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Project Summary

Emerging Technology Assessment of PhoStrip, A/O, and Bardenpho Processes for Biological Phosphorus Removal

This technology assessment addresses the process capabilities and limitations of three proprietary processes (PhoStrip,* A/O, and Bardenpho) to biologically remove phosphorus from municipal wastewaters. These processes are used as alternatives to the conventional method of treatment: activated sludge with chemicals added to precipitate phosphorus. The primary objective of this report is to provide guidance to individuals involved with reviewing new processes as part of the Innovative and Alternative Technology Program.

PhoStrip, A/O, and Bardenpho processes, all developed in the early 1970's, are based on the ability of the biological system to provide enhanced or so called "luxury" uptake involving the mechanism of phosphorus release by microorganisms under anaerobic conditions, followed by cellular phosphorus uptake under aerobic conditions. These three systems differ with respect to their specific process design and to their ability to provide phosphorus removal, as well as various degrees of nitrogen removal. The PhoStrip process employs sidestream (i.e., a portion of the return sludge) treatment in an anaerobic contact tank; biologically bound phosphorus is released to the aqueous medium, and the supernatant liquor is treated with lime to precipitate inorganic phosphorus as calcium hydroxyapatite. Both the A/O and Bardenpho processes involve mainstream (influent flow plus sludge recycle) anaerobic treatment to precondition the system for phosphorus removal via waste activated sludge.

The A/O process can be designed for phosphorus removal without nitrification by using anaerobic/oxic stages, or for phosphorus removal with nitrification by using anaerobic/anoxic/oxic stages plus additional internal, mixed-liquor recycle from the oxic to the anoxic stage. The Bardenpho system is a five-stage (anaerobic/anoxic/aeration/anoxic/reaeration) process designed to provide both phosphorus and total nitrogen removal.

The development status of these processes (including a list of pilot studies and full-scale installations), process theory, capabilities, and design considerations are addressed in this report.

Capital, operation and maintenance, and total present worth costs for these three processes, as well as for baseline technology of conventional processes, are estimated based on stated assumptions to compare these alternatives.

This Project Summary was developed by EPA's Water Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Since the early 1970's, chemical precipitation with either alum, ferric chloride, or lime has been widely used as a demonstrated technology for phosphorus removal. Where possible, steel mill waste pickle liquor has provided a relatively inexpensive chemical source for phosphorus precipitation, although it may also contain other undesirable heavy metals. The disadvantages of chemical precipitation to remove phosphorus are chemical costs, chemical handling and storage

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

requirements, increased sludge production, and related sludge handling and disposal costs.

Before the present application of systems specifically designed to remove phosphorus biologically, a series of studies and full-scale plant observations on this removal had been reported. These studies led to intensive studies on possibly applying this phenomenon to remove phosphorus in activated sludge plants. All the plants successfully removing phosphorus were high-rate, non-nitrifying, plug-flow-type activated sludge plants. By the early 1970's three proprietary processes to biologically remove phosphorus had been developed:

1. PhoStrip, developed by Levin et al., and marketed in the United States by Biospherics, Inc (4928 Wyaconda Road, Rockville, MD 20852, Telephone: 301-770-7700),
2. A/O, developed by Air Products & Chemicals, Inc., and marketed here by the Environmental Products Department of Air Products & Chemicals, Inc. (Box 538, Allen town, PA 18105, Telephone 215-481-4911); and
3. Bardenpho, developed by Barnard of South Africa, and marketed in the United States by EIMCO Process Machinery Division of Envirotech Corp. (669 West Second South, P O. Box 300, Salt Lake City, UT 84110, Telephone 801-526-2000)

Technology Descriptions

PhoStrip Process

The PhoStrip process is an activated sludge process that takes advantage of "luxury" phosphorus uptake and anaerobic phosphorus release. This process differs from conventional activated sludge in that a portion of the return sludge is subjected to "phosphorus stripping" by holding the sludge under anaerobic conditions in a stripper tank. The solids retention time (SRT) in this tank typically ranges from 8 to 12 hours. During this anaerobic period, phosphorus is released and is elutriated from the sludge in the stripper tank with a stream that is low in phosphorus content This stream may either be the overflow from the chemical treatment tank (reactor clarifier), as is shown in Figure 1, or be the primary effluent. The phosphorus-rich overflow from the stripper tank passes continuously to the chemical treatment tank where lime is added for phosphorus precipitation.

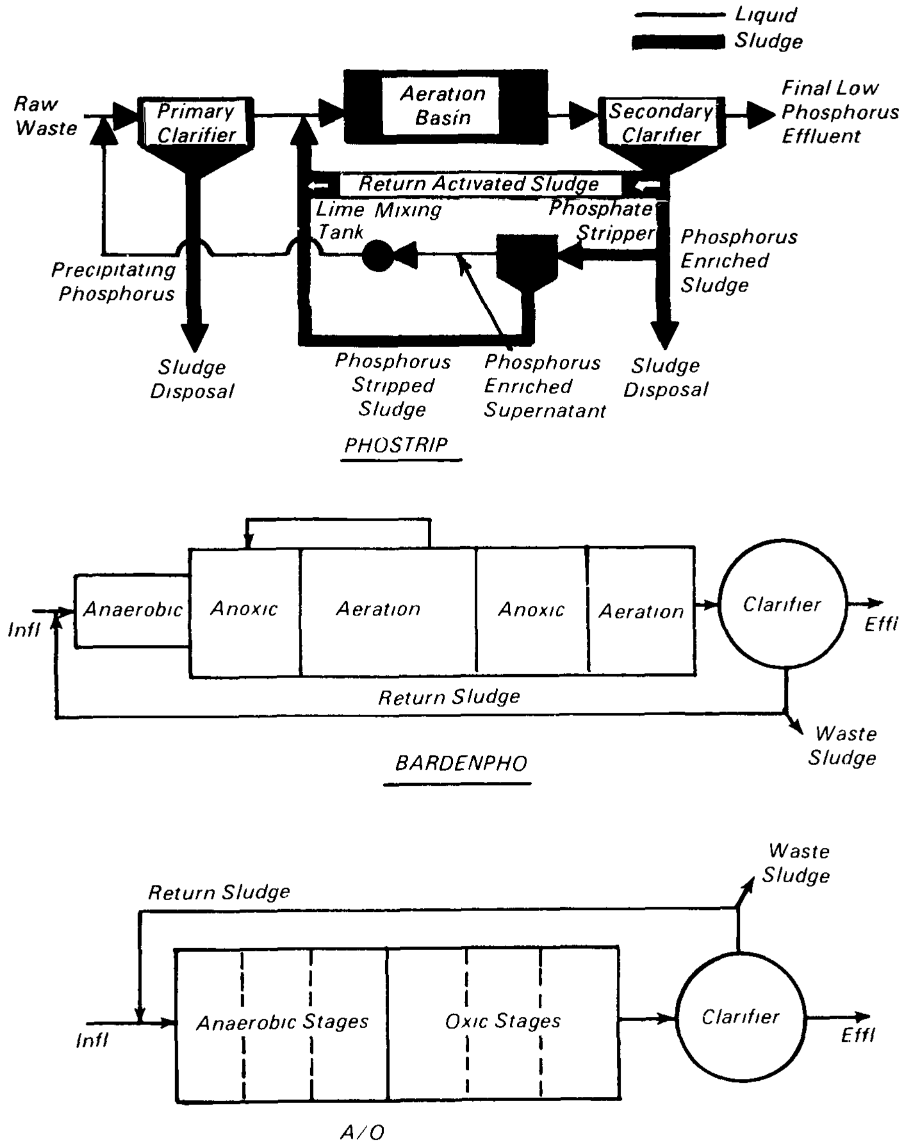

Figure 1. Phosphorus removal by three biological systems

A/O Process (Anaerobic/Oxic)

The A/O process is a single-sludge suspended growth system that can combine anaerobic, anoxic, and aerobic sections in sequence (Figure 1). The process can be designed for phosphorus removal with or without nitrification and denitrification. All sections are partitioned into several hydraulic stages to approach plug-flow and to prevent back-mixing. Typically, for removal of phosphorus, three anaerobic stages are followed by three or more aerobic or oxic stages. Recycled sludge from the secondary clarifier is mixed with either raw wastewater or primary effluent in the anaerobic section so that there is "sorption" of BOD by the organisms, with the accompanying phosphorus release necessary for biological removal of phosphorus. The anaerobic section is covered and equipped with mechanical mixers for mixing but not for aeration.

The oxic stage, essential for the metabolism of BOD and uptake of the phosphorus released in the anaerobic stage, may be aerated with either air or oxygen. Phosphorus is removed from the system in the waste sludge, which may contain 4- to 6-percent phosphorus by dry weight. Effluent phosphorus concentrations depend on sludge wasting, which in turn is controlled by the plant's operating SRT.

Bardenpho Process

Bardenpho stands for *Bar*nard-*den*itrification-*pho*sphorus, an activated sludge process designed to accomplish both biological uptake of phosphorus and nitrogen removal. The process is patented by the South African Inventions Development Corporation and licensed to Envirotech Corporation for marketing in the United States. The Bardenpho process is very similar to the previously described A/O process: anaerobic/anoxic/aerobic/anoxic/reaeration stages versus A/O's anaerobic/anoxic/oxic.

As shown in Figure 1, two anoxic stages are used to accomplish high levels of biological nitrogen removal by denitrification An anaerobic stage is added ahead of the original four-stage Bardenpho nitrogen removal system to create anaerobic-aerobic contacting conditions necessary for biological uptake of phosphorus. Return activated sludge, separated from the clarifier, is mixed with the influent wastewater before the anaerobic contactor; this initiates the luxury phosphorus uptake by first releasing phosphate. Mixed liquor from the anaerobic contactor then flows into the first anoxic denitrification zone where it is mixed with an internally recycled mixed liquor from the aerobic nitrification zone. In the first anoxic denitrification zone, nitrate is reduced to nitrogen gas using soluble organic matter in the wastewater as a carbon source. The mixed liquor then flows into the aerobic nitrification zone where luxury phosphorus uptake, ammonia oxidation, and additional BOD removal occurs. Following the aerobic nitrification zone, a second anoxic zone provides additional nitrate and minimize nitrate feed-back to the anaerobic contactor. The reaeration zone provides oxidation of remaining ammonia and raises dissolved oxygen levels for effluent discharge.

Process Capability and Limitations

All three proprietary processes have been demonstrated as capable of removing phosphorus from the 4- to 12-mg/L range normally found in municipal wastewaters down to the 1- to 2-mg/L ranges as total phosphorus (TP). It is important to consider effluent limitations in each specific case to determine the applicability of each of these processes. For example, the Great Lakes and Florida-Tampa Bay regions call for effluent limitations of 1 mg/L as TP, and some areas in South Africa have a standard of less than 1 mg/L of orthophosphate (O-PO_4) as P. Since these processes are often "marginal" in producing effluent quality of less than 1 to 2 mg/L as TP, or 1 mg/L as PO_4-P, other provisions, such as supplemental mineral addition to precipitate residual phosphorus and/or effluent filters, may be necessary unless the reliability of the selected process is demonstrated by treatability tests or pilot-plant data for a specific case.

Since PhoStrip, A/O, and Bardenpho are proprietary processes, typical design parameters and other considerations important to each should be sought when designing a specific biological system to remove phosphorus.

Cost Comparison

In the report, seven tables and eight figures provide estimated capital costs, operations and maintenance, total present worth for 1,890 m^3/d (0.5 mgd), 18,920 m^3/d (5 mgd), and 189,200 m^3 (50 mgd) systems. Estimates of the energy requirements for each system are also provided.

Risk Assessment

All three proprietary processes have been reasonably well developed. Generally, they are capable of providing 1 to 2 mg/L of residual phosphorus. Therefore, the risk involved in using any of these processes is not in its complete failure, but in its capability to meet a specific set of effluent limitations. From available data presented in Tables 1, 2, and 3 of the project report, it can be seen that these processes can, at times, marginally meet the total phosphorus concentrations of 1 to 2 mg/L. Conducting pilot tests to obtain data for application in a specific case, before design, can minimize such risk.

Providing additional facilities treatment, such as the use of effluent filters and supplemental mineral addition, will further reduce the risk of not meeting the effluent requirements. Such a provision would, however, reduce the cost-savings benefit that can be gained from the use of these alternative processes.

Comments from the three U.S. marketing firms are attached in the appendix to permit the user to identify specific supplier disagreements with the report and to pursue those issues with those suppliers when considering system(s) application.

Recommendations

All three proprietary processes for biological removal of phosphorus are based on the mechanisms that uses anaerobic treatment to pre-condition the microorganisms for subsequent enhanced uptake of phosphorus under aerobic conditions. Although significant data and experience have been obtained to substantiate the validity of the fundamental concept, numerous complex factors affecting the performance of the three different systems are not yet fully understood. Some of the more important aspects of research needs are:

- Basic studies involving organisms selection, physiological states, survival, and the direct impact of the anaerobic zone must be conducted before biologically removing phosphorus can be understood fully.
- Current design of the anaerobic section in each of the three proprietary processes appears to be empirical, and there is a lack of rational basis for sizing the anaerobic stage.
- The three processes are capable of producing effluent TP of less than 2 mg/L; however, effluent TP concentrations of 1 to 2 mg/L appear in the marginal area that can hardly be predicted with certainty. The TP consists of soluble phosphorus as well as phosphorus associated with the suspended solids form. The soluble phosphorus in the effluent is related to the performance of the process employed, whereas the phosphorus in the solids form is related to the settling characteristics of sludge maintained in the system. Further research is necessary to develop a better basis for predicting effluent quality under various operating conditions and wastewater characteristics.

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This Project Summary was prepared by staff of Weston, Inc., West Chester, PA 19380.
***E. F. Barth** was the EPA Project Officer (see below for present contact).*
The complete report, entitled "Emerging Technology Assessment of PhoStrip, A/O, and Bardenpho Processes for Biological Phosphorus Removal," (Order No. PB 85-165 744/AS; Cost: $13.00, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
*The EPA contact is **James F. Kreissl** and can be contacted at:*
Water Engineering Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

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