EXECUTIVE SUMMARY

Objectives

The project aimed to incorporate biological phosphorus removal into the framework of the PETRO concept. The following aspects of the PETRO system were to be investigated:

a) potential of the PETRO system to incorporate the rationale underlying biological P removal. More than 60% COD removal in the primary pond appears to be counterproductive for downstream P removal since it leaves an insufficient amount of readily biodegradable organics (RBCOD) to meet demands of phosphate accumulating organisms (PAO) in the BNR reactor;

b) full scale plant data on variations of the COD fractionation in the BNR reactor feed (pond effluent) with a view to optimizing availability of RBCOD;

c) potential of the primary pond sludge as RBCOD generator to meet requirements of PAO;

d) sludge production in the PETRO primary pond with a view to optimizing desludging strategies;

e) rationale for the primary pond fermentation pit operated as a novel *RBCOD Generating Pit* (GP) to produce ample quantities of readily biodegradable organics for downstream PAO;

f) impact of recirculation phenomena on the performance of the RBCOD Generating Pit;

g) potential role of microalgae in the P removal in the PETRO system;

Laboratory facilities were kindly offered by Prof W.A. Pretorius (Water Utilization Unit, University of Pretoria).

Research work at the Soshanguve PETRO plant was temporarily terminated. Decommissioning of the old ASP reactor, extension of the plant and lack of operational control made optimisation of aeration and biological P release impossible.

Furthermore, a costly construction of the envisaged pilot plant at Olifantsfontein (ERWAT) was avoided. In the meantime good working relations with the staff at the Newcastle and Sasolburg PETRO plants were established which enabled database collection at the full scale plants.

Towards the PETRO BNR facility

The PETRO system is an appropriate technology equally applicable in the developed and developing world (Fig. 1-2). It combines waste stabilisation ponding as a low tech primary stage and a polishing facility as a secondary stage (Meiring, 1993; Meiring et al., 1996). The system comprises two variants in which the secondary facility can be either a trickling filter (TF) or an activated sludge process (ASP) (Shipin et al., 1999 a, b). Upstream stabilization pond(s) treat up to 60% of incoming organic load. This substantially decreases the size of a

costly secondary facility. Hence the system's acronym - PETRO (Pond Enhanced TReatment and Operation).

Incorporation of biological P removal into the PETRO system is a logical development leading to a relatively low tech pond-based treatment facility. It produces final effluent, which compares favourably with the state-of-the-art high-tech BNR plants.

The process of biological P removal requires sophisticated monitoring. Generation of readily biodegradable organics, RBCOD (VFA etc.) is of critical importance for the concept of biological P removal. At the same time supply of readily biodegradable organics to the secondary activated sludge process (trickling filter) is an inherent feature of the PETRO concept. The organics generated in the primary pond boost PETRO activated sludge (TF) microflora and ensure removal of microalgae. On the other hand readily biodegradable organics cause release of phosphate by PAO in the BNR reactor. Thus production of RBCOD plays a crucial role both in the PETRO and biological P removal concepts.

Incorporation of biological P removal into the framework of the PETRO concept would result in an appropriate BNR technology retaining operational simplicity of the PETRO system and achieving a higher degree of treatment. The project sought to improve the performance of the PETRO system using these fortunate similarities of two processes.

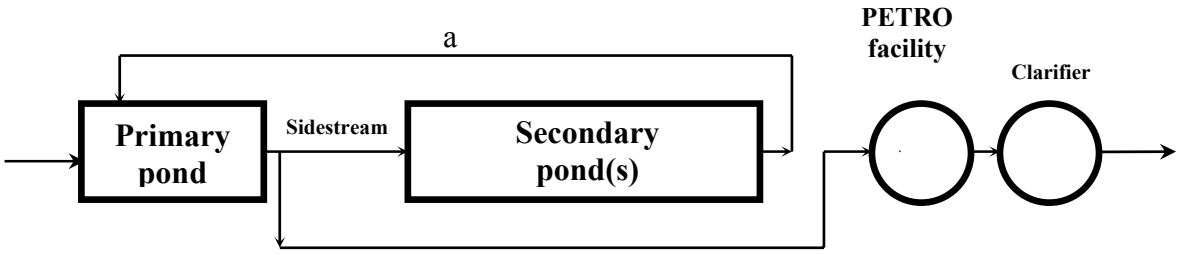

Fig. 1. Basic flow diagram of the PETRO system. a: algae-rich recycle; PETRO facility is either an activated sludge reactor or trickling filter.

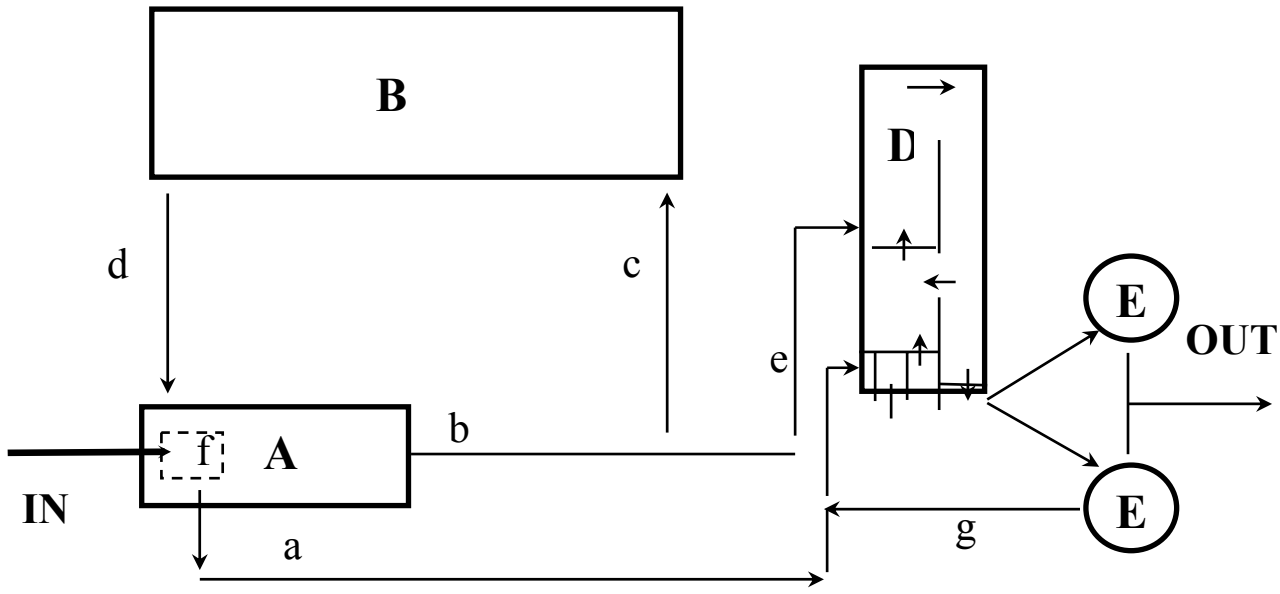

Fig. 2. Basic PETRO BNR flow diagram. A. Primary pond; B. Secondary pond (s); D. PETRO BNR facility; E. Clarifiers; a. Extraction point for BNR anaerobic zone feed; b., e. Primary pond overflow (aerobic zone feed); c. Recycle to secondary pond(s); d. Algae-rich recycle (c : e+a, recycle ratio); f. The RBCOD Generating Pit; g. RAS.

Production of readily biodegradable organics is an issue closely related to sludge production in the primary pond. In this light the desludging strategies require re-evaluation.

Microalgae originating from stabilisation ponds eventually enter the secondary PETRO facility (TF or ASP) where efficient removal of microalgal biomass occurs. Microalgae were shown to play an important role enhancing flocculation and nitrification rates in the activated sludge and trickling filter biofilm. It is known that microalgae take up a portion of phosphate into biomass and facilitate its precipitation as insoluble salts in stabilisation ponds but their role in P removal in the BNR facility downstream of ponds is not certain. This aspect is examined and discussed in relation to chemical precipitation of phosphates in activated sludge.

Overall, integration of ponds with a downstream secondary facility (TF or ASP) into the framework of the PETRO concept allows for substantial capital and operational savings. Incorporation of the biological phosphorus removal into the concept should retain operational simplicity of the PETRO system and achieve an even higher degree of treatment.

In the course of the project it was established that the RBCOD content of the effluent from the primary pond operated under the standard PETRO conditions fully meets only the requirements of the algal removal but not those of the biological P removal.

Observations made at a number of full scale plants strongly suggest that the primary pond used in a particular regime of operation is capable of the RBCOD production at the rates required for biological P removal.

Feasibility of biological P removal in the PETRO context was demonstrated full scale during several experimental periods at the Soshanguve plant. On occasions values below 1 mg.ℓ^{-1}

were attained for the inorganic P in the final effluent. However, shortage of RBCOD in the ASP reactor feed and excessive aeration were among the factors responsible for inferior P removal for more extended periods. Unfortunately it proved impossible to optimize the process at Soshanguve due to the factors over which there was no control and due to eventual decommissioning of the reactor as a part of the plant extension masterplan.

Sludge production rates in the PETRO ponds and current desludging strategies were reviewed. Sludge production rates under the conditions were found to be intermediate between those reported for acidogenic (0.257 kg VSS.kg^{-1} COD) and methanogenic reactors (0.08 kg VSS.kg^{-1} COD). A preliminary estimate obtained from the full scale primary ponds is 0.18 kg SS.kg^{-1} treated COD. The data require long-term confirmation. The RBCOD generating potential of the primary pond sludge was studied. It was found to correlate with the sludge age and sharply decrease downstream of the primary pond inlet. It continues to decrease further in the secondary ponds.

Pond stratification surveys demonstrated that the RBCOD production increases with an increase of the sludge pool in the pit and *vice versa*.

The PETRO fermentation pit was observed to feature high rate RBCOD production even at relatively long SRT (>15 days) combined with short HRT (<15 hours). Interestingly, SRT in the fermentation pit were significantly higher for the PETRO primary pond than those reported for optimal RBCOD production in acidogenic fermentors.

Recirculation of the algae-rich water from the secondary ponds to the surface of the primary pond is an inherent feature of the PETRO concept. This beneficial phenomenon, still underestimated in the world full scale practice, requires further study. Impact of the recirculation on the PETRO pond performance (particularly RBCOD production) is currently under long-term investigation.

Recirculation rate appears to be at least one of the key factors in the enhancement of the RBCOD production. The tentative data obtained suggest that the enhancement is effected through inhibition of extremely oxygen-sensitive methanogens. This offsets the balance of anaerobic digestion thereby increasing concentration of RBCOD (VFA and other readily biodegradable organics).

High rate recirculation appears to provide an opportunity to significantly increase RBCOD production in an open primary pond. Under these conditions a specific organic loading can be safely increased well beyond the value recommended for ponds without recirculation (0.6 kg COD.m^{-3}.d^{-1}).

Even a relatively low rate recycle (0.3 : 1) was shown to be an effective means to avoid a malodorous situation under conditions of high sludge content and enhanced RBCOD production in the pit. It was found permissible for the primary pond sludge to take up to at least 30% of the pond volume without any environmental consequences. Recirculation supplying oxygenated water allows for control of methanogens in the anaerobic microbial consortium. Sludge settleability in the pond appears to increase proportionally to the recycle rate, apparently as a result of a decreased floc buoyancy. Further full scale experiments are required to strengthen the rationale.

As a result of the investigation, the concept of *the RBCOD Generating Pit* located in the primary pond is being developed. It does not involve major structural changes and is based on the existing pond layout. Certain changes in the regime of operation are suggested. Generation of RBCOD in a conventional fermentation pit avoids other high-tech options (e.g. activated primaries, acidogenic fermentors etc.) which are capital cost intensive and more economical for large high-tech plants.

The concept combines a COD removal in the primary pond of up to 60% with a concomitant solubilisation of slowly biodegradable solids. It relies on the generation of RBCOD from the slowly biodegradable organic fraction of the sludge under mildly oxygen-stressed anaerobic conditions. Field observations suggest that the conditions for the enhanced RBCOD production are as follows:

- high specific organic load on the primary pond (0.21- 0.82 kg $COD.m^{-3}.d^{-1}$) and, particularly, on the pit which becomes the RBCOD Generating Pit;
- extensive pool of sludge in the pit;
- short hydraulic retention time (<15 hours);
- short sludge retention time (<15 days) may be beneficial though reasonable volatilization rates are attained even with high SRT (> 30 days);
- high rate recirculation, providing algal oxygenated water from the secondary ponds.

Under these conditions *no pond desludging* option may become feasible: enhanced sludge carryover into the ASP reactor would simplify O & M procedures.

Operational stability and effective attenuation of organic/hydraulic load peaks, which are typical of the primary pond, become features of the envisaged PETRO BNR plant.

Potential role of microalgae in the PETRO system P removal was researched. It was established in the laboratory experiments that apart from the recognized pH-dependent chemical P precipitation in the stabilisation ponds and activated sludge, the PETRO concept features another phenomenon. An *algae-mediated P precipitation* in the activated sludge reactor occurs concomitantly with the EPS-mediated algae removal. It is suggested that the phenomenon is brought about by precipitation of inorganic phosphate in the activated sludge flocs, apparently as calcium/magnesium salts. It appears that without microalgae, chemical precipitation would require much higher concentrations of Ca^{2+} and Mg^{2+}.

Suggested mechanism for the observed pH-dependent enhanced precipitation is the formation of the floc microzones with pH elevated by microalgal photosynthesis. Subsequent removal of waste activated sludge might result in an additional P removal of up to several milligrams per litre. The algae-mediated chemical process may contribute to biological PAO-mediated P removal and thus enhance the system's overall performance. Experiments on a full scale are required to elaborate on the practical importance of the phenomenon.