measure aimed at maximum indirect water reuse in this water-scarce country. The situation has deteriorated to such an extent that the regulatory authorities have introduced legislation requiring point dischargers of phosphates in sensitive river catchments to limit the soluble orthophosphate concentration in their effluents to less than 1 mg/l (as P) from August 1985. Limitation of nitrogen is also receiving close scrutiny, particularly for an important stretch of the Vaal River (Brodisch *et al.*, 1984). In order to assist local authorities and other operators of biological filter works who have to meet these standards, the South African Water Research Commission in collaboration with the City Councils of Boksburg and Pretoria and the National Institute for Water Research of the Council for Scientific and Industrial Research evaluated and further developed existing techniques for phosphate and nitrogen removal.

## Chemical phosphate removal

### Pre-filter chemical phosphate removal

Pre-filter phosphate removal using ferric chloride was investigated over a three year period (1980-1982) on an experimental basis at the Daspoort Sewage Purification Works, Pretoria. The works consist of eight parallel units of which Unit No 8 was used for chemical phosphate removal (Fig. 1 and Table 1) and Unit No 7 as a control. Ferric chloride (43 percent solution, ex Klipfontein Organic Products) and polyelectrolyte (0,2 percent solution, Cyanamid Superfloc A130) were sprayed by means of nozzles onto a turbulent flowing raw sewage stream in an open channel; flocculation took place in a grit chamber and the resultant chemical/raw sludge was separated from the liquid phase in a primary sedimentation tank. Average results for the period July 1981 to June 1982 are listed in Table 2.

The phosphate load on Unit 8 varied significantly, both as a result of changes in the total phosphate concentration, i.e. from 7 to 15 mg/l (as P) and as a result of changes in flow, i.e. from 80 to 125 kl/h. In order to meet this changing load it was decided to dose ferric chloride proportional to the raw sewage flow-rate. Although it was also considered desirable to adjust the ferric chloride dose rate in phase with changes in the phosphate concentration, this was not done since continuous analysis for phosphate in raw sewage was problematic and not considered practically feasible. Dosing ferric chloride on average at 28 mg/l (as Fe) over a one year period, resulted in the lowering of the

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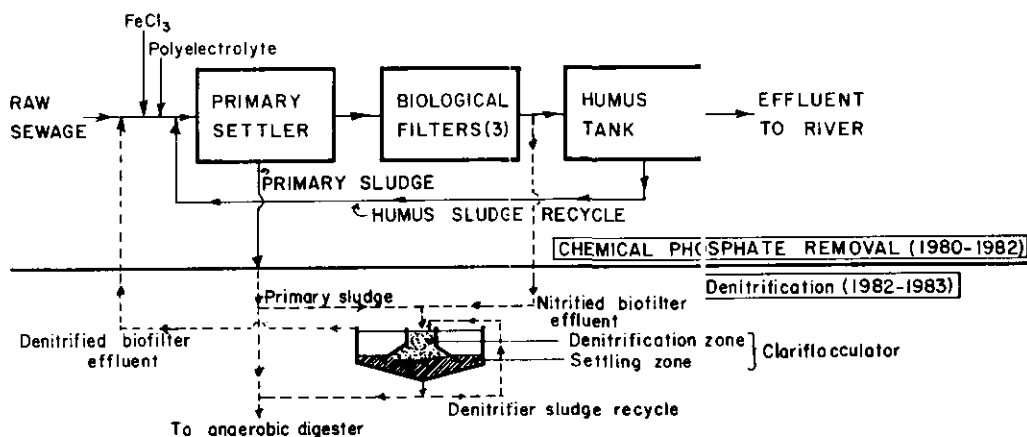


Figure 1  
Process schematic for Unit No 8 of the Daspoort Sewage Purification Works, Pretoria.

average total phosphate from 10,5 mg/l in raw sewage to 3,7 mg/l (as P) in the final effluent. Although it was possible to reduce the orthophosphate concentration in primary settler effluent to 1 mg/l (as P) or less, the total phosphate concentration could not be reduced to this level, even at high dosages of ferric chloride. The inability of pre-filter ferric chloride treatment to produce a humus tank effluent (i.e. the effluent from the secondary clarifiers) with an orthophosphate concentration of 1 mg/l (as P) or less, was caused by the fact that the ferric chloride did not effectively remove organic and polyphosphates from the raw sewage. These complex phosphates passed mostly unaffected through the pretreatment stage, hydrolysed in the biological filters and appeared predominantly as orthophosphate in the filter effluent.

TABLE 1  
DESIGN AND OPERATIONAL DETAILS FOR UNIT NO 8,  
DASPOORT SEWAGE PURIFICATION WORKS, PRETORIA

Average dry weather flow (ADWF):	Design - 2,3 Ml/d Actual - 2,3 Ml/d
Primary Settling Tank: Type	- Dortmund
Diameter	- 9,1 m
Upflow velocity	- 1,4 m/h
Biological Filters: Type	- 3 x 30 m diameter, 1,8 m deep, single filtration
Media	- stone
Design loading rate	- 18 g.PV/m <sup>3</sup> /d
Humus tank: Type	- Dorr clariflocculator
Diameter	- 12,2 m
Upflow velocity	- 1,6 m/h* and 0,82 m/h**
Denitrification Unit: Type	- Dorr Clariflocculator
Diameter	- 19,5 m
"Denitrification reactor"	
retention time	- ≈ 2 h
Solids retention time	- ≈ 5 - 10 d
Upflow velocity	- 0,32 m/h

\*Design upflow rate when handling effluents from both Units 7 and 8 during pre-filter chemical phosphate removal experiments.

\*\*Half of design upflow rate when handling effluent from Unit 8 only during pre-filter denitrification (and chemical phosphate) removal experiments.

on average a mass ratio of ferric to orthophosphate removed ( $\text{Fe}^{3+} : \Delta\text{PO}_4\text{-P}$ ) of 4,3:1, as compared to the stoichiometric mass ratio of 1,8:4, if it is assumed that all the iron is precipitated as  $\text{FePO}_4$ . The excess ferric chloride is utilized in the formation of ferric hydroxide and other iron complexes, for example, with heavy metals, sulphide and organic matter. As can be seen from Table 2, ferric chloride treatment resulted in considerably improved removal of organic matter which was also reflected by improved nitrification by the filters receiving chemically treated primary settling tank effluent. This demonstrated the potential of pre-filter chemical treatment for relieving filters which are organically overloaded. A further interesting observation on the control filter system (Unit 7) was the greater removal of nitrogenous compounds (Table 2) probably due to denitrification in anaerobic pockets in the filter. However, the major portion of the nitrogenous compounds in the effluent from this unit was in the environmentally less desirable ammonia form.

Ferric chloride treatment had two distinct disadvantages. Firstly, it increased the total dissolved solids and more specifically the chloride content of the effluent. For example, for the ferric chloride dosage of 28 mg/l (as Fe) the effluent chloride concentration increased by 53 mg/l (as Cl). Secondly, ferric chloride neutralized 2,7 parts of alkalinity (as  $\text{CaCO}_3$ ) for every 1 part of iron added, i.e. 76 mg/l alkalinity were neutralized by the addition of the 28 mg/l Fe. Although this did not result in an unacceptable effluent at Daspoort, for other raw sewages with low alkalinities this may require the addition of alkalinity, for example by adding lime.

Three further aspects related to chemical pre-treatment were noteworthy during the investigation. Firstly, ferric chloride pre-treatment resulted in considerably larger volumes of sludge, i.e. 13 versus 8 kl sludge/Ml raw sewage treated, and larger sludge masses, i.e. 800 versus 400 kg sludge (dry mass basis)/Ml raw sewage treated. However, the existing primary settlers and anaerobic digesters coped adequately with this additional load. Secondly, it was found that the biological filters treating normal settled sewage tended to pond during the study period, whereas the filters treating chemically pretreated settled sewage did not. Thirdly, the Pretoria Municipality was concerned that the phosphate removed chemically in the primary settlers would be released when the raw/chemical sludge was anaerobically digested. However, one year's continuous operation proved conclusively that no significant phosphate release from the sludge took place in the anaerobic digesters.

To obtain a residual orthophosphate concentration of the order of 1 mg/l (as P) in primary settling tank effluent, required

TABLE 2  
COMPARISON OF SEWAGE PURIFICATION WITH (UNIT 8) AND WITHOUT (UNIT 7) PRE-FILTER FERRIC CHLORIDE TREATMENT AT THE DASPOORT WORKS, PRETORIA\*

Waste Stream	Chemical Oxygen Demand (mg/l)	Total Nitrogen* (mg/l as N)	Nitrate (mg/l as N)	Total Phosphate (mg/l as P)	Ortho-phosphate (mg/l as P)
Raw Sewage	528 (440 - 660)	43 (36 - 56)	-	10,5 (7,0 - 14,5)	7,5 (5,0 - 9,8)
Biological Filter Effluent†	85 (30 - 160)	19 (11 - 27)	7,8 (1 - 25)	7,8 (6,8 - 9,4)	6,8 (5,0 - 8,2)
Biological Filter Effluent with chemical pretreatment*	60 (30 - 100)	24 (16 - 38)	16 (10 - 25)	3,7 (2,0 - 6,0)	2,6 (1,0 - 4,0)

\*The values listed are annual averages for the period July 1981 - June 1982. Samples were collected daily, composited over a week and then analysed. The analyses were made on unfiltered samples except for nitrates. The figures in brackets give the range of weekly values found.

†Analyses for Unit 7, i.e. control unit. Samples were collected and settled for one hour in an Imhoff cone and the supernatant, i.e. the equivalent of humus tank effluent, was then analysed.

\*Analyses for Unit 8, i.e. chemically pretreated with ferric chloride, 28 (15 - 44) mg/l as  $Fe^{3+}$ . Sample preparation identical to that for Unit 7.

\*Total nitrogen = Total Kjeldahl nitrogen plus nitrate and nitrite nitrogen.

### Post-filter chemical phosphate removal

Post-filter chemical phosphate removal was studied over a three year period (1980-1982) on an experimental basis at the Vlakplaats Water Pollution Control Works, Boksburg. The works comprised two parallel units, with Unit No 2 being used for this investigation (Fig. 2 and Table 3). Based on extensive laboratory and pilot-scale (2 Ml/d) studies, ferric chloride was selected as the most cost-effective chemical for phosphate removal at this works. Ferric chloride (43 per cent solution as  $FeCl_3$  (m/m) and polyelectrolyte (0,2 per cent solution, Cyanamid Superfloc A130) were added to the biological filter effluent stream; flocculation and floc conditioning took place in the conditioning zones of the humus tanks (secondary settlers) and the humus/chemical solids were then removed from the liquid phase in the settlement zones of humus tanks. Effluent from these tanks was recycled ( $\approx 9$  Ml/d) to a point upstream of the filters and mixed with settled sewage ( $\approx 25$  Ml/d) to ensure that the surface of the filter media was fully wetted at all times. Typical results for two representative intensive sampling runs are listed in Table 4.

The flow to the biological filters varied significantly over the day, typically between 1,0 to 1,7 Ml/h, but the average daily flow was fairly constant at approximately 34 Ml/d. The ortho-phosphate concentration in the filter effluent ranged between 3 to 12 mg/l (as P), with annual average of 6,8 mg/l (as P). In order to partially meet this changing phosphate load, it was decided to dose ferric chloride (and polyelectrolyte) proportional to the flowrate of biological filter effluent. Dosing ferric chloride at 20 mg/l (as  $Fe^{3+}$ ) and polyelectrolyte at 0,2 mg/l (as A130) over a one year period (1982), resulted in an effluent which met

the RSA regulatory phosphate standard 85 per cent of the time. The average mass ratio of ferric to orthophosphate removed ( $Fe^{3+} : \Delta PO_4-P$ ) was 3,4:1, as against the stoichiometric ratio of 1,8:1 for  $FePO_4$  precipitation only. However, this chemical precipitation also resulted in improved COD (Table 4) and suspended solids removal from the biological filter effluent. In order to further utilize the phosphate removal capacity of the predominantly chemical sludge, it was recycled to the head of works where it was mixed with raw sewage and resulted in improved phosphate removal and sedimentation in the primary settlers.

As in the case with pre-filter ferric chloride treatment, the chloride content of the effluent was also increased, in this case by about 38 mg/l (as Cl) and the alkalinity dropped by about 54 mg/l (as  $CaCO_3$ ). A recurring problem was the carry-over of colloidal and particulate iron. The use of polyelectrolyte reduced the problem but did not completely solve it. Based on further laboratory jar tests it is anticipated that the problem will be overcome once the overloaded hydraulic conditions of the humus tanks are relieved when a new extension to the plant (Unit No 3) is commissioned and chemical precipitation and flocculation have been further optimised. Scraped-bottom secondary clarifiers including proper flocculation and floc conditioning zones and with an upflow rate of 1,0 m/h as against 1,9 m/h, are currently being commissioned.

Post-filter chemical phosphate removal required increased humus tank sludge withdrawal rates, from once per day (15-20 kl/d) to continuous withdrawal ( $\approx 700$  kl/d). This thin sludge was recirculated to the head of works, mixed with raw sewage and settled in the primary clarifiers where the normal rate

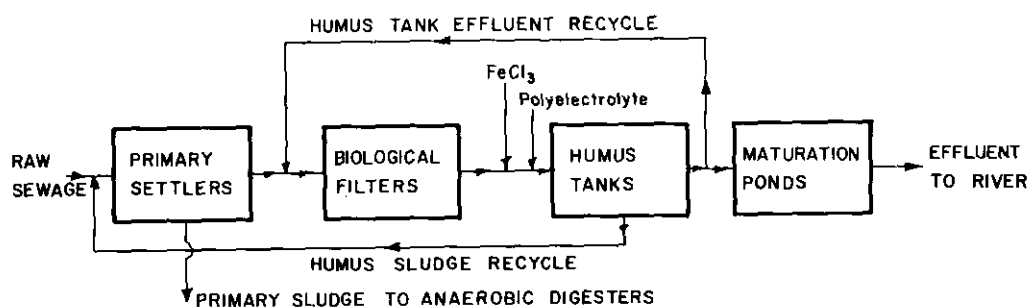


Figure 2  
Process schematic for Unit No 2, Vlakplaats Water Pollution Control Works, Boksburg.

**TABLE 3**  
**DESIGN AND OPERATIONAL DETAILS FOR UNIT 2 OF THE VLAKPLAATS WATER POLLUTION CONTROL WORKS, BOKSBURG**

Average Dry Weather Flow (ADWF):	Design	- 18 Ml/d
	Actual	- 25 Ml/d
Primary settlers (6x):	Type - Dortmund	
	Diameter	- 11 m
	Upflow velocity - Design	- 1,3 m/h
	Actual	- 1,8 m/h
Biological filters (8x):	Type - Single filtration, stone	
	Diameter	- 37,8 m
	Ave Depth	- 2,3 m
	Loading rate - Design	- 25 g PV/m <sup>3</sup> /d
	Actual	- 48 g PV/m <sup>3</sup> /d
Humus tank (8x):	Type - Dortmund	
	Diameter	- 11 m
	Upflow rate: Design (with 1:1 recirculation)	- 2,0 m/h
	Actual (with 0,36:1 recirculation)	- 1,9 m/h
MATURATION PONDS (17x):	Total Retention time	- 12 days

**TABLE 4**  
**COMPARISON OF SEWAGE PURIFICATION WITH AND WITHOUT POST-FILTER FERRIC CHLORIDE TREATMENT IN UNIT 2 AT THE VLAKPLAATS WORKS, BOKSBURG\***

Waste Stream	Chemical Oxygen Demand (mg/l)	Ammonia (mg/l as N)	Total Kjeldahl Nitrogen† (mg/l as N)	NO <sub>3</sub> + NO <sub>2</sub> (mg/l as N)	Total Nitrogen† (mg/l as N)	Ortho-Phosphate (mg/l as P)	Total Phosphate (mg/l as P)	Alkalinity (mg/l as CaCO <sub>3</sub> )
WITHOUT POST-FILTER CHEMICAL TREATMENT (16 to 2: MAY 1981) <sup>+</sup>								
Raw Sewage	844	33	53	1,8	55	6,5	15,3	230
Settled Sewage	452	32	45	1,2	46	4,6	8,5	244
Biological Filter Effluent	152	8	16	9,9	26	6,3	9,1	163
Humus Tank Effluent	93	8	13	10,2	23	6,3	7,8	165
Maturation Pond Effluent	64	6	8	2,3	10	4,8	5,6	200
WITH POST-FILTER FeCl <sub>3</sub> TREATMENT (20 mg/l as Fe) (20 to 30 JANUARY 1982) <sup>++</sup>								
Raw Sewage	615 (270 - 951)	20 (13 - 26)	32 (26 - 40)	4 (0,4 - 10)	36	4,6 (2,8 - 6,5)	9,1 (5,6 - 17,6)	202 (171 - 265)
Settled Sewage	369 (261 - 518)	21 (14 - 31)	29 (24 - 42)	0,9 (0,3 - 3,4)	30	3,8 (1,5 - 5,4)	7,2 (3,6 - 13,6)	210 (169 - 260)
Biological Filter Effluent	137 (75 - 347)	5,8 (3,1 - 10,2)	9,0 (6,3 - 12,0)	6,5 (4,8 - 9,6)	16	4,1 (3,0 - 5,8)	4,8 (3,6 - 7,6)	144 (122 - 185)
FeCl <sub>3</sub> Treated Humus Tank Effluent	68 (38 - 95)	4,9 (3,1 - 9,2)	6,8 (5,1 - 9,8)	6,9 (4,5 - 9,2)	14	0,8 (0,4 - 1,9)	2,8 (1,6 - 8,8)	106 (78 - 153)
Maturation Pond Effluent	67 (29 - 102)	3,5 (2,7 - 5,3)	4,4 (3,4 - 5,2)	1,4 (0,7 - 1,9)	5,8	3,4 (2,5 - 4,5)*	3,5 (2,4 - 6,2)*	141 (112 - 165)

\*Results listed are averages for seven day<sup>+</sup> and eleven day<sup>++</sup> intensive sampling runs; Samples were collected hourly and composited proportional to flow on a daily basis and were then analysed; Analyses were made on unfiltered samples except for ammonia, nitrate plus nitrite, and alkalinity.

†Total nitrogen = Total Kjeldahl nitrogen plus nitrate and nitrite nitrogen.

\*Pond effluent is approximately twelve days out of phase with rest of samples and corresponds to a period when no FeCl<sub>3</sub> was dosed, as is apparent from the high phosphate concentrations.

of raw sludge withdrawal of once per shift ( $\approx 550$  kl/d) had to be increased to twice per shift ( $\approx 660$  kl/d). The raw/chemical/humus sludge withdrawn from the primary settlers was thinner than the normal raw sludge, approximately 5,6 versus 6,2 per cent solids (dry basis). Because of the higher hydraulic load on

the anaerobic digesters, the digestion time decreased from about 22 to 18 days. Notwithstanding this shorter digestion time a stable digested sludge was still produced. However, in plants where existing digesters are already operating at full capacity, pre-digester thickening of primary settling tank sludge may be re-

quired. No phosphate release from the chemical sludge took place during the digestion process.

### Biological Nitrogen removal

Studies were undertaken at both the Daspoort and Vlakplaats Works to quantify the nitrogen removal obtained under conventional operation and in addition various techniques were investigated for enhancing nitrogen removal. The most promising technique was pre-filter denitrification of recycled nitrified biological filter effluent, using raw sewage as a carbon source. This technique has been thoroughly researched for the activated sludge process (Water Research Commission, 1984) and widely applied in the RSA (Pitman *et al.*, 1983).

#### Pre-filter nitrogen removal

A pilot-scale unit (1,2 kℓ/d) for testing various modes of operation for the denitrification of biological filter effluent using settled sewage as an energy source, was operated for about a year at the test site of the National Institute for Water Research, Daspoort, Pretoria. Settled sewage was mixed in a 1:1 ratio with nitrified humus tank effluent and allowed to react in a completely mixed 95 ℓ reactor. The settled sewage was spiked with sodium nitrate to raise the nitrate load on the reactor in order to assess the unit's full denitrification potential. Typical results are listed in Table 5.

An average net denitrification rate of 17 mg NO<sub>3</sub>-N/gVASS\*/h was maintained which compares favourably with a rate of 30 mg NO<sub>3</sub>-N/gVASS/h reported for activated sludge systems (Water Research Commission, 1984). This rate was achieved at an average mixed liquor suspended solids concentration of 600 mg/ℓ and an effective sludge age of about one day. Most of the biomass was in a very active state as indicated by the small difference in concentration between the mixed liquor suspended solids (618 mg/ℓ) and the volatile suspended solids (502 mg/ℓ). A difficulty experienced with the system was the development of pinpoint flocs which resulted in loss of suspended solids, i.e. the average solids in the settling tank effluent was 71 mg/ℓ. Although this did not significantly affect the reactor's denitrification potential, it was anticipated that in practice solids loss from primary clarifiers may present an additional and possibly unacceptable load to biological filters. However, this problem was overcome during prototype-scale tests by combining pre-filter denitrification with chemical phosphate removal.

The pilot-scale study was followed-up with a preliminary evaluation at prototype-scale (2,3 Mℓ/d) at the Daspoort Works. A disused clariflocculator was incorporated into the conventional flow scheme of Unit No 8 and used as a make-shift denitrification reactor/settling tank (Fig. 1 and Table 1). The floc conditioning zone of this unit was used as the "denitrification reactor" and settling zone for separating solids from the liquid phase. The denitrifiers were retained in the system by recycling the underflow from the unit to the "denitrification zone". Typical results are listed in Table 6.

Pre-filter denitrification resulted in a humus tank effluent (i.e. secondary clarifier effluent) low in both ammonia and nitrate, with a total nitrogen concentration of less than 10 mg/ℓ (as N). This compared favourably with the average total nitrogen concentration of 20 mg/ℓ (as N) for biological filtration without pre-denitrification (Table 2). Combined biological nitrogen and chemical phosphate removal produced a good quality effluent, i.e. a low COD (52 mg/ℓ), total nitrogen (8,1 mg/ℓ as N) and orthophosphate (1,1 mg/l as P), respectively.

#### Within-filter nitrogen removal

Mass balances for nitrogenous matter over the biological filters at the Daspoort and Vlakplaats Works indicated significant within-filter nitrogen losses, e.g. at the Vlakplaats Works the total nitrogen concentration of 46 mg/ℓ (as N) in the settled sewage was reduced to 26 mg/ℓ (as N) in the filter effluent (Table 4). Analysis of this data indicates that the major mechanisms through which nitrogen is removed in the filters is by incorporation into the attached growth bacterial cell mass, as well as smaller losses due to denitrification in anoxic pockets of the somewhat organically overloaded filters and possibly loss by ammonia volatilization. Attempts to increase nitrogen removal through denitrification within the filters at Daspoort, by recirculating nitrified effluent back to the filters, were not successful.

#### Post-filter nitrogen removal

Monitoring of the maturation ponds at the Vlakplaats Works over the 1980-82 period, indicated significant nitrogen removal. For example, during the intensive sampling run during 1981 (Table 4) the total nitrogen concentration to the ponds was 23 mg/ℓ (as N) and the pond effluent contained 10 mg/ℓ (as N). The factors controlling nitrogen removal in the Vlakplaats maturation ponds were not identified and quantified in depth. However, it was noted that algae played an important role, since filamentous

TABLE 5  
TYPICAL RESULTS FOR TECHNICAL SCALE DENITRIFICATION OF HUMUS TANK EFFLUENT USING SETTLED SEWAGE AS CARBON SOURCE

Waste Stream	Total COD (mg/ℓ as O)	Total Kjeldahl Nitrogen (mg/ℓ as N)	NH <sub>4</sub> <sup>+</sup> (mg/ℓ as N)	NO <sub>3</sub> <sup>-</sup> + NO <sub>2</sub> <sup>-</sup> (mg/ℓ as N)
Settled sewage	345	34,4	24,8	nd
Humus tank effluent	60	8,0	6,7	6,5 (47,6)*
Feed entering unit	202	21,2	15,8	24,0
Denitrification reactor contents	nd	nd	13,1	8,8
Settling tank effluent	193	21,6	16,3	9,2

Results represent averages for 20 samples taken over a two months period; nd = not determined.

\*Humus tank effluent nitrate concentration after spiking with sodium nitrate

\*VASS - Volatile active suspended solids.

TABLE 6  
PRE-FILTER BIOLOGICAL NITROGEN AND CHEMICAL PHOSPHATE REMOVAL IN UNIT 8 OF THE DASPOORT SEWAGE PURIFICATION WORKS, PRETORIA\*

Waste Stream	COD (mg/l)	Total Kjeldahl Nitrogen (mg/l as N)	Ammonia Nitrogen (mg/l as N)	NO <sub>3</sub> + NO <sub>2</sub> (mg/l as N)	Ortho-Phosphate (mg/l as P)	Chlorides (mg/l)	pH
BIOLOGICAL NITROGEN REMOVAL ONLY (18/19 NOVEMBER 1982)							
Raw sewage (3,0 Ml/d)	505	37	14,5	—	9,7	—	7,5
Primary settler effluent	225	20	11,5	—	9,5	80	7,6
Humus tank effluent	60	3,2	0,9	5,4	9,3	82	8,0
BIOLOGICAL NITROGEN AND CHEMICAL PHOSPHATE REMOVAL (55 mg/l FeCl <sub>3</sub> as Fe) (21/22 DECEMBER 1982)							
Raw sewage (4,2 Ml/d, 55 mg/l FeCl <sub>3</sub> as Fe)	520	29	19,5	—	5,6	88	7,5
Primary settler effluent	200	15	8,8	—	0,6	152	7,3
Humus tank effluent	52	2,0	0,3	6,1	1,1	148	7,9

\*Two sets of data listed above give average results for 24 samples taken over 24 h period and composited proportional to flow.

algae grew profusely in this system, necessitating mechanical removal twice per week in summer and once per month in winter.

## Conclusions

The investigations at the Daspoort and Vlakplaats sewage purification works demonstrated that the upgrading of existing biological filter sewage purification works to meet the RSA regulatory effluent phosphate standard of 1 mg/l dissolved orthophosphate (as P), is practically feasible under local conditions. Furthermore, by relatively minor process additions and modifications an effluent with a nitrogenous matter content of less than 10 mg/l (as N) can be produced.

Pre-filter chemical treatment of raw sewage is a suitable technique for partial phosphate removal as well as relieving organically overloaded filters. Post-filter chemical treatment is the most suitable technique for meeting the regulatory effluent phosphate standard. One area of concern is the need for the more accurate quantification of the masses and volumes of chemical sludge formed during these processes, as well as their physical characteristics. Although this was not an important factor at the Daspoort or Vlakplaats works, it may be important for works where the solids handling, treatment and disposal equipment is already operating at its maximum capacity.

Pre-filter denitrification using raw sewage as a carbon source resulted in excellent nitrogen removal. Significant nitrogen removal from biological filter effluents can also be achieved in maturation ponds. Both techniques therefore hold considerable potential for upgrading existing filter works for nitrogen removal.

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