PETRO® system: A low-tech approach to the removal of waste-water organics (incorporating effective removal of micro-algae by the trickling filter)

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Abstract

The system offering low-tech low-cost treatment of municipal sewage is described. It is based on a ponding process followed by a trickling filter (TF). Micro-algae produced in stabilization ponds are removed in the TF. It is suggested that micro-algae contribute to biofilm production and organic load reduction in the TF.

Introduction

The name PETRO® is a proprietory name which is an acronym of the concept title **P**ond **E**nhanced **TR**eatment and **O**peration. The system sets out to make maximum use of anaerobic biodegradation followed by aerobic degradation in oxidation ponds prior to the polishing stage in a secondary unit. As the name implies the efficiency of a secondary biological treatment unit (a trickling filter (TF) or an activated sludge process) is enhanced by a series of waste stabilisation ponds which is an effective primary stage for the removal of most of the organic material.

The system consists of a line-up of a number of well-known and reliable unit processes. The units are positioned in such a way that the shortcomings of the individual components are avoided and advantages of the constituent components are used to the best effect.

The system is aimed at employment in the current SA situation as it is particularly applicable in developing countries. This situation dictates that a waste-water treatment system must:

- produce an effluent of a superior quality suitable for discharge into a watercourse;
- be a low-capital cost facility with low operational costs;
- be simple in operation;
- lend itself for progressive upgrading;
- perform well despite of lack of human skills and other restrictions, typical of a developing country environment.

Low-tech systems are of increasing importance in the context of the world-wide situation. A former IAWQ president PGrau has questioned whether world problems of water quality can be solved by "a high-technology and expensive treatment plants" approach (Grau, 1994). A viable solution is a promotion of the "GNP appropriate technology", i.e. a technology appropriate for countries with a low Gross National Product.

The PETRO® system is an example of such "GNP appropriate technology". It is a conceptually innovative process which has been tested on a large scale for more than a decade.

The system was developed in successive stages from a series of oxidation ponds which are indigenous to South Africa. The innovative concept of high-rate recirculation of algae and oxygen-rich effluent from an oxidation pond back to primary pond was described by Abbott (1963) and is still widely used.

However, as the effluents from most oxidation ponds do not comply with the statutory effluent requirements for return to a public stream an exemption has to be granted whenever ponds are to be used. The granting of exemption is only considered in instances where less than 800 $k\ell \cdot d^{-1}$ of sewage is to be treated and where there is little prospect of growth (Meiring et al., 1968).

The advantages of a pond system were so obvious that efforts were made to overcome the shortcomings. A major approach was to try and upgrade the effluent quality. In an attempt to achieve this goal Vosloo (1973) linked a biological filter and humus tank downstream of the oxidation ponds. The process was not effective as algae passed through the biological TF undetained.

The initial design by one of the authors for upgrading the quality of the final oxidation pond effluent in Kanyamazane (Mpumalanga) in 1974 was based on the same premise. However, certain changes were introduced in the design. These changes were of an experimental nature and aimed at supplying primary pond effluent as a source of organic nutrients for TF biofilm in an attempt to enhance the ability of the slime microbial consortium to remove algae, or alternatively, to avoid the prolific growth of algae due to by-passing the secondary oxidation ponds. The process was taken a step further when at Letlhabile (North-West Province) another PETRO® full-scale plant was built 1982. The Letlhabile Sewage Works was specifically designed as an installation requiring minimum skilled attention but producing an acceptable effluent even if a prolonged power failure should occur. Information obtained from operating the Kanyamazane facility was applied and the PETRO® concept was formulated (Meiring, 1992).

The PETRO® concept constitutes an integrated pond system incorporating a facultative stabilisation pond and oxidation ponds interlinked by high-rate interpond recirculation in a peculiar line-up. In a hybrid arrangement it also involves a secondary facility such as a TF.

The operational advantages, low cost and effluent quality achieved consistently for more than a decade prompted a Water Research Commission-funded project to explain the nature of the biological phenomena involved in order to establish informed procedures for optimising the PETRO system.

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TABLE 1 OPERATION PARAMETERS OF THE PETRO TF PLANTS					
PETRO plant	**Population served**	**Hydraulic load (Mℓ.d^{-1})**	**Organic load (kg COD.d^{-1})**	**Number of TFs**	**TF volume (m^3)**
Kanyamazane	50 000	7	4150	2	4162
Letlhabile	30 000	1.6	1000	2	3200
Elliot	13 000*	0.8	660	2	656
* - design population 20 000					

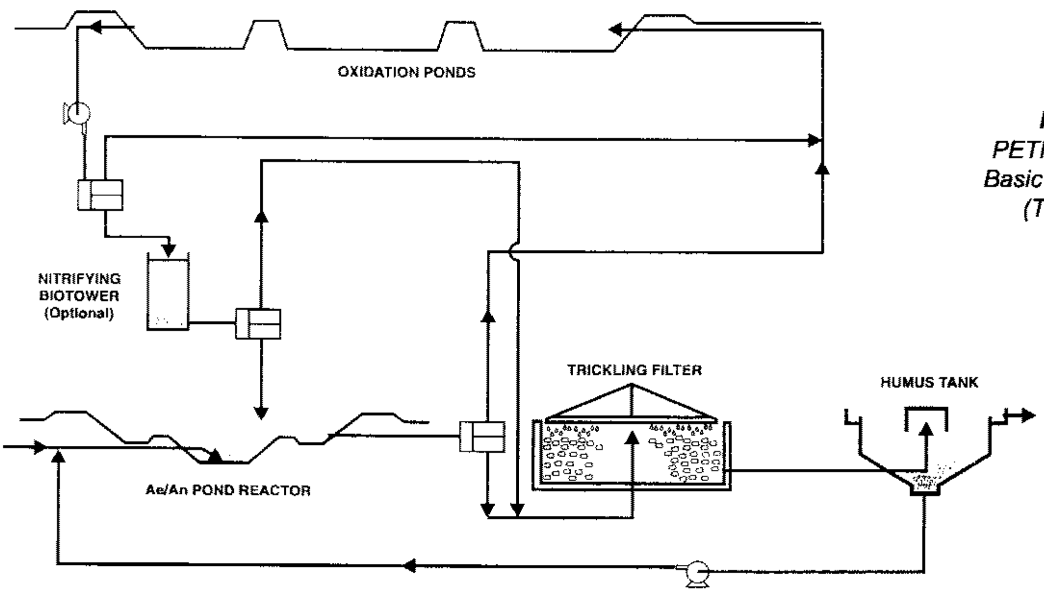

Figure 1
PETRO® system.
Basic flow diagram
(TF variant)

Materials and methods

Three full-scale PETRO® installations were studied: the municipal sewage works in Kanyamazane (Mpumalanga), Letlhabile (North-West Province) and Elliot (Eastern Cape). An inefficient system of oxidation ponds in Elliot was upgraded according to the PETRO concept in July 1994.

Current operation parameters for the plants are given in Table 1.

The system operation parameters (TKN, ammonia, nitrate, VSS, VDS) and chlorophyll *a* concentration were determined according to the *Standard Methods* (1989).

The TF biofilm was collected at a depth of 1 m below the surface. An amount of the biofilm was measured gravimetrically and expressed in kg of dry biofilm per m^3 of the rock medium.

The systems were studied at different seasons (summer-autumn 1994: average T_{water} =23°C and 20°C; winters 1994 and 1995: average T_{water} =15°C and 13°C, for Kanyamazane and Letlhabile, respectively).

Results and discussion

Description of the PETRO system

The basic flow diagram is presented in Fig. 1. The system comprises a deep primary facultative (Aerobic/Anaerobic, Ae/An) pond and one or a number of shallow secondary oxidation ponds as a primary stage of the process removing more than 70% of the incoming organic load. As the secondary stage a biological TF filled with stone medium followed by a humus tank is used. The TF may be substituted with an activated sludge process (ASP).

An important feature of the system is recirculation to ensure that the primary anaerobic pond does not constitute an environmental hazard. The recirculation of oxygen-rich water from the secondary oxidation ponds and nitrate-rich humus tank underflow into the primary pond allays obnoxious odours by sulphide oxidation. The design and positioning of the primary pond obviates the hazard of employing open impeller pumps. This feature constitutes an important maintenance and operational advantage, particularly on small installations. In case of an emergency such as prolonged power failure which prevents pumping, the inflow of raw sewage will pass through the anaerobic pond into the secondary oxidation ponds for temporary storage.

The secondary oxidation ponds are incorporated in the system in a closed side-loop in which the required flow rates can be selected. The functions performed by the PETRO® oxidation ponds are the following:

- further reduction of primary pond organic matter effected by the algo-bacterial consortium

TABLE 2 TYPICAL PERFORMANCE CRITERIA OF PETRO® SYSTEM (KANYAMAZANE, WINTER 1995)						
Parameter, mg.ℓ$^{-1}$	**Raw sewage**	**Primary pond**	**TF inflow**	**TF outflow**	**HT outflow**	**Overall removal, %**
COD	556	371	149	97	45	92
TKN	67	48	16	5	2	97
NH_4^+-N	25	33	9	2	1	96
NO_3^--N	-	5	6	17	21	-
VSS	80	63	21	29	3	96
VDS	111	81	23	17	8	93

- supply of algae- and oxygen-rich water to suppress odours in the primary pond
- reduction of ammonia which otherwise would have to be nitrified downstream
- generation of bicarbonate alkalinity which assists in offsetting the effect of advanced nitrification in the TF
- providing a balancing reservoir for attenuation of the daily and wet weather peak flows
- providing an effective emergency treatment for the primary pond effluent prior to its final discharge should a power failure occur or pumping be interrupted
- providing a satisfactory treatment facility during initial stages of a progressive development program prior to the introduction of a TF (or ASP) as a polishing step.

The micro-algae make a significant synergistic contribution to successful effluent treatment in oxidation ponds (Abeliovich, 1986; Oswald, 1988; Rose et al, 1992). Algae producing oxygen thus facilitate organics breakdown by bacteria and other components of the microbial consortium. Carbon dioxide and low molecular organics consumed by algae result in a photosynthetic conversion of a substantial portion of the organic load into algal biomass (Abeliovich and Weisman, 1978). COD of the final effluent may be high with a large contribution by algal biomass in the form of filterable solids. Removal is problematic with a potential for nuisance in the form of secondary pollution by algal wastes and decay products (De Pauw and Solomoni, 1991).

Conventional TFs, among other options including in-line activated sludge reactors, when evaluated, have been found unable to remove algae from well-stabilized oxidation pond water (Vosloo, 1973; Meiring,1993; Meiring and Hoffmann, 1994).

The performance of a TF in general depends not only on soluble organics removal but to a greater extent on the ability of the secondary clarifier to separate the volatile suspended solids sloughed off from the TF medium (Bruce and Hawkes, 1983). It is even acknowledged that the inferior performance of the TFs in comparison to the ASP was due to the poor efficiency of the TF to produce settleable material or the downstream clarifier to effect its sedimentation (Anon., 1990). One of the major recent trends in the field of TF applications is to ensure effective flocculation in the TF and downstream by enhanced slime production (Parker et al., 1990).

Typical operational parameters of the PETRO® system are reported in Table 2. While the integrated PETRO® oxidation ponds effect a substantial organic load removal (>70%), the TF and humus tank (HT) achieve a substantial result in terms of polishing oxidation pond effluent and particularly in reduction of

TABLE 3 VOLATILE SOLIDS REDUCTION IN THE TRICKLING FILTER-HUMUS TANK SECTION OF THE PETRO® SYSTEM (KANYAMAZANE, WINTER 1995; LETLHABILE, AUTUMN, 1994)			
Parameter	**Reduction in the TF,%**	**Reduction in the HT,%**	**Overall reduction,%**
KANYAMAZANE			
Volatile suspended solids	0	90	86
Volatile dissolved solids	26	53	35
LETLHABILE			
Volatile suspended solids	0	82	78
Volatile dissolved solids	41	64	76

VSS, TKN and ammonia. The latter is converted to nitrate in the TF.

The PETRO® TF and humus tank are essential algae-removing components of the system removing 35 to 76% of the volatile dissolved solids (Table 3).

No reduction of the mass of volatile suspended solids (VSS) appears to occur in the PETRO® TF. On the contrary, VSS increase in the TF outflow compared to the influent but passage of organics through the PETRO® TF considerably enhances their settleability. Flocculation of organics including algal residue is a most important function of the PETRO® TF.

An enhanced flocculation in the PETRO® TF leads to an effective humus tank performance as up to 82 to 90% of incoming VSS sediment is removed in the PETRO® humus tank.

Many factors contribute towards the remarkable performance of the PETRO® system which do not apply in a conventional system. Consequently, whereas the current SA design criteria for a conventional TF would indicate a requirement of a 1 m^3 filter medium for every 4 to 5 persons served by the waste treatment facility, this number can be increased by a factor of more than 2 when using the PETRO® system.

Microflora of the PETRO® system

An investigation of microflora in three full-scale systems was undertaken. Typical data are presented in Table 4. All components of the PETRO® system containing micro-algae were surveyed. These include a primary pond, secondary ponds, TF influent combining primary pond and secondary pond effluents, TF and HT effluents.

A comparison of the systems has shown that the total amount of micro-algae is substantially greater in the Kanyamazane system than in both the Letlhabile and Elliot systems. Chlorophyll concentrations in the Kanyamazane TF influent is more than 7 times higher compared to Letlhabile in summer-autumn period (799 and 102 $\mu g \cdot \ell^{-1}$, respectively) and 2 to 7 times higher than in Elliot at different seasons. A winter algal concentration in Elliot was deceptively high (451 $\mu g \cdot \ell^{-1}$) due to residual algae generated prior to conversion. At that time the oxidation ponds received raw sewage which resulted in a higher nutrient input and subsequent algal bloom.

Algal numbers in the oxidation pond effluent decrease somewhat in winter apparently due to the lower light intensity and temperature. Chlorophyll *a* concentration dropped twofold in Kanyamazane.

The green algae Chlorophyta and Euglenophyta were numerically by far the predominant chlorophyll-containing organisms. Chlorophyta were represented by *Chlorella* spp., *Scenedesmus obliquus*, *S. quadricauda* and residual *Volvox* spp. Cells of *Chlorella* spp. were found in much greater numbers than those of the other species. Cells were both free and in clumps as these produced mucilages consisting of exopolysaccharides (EPS). The majority of algal cells in the primary pond and the TF influent were freely dispersed (in Kanyamazane: 85% and 80%, respectively; in Letlhabile: 60 and 70%, respectively; in Elliot: 76 and 65 %, respectively). The rest of the cells were entrapped in an EPS mucilage. The percentage of entrapped algae increased dramatically after the TF (up to 98%). The entrapment appears to facilitate downstream removal as humus attains a high settling characteristic.

Euglenophyta were represented by several species including *Euglena* spp., *Lepocinclis* spp., *Phacus pyrum* and *P. pleuronectes*. The vast majority of *Euglenophyta* were *Phacus* spp., motile and non-motile (due to aging and entrapment). These were found throughout the system down to the HT effluent. Most of the Euglenophyta cells were also found entrapped in a mucilagenous substance. The percentage of the free organisms varies greatly in different components of the system. Approximately 5 to 15% (and 11 to 16%) of the total number of Euglenophyta in the TF effluent (and final effluent) were free cells while the percentage was much higher in the primary and secondary ponds: 69 to 82 and 60 to 80%, respectively.

Diatom algae (Bacillariophyta) were represented by a number of species both unicellular (*Nitzschia* spp.) and filamentous (*Synedra* spp.) and did not constitute a substantial part of the algal consortium.

Thus all studied PETRO® systems were characterised by surprisingly uniform algal microflora. The dominant species include green alga *Chlorella* spp., euglenoid *Phacus* spp. and to a considerably lesser extent diatom *Nitzschia* spp. and green alga *Scenedesmus* spp.

A substantial number of *Protozoa* spp. were observed in the system. Only holozoic feeders capable of ingesting algal cells were counted. These belong to classes Ciliata and Rhizopoda. Stalked ciliates (*Vorticella* spp.) dominated in the oxidation ponds and downstream. Amoeboid organisms were found only in the TF and downstream.

Relatively low numbers of protozoa containing unicellular algae were found prior to the TF. A much greater ratio of *number of algae-containing protozoa : total number of protozoa* for the TF effluent compared to that of the TF influent was observed in all systems. While the ratio prior to the TF was not more than 0.03, the ratio increased after the TF to at least 0.6 in every system. It suggests that most of grazing activity of protozoa is concentrated in the TF.

The same phenomenon was observed for rotifers. Rotifers, both stalked and free-swimming, were found in the TF and downstream. Many contained unicellular algae and even larger euglenoid organisms (12 to 100% of total rotifer population depending on the particular system).

The presence of live algae in a TF increases the importance of the predation phenomenon. Numbers of protozoa and rotifers appear to increase with an increase of algal concentration.

Rotifers, as much as protozoa, are known to have a very high potential to eliminate algae. It has been estimated that one rotifer *Brachionus calyciflorus* can ingest about 2 000 *Chlorella* cells per hour (Seaman et al.,1986).

An increased concentration of particulate organic matter in the form of chlorophyll-containing organisms requires substantially higher activity of protozoa and rotifers as grazers on algal biomass. Being larger than algae these forms would increase settleability of the TF effluent.

Low numbers of fungal hyphae were observed in the oxidation ponds and the TF. Substantially lower numbers of hyphae were present in the Kanyamazane TF compared to those in a conventional TF.

Nematodes were found in the TF and downstream. No chlorophyll-containing organisms were detected inside the nematodes although some contained brown algae-like structures.

Overall, it is evident that an efficient removal of the algal and protozoal components of effluent VSS is effected on passing through the PETRO® TF and humus tank.

These results are corroborated by the data obtained by Oellermann et al. (1994).

Algal removal in the PETRO TF and biofilm development

A principal difference between the PETRO® and conventional trickling filters is that the former receives an organic load a substantial portion of which is in a form of live algal biomass. The presence of algae in the inflowing wastewater appears to have important consequences for the TF operation (Meiring, 1992).

Five PETRO® TFs have been investigated during different seasons. The higher-rate TF in Kanyamazane (receiving 75% of total load) was compared to the lower-rate TF (25% of load). The Kanyamazane system was compared to the Letlhabile system with the higher-rate TF receiving 67% of total load and the lower-rate TF (33%). The percentage supplementation of the PETRO TF influent with primary effluent varied between the two systems with 12% supplementation at Kanyamazane and 58% in the Letlhabile system. The data are reported in Table 5.

The results show that a high supplementation rate does not correlate with specific biofilm productivity, neither does the

TABLE 4
TYPICAL PARAMETERS OF REMOVAL OF ALGAL AND OTHER COMPONENTS OF MICROBIOLOGICAL CONSORTIUM IN THE PETRO SYSTEM REPRESENTED AS CELL COUNTS

Parameter, cells.mℓ$^{-1}$	TF inflow	TF outflow	HT overflow	Overall removal, %
Chlorophyta	$3.5x10^5$	$2.3x10^4$	$9.1x10^3$	97
Euglenophyta	$4.6x10^4$	$1.9x10^3$	$2.2x10^2$	99
Protozoa total	1700	450	80	96
Protozoa with algae inside	49	280	0	100
Rotifers total	0	170	0	100
Rotifers with algae	0	20	0	100
Chlorophyll *a* (µg.ℓ$^{-1}$)	799	168	40	95

loading rate to individual filters. The results indicate higher biofilm productivity at both lower supplementation and loading rates. Compared to this parameter biofilm mass, however, does appear to be influenced by the quantity of COD loaded to the TF and the supplementation rates employed. The total biofilm mass appears to correlate with increased levels of algal biomass (chorophyll *a*) fed to the TF.

The biofilm mass in a conventional TF is known to substantially increase in winter due to temperature-induced lower levels of biological oxidation by bacteria and fungi (Hawkes, 1983). In contrast, the biofilm mass decreases in the PETRO® TF 1.6 and 2.4 times for the higher- and lower-rate Kanyamazane TF, respectively. A correlation of the decrease with a seasonal twofold drop of algal concentration in the TF inflow suggests other mechanisms controlling biofilm production.

Biofilm of the conventional TF is dominated by bacteria and/or fungi which are the major producers of the slime known to consist of exopolysaccharides (EPS) (Mack et al., 1975). EPS impart viscosity to a biofilm thus enhancing immobilisation of microbial consortium and preventing its wash-off. The role of micro-algae in this case is limited to the marginal development on the surface of the TF which is exposed to the light (Wolowski, 1989).

However, large number of algal species were shown to function heterotrophically in the dark (Neilson and Levin, 1974; Abeliovich and Weisman, 1978; Day et al.,1991; Pearson et al., 1987) and continue to produce chlorophyll (Diakoff and Scheibe, 1975). Many micro-algae were also reported to produce slime including massive quantities of EPS under both light and dark conditions (Ramus, 1980; Kroen and Rayburn, 1984). Excellent flocculating properties of the algal EPS were demonstrated (Avnimelech and Troeger, 1982).

These features of micro-algae in conjunction with the data reported strongly suggest that micro-algae may play a much more important role in the PETRO® TF compared to a conventional TF. Their active growth appears to extend below the surface of the filter. Micro-algae entrapped in the TF may contribute to the removal of volatile dissolved solids (VDS) and to an increase in volatile suspended solids (VSS) by production of EPS (Table 3) thus enhancing flocculating properties of humus sloughed off. This may determine excellent performance of the TF as a polishing stage and ensure sparkling quality of effluent (Meiring et al., 1994).

Conversion of the Elliot Sewage Works into the PETRO system

The original Elliot Sewage Works built in 1974 consisted of two relatively large oxidation ponds (2.5 and 0.9 ha) followed by the TF which was designed for the removal of algae. The TF and therefore the original system as a whole failed to perform satisfactorily due to a low level of algal removal (50 to 60%).

The conversion of the Elliot system to function as a PETRO® system in 1994 offered an opportunity to study the changes in performance parameters, biofilm production and the TF microbial consortium.

A primary pond reactor preceding the oxidation ponds was built and a supplement of primary pond water to the TF inflow provided.

Poor algal removal in the Elliot TF during the early period of the PETRO® operation was apparently due to insufficient development of a biofilm consortium (Table 5 to 6). High algal concentration in the oxidation ponds 1 month after conversion could be a consequence of increased nutrient loads since, prior to conversion, raw sewage was originally supplied to the oxidation ponds as the system did not include an anaerobic primary pond. A period of imbalanced operation followed when the primary pond was in a start-up period. The development of the TF biofilm mass increased over time and was independent of loading rate while efficiency of algal removal was directly dependent on the mass of biofilm present.

Seven months of the PETRO® operation led to a significant overall improvement in performance parameters (Table 6) and particularly in the removal of algae which has reached 79% suggesting that the algae-removing TF consortium is in a process of development. In retrospect, a poor development of the biofilm and its consortium, and as a result an inferior performance of the plant prior to conversion, appears to be due to a lack of supplementation of organic matter to the TF facilitating development of a heterotrophic microbial consortium (Meiring and Hoffmann, 1994).

TABLE 5
COMPARISON OF BIOFILM PRODUCTIVITY AT DIFFERENT SUPPLEMENTATION, COD AND ALGAL LOADING RATES (CHLOROPHYLL *A* IN THE INFLUENT) APPLIED TO THE TRICKLING FILTER OF THREE PETRO® SYSTEMS

Trickling filter	Specific loading rate[1]	Biofilm mass ($kg \cdot m^{-3}$)	Specific biofilm productivity[2]	Algal concentration[3]	VSS removal in TF+HT, %
KANYAMAZANE					
Higher-rate TF	133	1.19	9.0	599	89
Lower-rate TF	45	0.69	15.3	200	69
LETLHABILE					
Higher-rate TF	99	0.64	6.5	81	78
Lower-rate TF	25	0.12	8.4	21	-
ELLIOT					
1 month operation	148[4]	0.15	1.0	225	24
7 months operation	74	0.44	6.0	90	80

[1] - in $g\ COD \cdot m^{-3} \cdot d^{-1}$;
[2] - in g biofilm produced from 1 g of COD loaded per day;
[3] - chlorophyll *a*, in $\mu g \cdot \ell^{-1}$;
[4] - high loading rate was due to an ineffective operation of upstream ponds.

TABLE 6
PERFORMANCE OF THE ELLIOT PETRO SYSTEM 1 MONTH AND 7 MONTHS AFTER THE START-UP

Parameter, $mg \cdot \ell^{-1}$	Raw sewage	Anaerobic pond outflow	TF inflow	TF outflow	HT overflow	Overall removal,%
1 month operation						
COD	486	315	301	189	150	69
TKN	76	63	59	50	48	-
NH_3^+-N	53	29	45	41	39	-
VSS	101	89	68	48	52	42
VDS	213	184	156	120	103	44
Chlorophyll *a*, $\mu g \cdot \ell^{-1}$	-	74	451	360	383	15
7 month operation						
COD	828	293	150	102	75	90
TKN	69	58	40	19	14	80
NH_3-N	36	41	20	4	2	95
NO_3-N	<1	<1	2	29	32	-
VSS	250	91	50	62	10	96
VDS	106	113	83	30	31	71
Chlorophyll *a*, $\mu g \cdot \ell^{-1}$	-	16	180	79	38	79

TABLE 7
IMPROVEMENT OF THE FINAL EFFLUENT QUALITY IN THE NEWCASTLE TF PLANT AFTER THE CONVERSION

Parameter mg/ℓ	Prior to conversion	After the PETRO retrofit
COD (raw inflow)	514	625
COD (clarifier overflow)	56	46
COD (final effluent)	55	34
NH_4^+-N (raw inflow)	23	17
NH_4^+-N (clarifier overflow)	4	2
NH_4^+-N (final effluent)	0.6	1
NO_3^--N (raw inflow)	0.3	0.8
NO_3^--N (clarifier overflow)	22	18
NO_3^--N (final effluent)	13	16
SS (raw inflow)	300	300
SS (clarifier overflow)	10	8
SS (final effluent)	6	0

The PETRO® system is ideal for a stage-wise development and capital investment can be done accordingly. To upgrade an existing pond the system has much to offer. Where the necessary land is available, the annual cost of providing and running a PETRO® system can be appreciably less than 50 % of that of a conventional system producing an effluent of a similar quality. In instances where existing TF plants require upgrading, the potential benefits of converting them into the PETRO® linked to a pond system should be considered.

Retrofitting Newcastle TF plant

Retrofit of Ngagane Sewage Purification Works (Newcastle, KwaZulu-Natal) is a typical example of a cost-efficient upgrading of the works with a concomitant doubling of the flow. Original works operated until 1996 and received municipal sewage with an industrial component (12.5 Mℓ/d). It consisted of three anaerobic digesters preceded by two primary sedimentation tanks. In parallel settled sewage was treated by four TFs filled with furnace slag followed by three clarifiers which discharged effluent into three maturation ponds. Works had to be extended due to a flow increase up to 25 Mℓ/d. Instead of building another series of four TFs and clarifiers a PETRO® retrofit was chosen. A ponding system consisting of two primary and three secondary ponds was constructed at a cost of one new TF to tackle the bulk of organic load (>70%). Two new clarifiers were built to account for an increased hydraulic load. Another feasible option alternative to the PETRO was the construction of four TFs with four clarifiers preceded by two new digesters with two primary tanks.

Overall cost savings amounted to nearly 40% since PETRO® retrofit cost R 800 000 per 1 Mℓ extention while new TF plant would cost R 1 300 000 per 1 Mℓ. Furthermore, due to the PETRO® retrofit redundant anaerobic digesters, primary sedimentation tanks and sludge drying beds could be used to treat additional abattoir flow. Most notably apart from the fact that the system was capable of treating a double load with the same number of TFs, the retrofit also resulted in a marked increase of final effluent quality (Table 7).

Conclusions

The study reported here confirmed previous observations concerning the functioning of the PETRO® system (Meiring, 1993; Meiring and Oellermann, 1993). The system offers an efficient method of low-tech and low-cost treatment of municipal sewage which has been demonstrated in three full-scale plants for more than a decade.

The system incorporates a stage of effective removal of micro-algae from the oxidation pond water. The key element of the algae removal is the PETRO® TF. Unlike the conventional TF polishing systems, the algal biomass is now retained in the biofilm. The humus fraction produced has a high settling characteristic. It is recovered in the humus tank and a final effluent of a sparkling clarity is produced.

The results obtained suggest a much greater importance of micro-algae in the PETRO® TF compared to a conventional TF. Algal biomass appears to contribute to both biofilm production and an organic load reduction in the TF.

The operation of the system relies on the estabishment of a heterotrophic biofilm on the filter medium effected by supplementation of the TF oxidation pond feed with a nutrient- containing component of the partially treated effluent. The supply of primary pond effluent to the TF inflow is a prerequisite for development of an effective algae-removing biofilm consortium comprising algae, bacteria, fungi, protozoa and metazoa. Protozoa and rotifers grazing on algae in the TF also substantially contributes to the algal removal.

A thorough understanding of the nature of the biological phenomena involved is required in order to optimise the process and extend its field of application.

Trickling filters in general being reliable and simple in operation are classified as "appropriate" technology perfectly suitable to serve developing communities. Nevertheless designers regularly shy away because of their high initial cost. As far as capital cost is concerned the PETRO® system has brought about a dramatic change. Affordability has once again become an attractive feature. A substantial reduction of the volumetric requirements of the TF and sludge drying beds, omission of the primary sedimentation tanks and digesters significantly reduces the construction cost. Low power consumption, simplicity of operation, low manpower requirements and minimum mechanical equipment requirements facilitating phase-wise construction, result in a reduced maintenance expenditure. Overall, the PETRO® system is versatile and site-specific and can be employed in a number of flexible modes.

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