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FACTORS AFFECTING THE BIOLOGICAL PHOSPHORUS REMOVAL EFFICIENCY

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Abstract

This paper reviews the most important factors having effect on the efficiency of enhanced biological phosphorus removal. The influent sewage characteristics relevant to the topic are discussed. The possibilities to avoid the impairing effects of nitrates in the anaerobic zone are overviewed. The problems arising from inadequate secondary clarifier performance and sludge processing are considered. The importance of the compartmentalization and plug-flow type anaerobic reactor are pointed out.

Keywords: biological phosphorus removal, nitrate feedback; design considerations.

Introduction

Until recently, chemical precipitation of phosphorus with metal salts at the primary, secondary or tertiary stages of treatment has been the most widely applied method for removing phosphorus from wastewaters. Chemical precipitation is a reliable technology, however, it has some shortcomings, i.e., production of larger quantities of chemical sludge difficult to thicken and to dewater, 30 to 100 % additional costs as compared to conventional biological treatment, introduction of extra anions into the effluent. To overcome these problems several new wastewater treatment processes have been developed to biologically achieve an efficient P-removal. Although the basic principle of enhanced biological phosphorus removal (EBPR) is not entirely known, based on the recent advances in the understanding a large number of wastewater treatment plants accomplishing EBPR are currently being designed and operated in many countries. This technology seems to be a promising alternative of the conventional chemical precipitation in Hungary as well. The purpose of this paper is to review the most important factors affecting the efficiency of EBPR. Because a reliable, generally applicable design procedure is not available yet,in the process design is especially important to take into account the full-scale and pilot-scale experiences.

Basic Principle

Exposed to alternating aerobic and anaerobic conditions certain P-accumulating bacteria — generally termed polyP bacteria (WENTZEL et al., 1988a) — gain a positive advantage over other members of the activated sludge community and overgrow them. This advantage is conferred — as proposed by the most recent models (COMEAU, 1985; WENTZEL, 1985) — by their capability to absorb short-chain volatile fatty acids (SCVFAs) under anaerobic conditions. The consumed SCVFAs serve as carbon reserves in the form of poly-β-hydroxybutyrate and higher fatty acids for later use. The energy required for that is made available by the hydrolysis of ATP accompanied by the release of orthophosphate. Under the subsequent exposure to aerobic conditions, when the exogenous carbon sources are depleted, the stored organic matter provides the energy for growth and to restore the polyP reserves by taking up orthophosphate from the waterphase. The net result is an excess P-content in these organisms. The overall degree of P-removal is in a positive correlation with the growth of P-accumulating bacteria. Under favourable conditions these bacteria can make up about 60 % of the population, resulting in a much higher P-content (from 5 % to 35 % P/VSS, dry weight) than the normal metabolic requirements of the activated sludge (MARAIS et al., 1983; ARVIN et al., 1985; NICHOLLS et al., 1985).

The COMEAU/WENTZEL model recognizes that a number of organisms might be involved in EBPR. Accepting the experimental evidence (FUHS – CHEN, 1975) the Acinetobacter-Moraxella is considered by both models as a typical polyP organism. This is consistent with the findings of many other researchers.

Factors Affecting the Efficiency of the EBPR Process

Wastewater Characteristics

The amount of P taken up under aerobic conditions has been found to be proportional to the amount of P released under anaerobic conditions (WENTZEL et al., 1985). This depends very much on the amount and the type of the substrate available for the growth of Acinetobacter, that is on the amount of SCVFAs or readily biodegradable COD (RBCOD) from which SCVFAs can be produced as intermediate products of the acidic fermentation. From among the different types of SCVFAs the acetic acid plays a central role.

Other important sewage characteristics affecting the EBPR efficiency are the COD:TKN or COD:TP ratio. If this latter one is lower than 50 g/m^3, a complete biological P removal can hardly be achieved and simultaneous chemical precipitation is required in case of stringent effluent standards (PITMAN, 1991). Before giving particular values for the necessary COD:TKN ratio, the role of nitrates in the EBPR process has to be overviewed.

The presence of nitrates in most of the EBPR systems has a marked impairing effect on EBPR via their influencing the availability of SCVFAs for Acinetobacter. According to the current understanding nitrates can act in at least two different ways:

- Inhibiting the production of SCVFAs due to the high redox-potential characteristic of the anoxic environment (RENSINK, 1991).
- Causing substrate competition between the facultative bacteria using nitrates as electron acceptor and the Acinetobacter (WENTZEL et al., 1985; SPATZIERER et al.,1989). As the uptake of SCVFAs by the denitrifiers is faster than by the Acinetobacter, only that fraction of the SCVFAs is available for P-removal which remains after the substrate demand of the denitrifiers has been satisfied (LOOSDRECHT, 1991; RENSINK, 1991;).

If the nitrate inhibition can be experienced as a long term effect (10 –15 days) then it can be safely attributed to the substrate competition (LOOSDRECHT, 1991).

In the following three different approaches for avoiding the unfavourable effects of nitrates are described.

The first approach is the simplest one. When the incoming wastewater contains a high amount of RBCOD or SCVFAs (greater than 100 g/m^3) no special care in the process design is required with regard to nitrate inhibition (PITMAN, 1991). The high concentration of these sewage components ensures that enough substrate is available and for the denitrifiers, both for the Acinetobacter. Provided that the other process parameters and operation conditions are appropriate, an efficient denitrification and EBPR can be achieved (NICHOLLS, 1985). There are two sources of the high RBCOD or SCVFA content:

- due to the long travelling time in the sewerage system, the sewage becomes septic;
- due to a considerable portion of industrial sewage containing high concentration of RBCOD or SCVFAs (e.g., dairy factories, slaughterhouses).

The other two approaches come into the picture when the RBCOD or SCVFA content of the sewage is lower than 50 g/m^3. In this case — depending on the COD:TKN or COD:TP ratio — special care must be taken during the process design (PITMAN, 1991). Either

- the nitrate feedback into the anaerobic reactor has to be minimized by using an appropriate process configuration, or
- the incoming sewage quality has to be altered to make it suitable for EBPR.

According to the UCT (University Cape Town) mathematical model (WENTZEL et al., 1988b) the 3-stage Phoredox/Bardenpho process(which is the simplest process configuration for EBPR) is applicable only when the COD:TKN ratio is higher than 14:1. Below this value this process is not capable of removing nitrates to the extent that anaerobic conditions could be maintained in the first reactor.

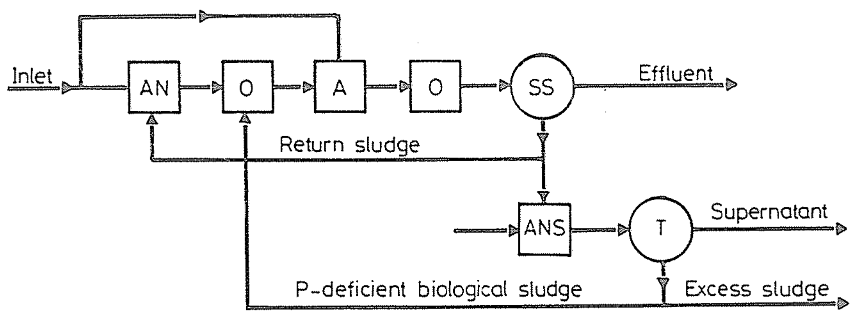

Fig. 1. Sematic of the RENPHO process

When this is the case (which often happens, especially when primary sedimentation is incorporated into the process train), the nitrate feedback has to be prevented. This can be accomplished either

- by incorporation of an additional anoxic zone (e.g., 5-stage Bardenpho process, Renpho process (*Fig. 1*)), in order to have full denitrification, or
- by incorporation of an additional internal recycle (e.g., UCT process (*Fig. 2*)) to decrease the nitrate content of the RAS.

By using the latter solution for instance, a low effluent P concentration can be achieved with a COD:TKN ratio as low as 7.5:1. The simulation results of the model are consistent with the findings of other researchers (DAIGGER et al., 1988). It has to be mentioned that the performance

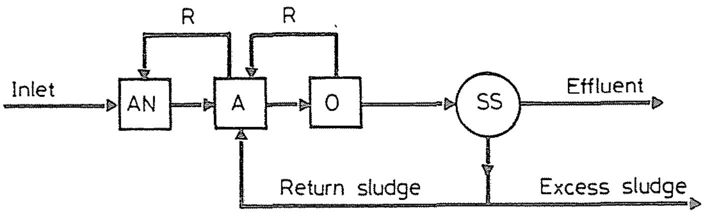

Fig. 2. Sematic of the UCT process

of several full-scale Bardenpho-type EBPR plantsare at variance with the predictions of the UCT model (BARNARD, 1984; BARNARD et al., 1985; HUYSSTEEN et al., 1990). The possible explanation for this anomaly brings us to the third option of handling the nitrate problem.

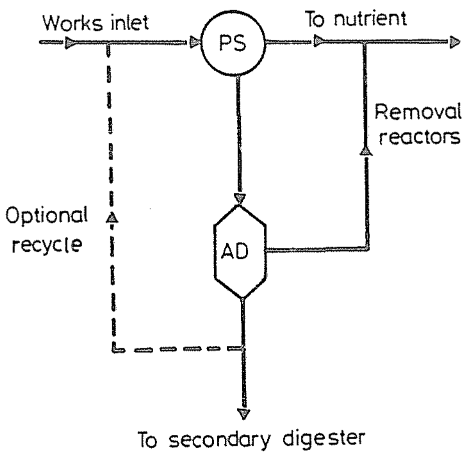

Fig. 3. High rate acid digestion

There are several possibilities the make to incoming sewage more suitable for EBPR via increasing the SCVFA content:

- High rate acid digester supernatant liquor can be added to the EBPR process (*Fig. 3*)(PITMAN, 1991).
- Primary sedimentation tanks can be used for acid fermentation (BARNARD, 1984; RABINOWITZ, 1990). To achieve this, a sludge retention time of 2–6 days has to be provided. In order to avoid the conversion of the SCVFAs to methane a comprehensive control of the sludge retention time seems to be necessary. The

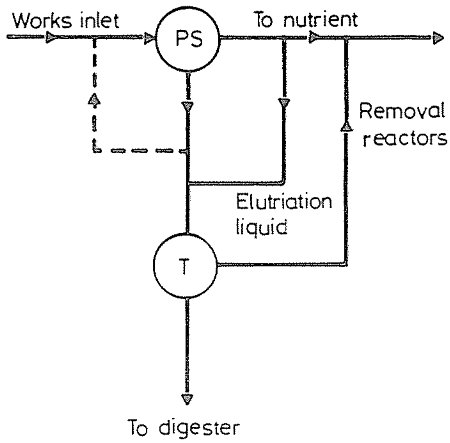

Fig. 4. Primary sludge accumulation and elutriation thickening

generated SCVFAs can be added directly to the anaerobic reactor or by elutriation out of the sludge. The elutriation can be carried out either by recirculating the sludge to the sewage inlet, or by using elutriation thickeners. These are raw sludge gravity thickeners with elutriation facilities (*Fig. 4*) (PITMAN, 1991). In a pilot-scale experiment RABINOWITZ et al. (1990) compared two UCT systems, one of which had primary sludge fermentation. They have found that over a course of one year, the process having primary fermentation removed approximately 50 % more P than the control process.

Sludge Loading/Sludge Age

There is a direct relationship between the sludge loading rate and the phosphorus removal efficiency: systems with higher sludge loading have a higher P-removal performance. There are two main reasons for this:

- At higher sludge loading the process produces more sludge as compared to the process operated at lower sludge load. As a consequence the amount of P which can be removed via the waste activated sludge is bigger.
- The P content based on dry solid weight is higher at higher sludge loading (RENSINK, 1985). This might be explained partly

by the higher degree of mineralisation and nitrification (with its adverse effect on phosphorus removal).

The full-scale experiences at the wastewater treatment plants of West-Berlin fully support this (BOLL et al., 1989).

Hydraulic Retention Time (HRT)

From experiments and full-scale experiences it seems that it is the aerobic zone where the HRT significantly affects the EBPR process: it can have an adverse effect above a critical value. This upper value depends on the specific system and operating conditions (DAIGGER et al., 1988; FUKASE et al. 1985). One possible explanation is for this that exceeding the upper limit (overaeration) causes P-release, to provide energy, when extracellular energy sources become depleted (VAN GROENESTIJN, 1991).

Secondary Clarifier Performance

The secondary clarifier performance can decrease the efficiency of P-removal in two ways:

- High concentration of suspended solids in the clarifier effluent (even when assuming only 5 % phosphorus content on dry solid base) results at high effluent total phosphorus concentration.
- At long sludge detention time in the secondary clarifier, especially in the case of high-loaded non-nitrifying systems, a release of P happens, increasing the amount of dissolved P concentration in the effluent. A sludge detention time not longer than 1 hour is proposed (SCHONBERGER, 1990).

Sludge Processing

Sludge processing and disposal techniques are both critical in terms of EBPR. P-rich gravity thickener and anaerobic digester supernatant when recycling back to the first step of the treatment process have an adverse effect on the P-removal efficiency (TRACY et al. 1985; Report EPS, 1986; BUNING, 1991). To avoid this sludge treatment process has to be changed (e.g., using air flotation instead of gravity thickening and/or using mixed digesters) or the supernatant has to be treated chemically to precipitate phosphorus prior to recycle. Increasing the feed sewage SCVFA content by one of the means described previously can provide a solution too.

Composition of the Microorganisms in the Activated Sludge

The conditions promoting the growth of Acinetobacter and other phosphorus removing bacteria can encourage the growth of filamentous bacteria like Microthrix (STREICHAN et al., 1990; HUYSSTEEN et al., 1990) causing sludge bulking. By having a plug flow system or a plug flow selector instead of completely mixed anaerobic zone, the growth of filamentous bacteria can be suppressed (PITMAN, 1991).

Compartmentalization

Based on the experiences it seems that those Bardenpho or A/O type plants, which have highly compartmentalized anaerobic and anoxic basins in general show better P-removal efficiency (Report EPS, 1986). Compartmentalization results in higher operational flexibility: it makes possible to optimize the process by varying the volumes of the anaerobic, anoxic and aerobic basins. Another factor might be that a better isolation of the process can be achieved that way.

Conclusions

In order to achieve good biological P-removal efficiency the following aspects have to be considered during the design procedure:

- Exclusion of nitrates from the anaerobic zone and/or providing source of readily biodegradable carbon or short-chain volatile fatty acids to make the influent sewage more suitable for enhanced biological P-removal.
- Eliminatiom of P-rich sludge processing recycle side-stream.
- Providing adequate secondary clarifier performance.
- Providing flexibility in basin environment by high degree of compartmentalization.
- Having plug-flow system instead of having completely mixed anaerobic reactors.
- Providing the possibility of additional chemical treatment when the feed sewage has low COD:TP ratio.

Abbreviations to the figures:

AN	Anaerobic basin
A	Anoxic basin
O	Aerobic basin
ANS	Anaerobic stripper

PS	Primary sedimentation tank
SS	Secondary sedimentation tank
T	Thickener
AD	Acid digester

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