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Biological Nutrient Removal in a Pilot-Scale Fixed-Suspended Growth System

A.J. Gibb¹, M.F. Crowe¹, H.G. Kelly², W.K. Oldham³, and F.A. Koch³

Abstract

A pilot-scale project was developed to extend and refine the design criteria for biological phosphorus removal and nitrification-denitrification in a combined fixed and suspended growth (coupled trickling filter-activated sludge) wastewater treatment system. Preliminary results confirm that the process is effective in removing both ammonia and phosphorus from domestic wastewater, without the use of chemicals. Initial results suggest that the total nominal hydraulic retention time for the suspended growth component can be reduced to as little as five hours, without compromising effluent quality.

Introduction and Background

Current technology for biological phosphorus (bio-P) removal is generally based on the (suspended growth) diffused air activated sludge process. Oxidation of ammonia (NH_3) to nitrate and nitrite (NO_x) through biological nitrification is carried out in both suspended growth (activated sludge) and fixed growth (e.g., trickling filter) systems. Reduction of NO_x to gaseous forms of nitrogen through biological denitrification is generally accomplished in suspended growth systems.

This project is designed to further develop a process which incorporates both fixed and suspended growth components for bio-P and nitrogen removal. The

¹ British Columbia Research Corp., 3650 Wesbrook Mall, Vancouver, B.C., Canada, V6S 2L2

² M.ASCE, Dayton & Knight Ltd., P.O. Box 91247, West Vancouver, B.C., Canada V7V 3N9

³ University of B.C. Dept. of Civil Eng., 2324 Main Mall, Vancouver, B.C., Canada, V6T 1W5

combined system includes two fixed growth reactors (FGRs), commonly referred to as trickling filters, in series with three suspended growth reactors (SGRs), commonly referred to as activated sludge basins. The system, termed the FGR-SGR process, was developed from known principals for bio-P removal in activated sludge systems, and for oxidation of biochemical oxygen demand (BOD) and nitrification in trickling filter systems, as described by Kelly (1987).

The engineering significance of the FGR-SGR process includes the following: 1) existing FGR (trickling filter) plants can be retro-fitted for bio-P removal, with maximum use of existing facilities; 2) energy costs for aeration are lower for FGR systems than for diffused air activated sludge systems; 3) process stability is improved by the addition of fixed growth biomass to activated sludge systems; and 4) the long hydraulic retention times (HRTs) and solids retention times (SRTs) required for nitrification in activated sludge systems are eliminated (Kelly, 1987).

Feasibility studies carried out during 1988-1989 at a full-scale FGR-SGR wastewater treatment plant in the town of Salmon Arm, British Columbia, Canada, showed that the process has the capacity for effective bio-P removal. Biological removal of phosphorus from the process influent over an eight month study period averaged approximately 7 mg P/L. The dried process suspended solids consistently contained 4-5% phosphorus by weight during this period (Kelly and Gibb, 1989 and Gibb et. al., 1989). However, the difficulties associated with full-scale research, such as the inability to control influent flow rates and reactor HRTs, fluctuating environmental conditions, and the need to meet permit requirements, prevented development of detailed criteria required for the next generation of design. Further, the full-scale study did not include nitrogen removal, although the plant at Salmon Arm includes a fixed growth component for nitrification.

The current study is being undertaken at pilot scale to allow control of process flow rates and reactor HRTs. In addition, this study includes an investigation of nitrification-denitrification in the FGR-SGR process. Design of the pilot-scale process was developed from the design of the full-scale facility at Salmon Arm.

Description of the Pilot-Scale Facility

The FGR-SGR pilot plant is designed to treat domestic wastewater in two parallel, identical process trains. A process schematic is shown in Figure 1. Each process train includes two FGRs and a primary and secondary clarifier, as well as complete-mix tankage for fermentation of primary solids and treatment of the process mixed liquor under anaerobic (neither oxygen or NO_x present), anoxic (NO_x but no oxygen present), and aerobic conditions. The fermentation, anaerobic, anoxic, and reaeration reactors in each train are

Biological uptake and storage of phosphorus, nitrification, and further BOD removal are achieved by irrigating the mixed liquor from the anoxic reactor over two trickling filters operating in series (FGR 1 and FGR 2 in Figure 1). Oxygen for phosphorus uptake by suspended organisms is provided by cascade aeration; the aeration rate can be increased by increasing the FGR irrigation rate. Nitrification occurs through the action of fixed growth organisms attached to the FGR media. The relatively long HRT and suspended growth SRT required for nitrification in activated sludge systems are therefore unnecessary in the FGR-SGR system.

Mixed liquor is pumped from the FGR effluent sump to the reaeration reactor, where flocculation of sloughed FGR solids and removal of residual phosphorus, NH_3 , and BOD by suspended bacteria occurs. Mixed liquor from the reaeration reactor flows to the final clarifier, where the clarified effluent is discharged to sewer, and settled biological solids are returned to the anoxic reactor.

Study Objectives

The purpose of this study is to further develop design and operational criteria for bio-P removal and nitrification-denitrification in the FGR-SGR process under controlled conditions. The study objectives are as follows: 1) investigate the optimum HRTs in the SGR component; 2) investigate the optimum internal recycle flow rates in both the FGR and SGR components; 3) investigate the optimum SRT in the SGR component; and 4) compare the nutrient removal effectiveness of the FGR-SGR process with that of an existing pilot-scale UCT system treating a common waste stream.

Study Design

Parallel operation of the two pilot-scale FGR-SGR process trains treating a common waste stream will allow valid comparisons between different design and operational modes. During plant start-up and stabilization, both trains were operated according to the parameters summarized in Table 1.

Optimization of system design and operating parameters will be carried out using an iterative approach, with one process train serving as the control side, and the other as the experimental side. In order to produce maximum bio-P removal and nitrification, the sizes of the anaerobic, anoxic, and reaeration basins will be reduced or expanded as necessary, and internal recycle rates (denitrified mixed liquor recycle, return settled biosolids, and FGR irrigation rates) will be increased or decreased. In addition, the effects of increasing and decreasing the SRT in the SGR component will be investigated.

Table 1 - Initial Design and Operating Parameters

Plant Influent (Q) = 4.8 L/min		Fermenter Feed = 0.2Q			
Denitrified Recycle = Q		FGR 1 Recycle = 5Q			
Return Settled Biosolids = Q		FGR 2 Recycle = 5Q			
Reactor	Fermenter	Anaerobic	Anoxic	FGR Sumps	Reaeration
Volume (L)	790	630	1260	580	940
Nominal HRT (hr) ¹	14	2.2	4.4	2	3.3
Actual HRT (hr) ²	14	0.7	1.1	1.0	1.6

¹ Reactor Volume/Q

² Reactor Volume/(Q + Recycle Flows) - see Figure 1

Throughout the study period (approximately 2 years), process performance will be monitored through the analysis of 24-hour composite samples of process influent and effluent for BOD₅, NH₃, NO_x, total kjeldahl nitrogen (TKN), total phosphorus, orthophosphate (PO₄³⁻), and total suspended solids (TSS). Mass balances on unit operations within the process (e.g., PO₄³⁻ release and uptake rates, soluble carbon removal rates, and nitrification and denitrification rates) are also being carried out. The percent phosphorus by weight in the dried process suspended solids is being monitored, to assess the degree of phosphorus storage by the process biomass. Sampling and analysis of the above parameters is conducted twice weekly. On-line monitoring of dissolved oxygen concentration, oxidation reduction potential, and pH is also carried out at appropriate points in the process trains.

In addition to monitoring pilot-scale process performance, bench-scale batch tests designed to simulate the performance of the anaerobic, anoxic, and reaeration reactors are periodically conducted. Grab samples of the flows influent to the anaerobic reactor are obtained from the process, and are mixed together in a 2.8 L batch reactor, in amounts relative to the actual flow rates in the process. The batch reactor is kept under fully mixed, anaerobic conditions for a duration which matches the actual HRT of the process anaerobic reactor. Samples are withdrawn at regular intervals and analyzed for the appropriate parameters. Similarly, the anoxic and reaeration reactors are sequentially simulated in the batch reactor. Due to practical difficulties, FGR performance cannot be simulated in bench-scale batch tests.

Preliminary Results

The pilot plant has been in continuous operation since late August, 1992. Process performance stabilized approximately four months after start-up. Preliminary operating data for both trains during early January, 1993, through early February, 1993, are summarized in Table 2. The data indicate that both process trains are currently achieving effective removal of phosphorus, TKN, NH₃, TSS, and BOD₅, and that the process suspended solids are significantly enriched in phosphorus (approximately 4% phosphorus by dry weight).

Table 2 - Summary of Pilot Plant Preliminary Performance

Parameter	Number of Samples	Mean Concentration (Range)			
		Primary Clarifier Overflow		Final Effluent	
		A Side	B Side	A Side	B Side
Phosphorus (mg P/L)	7	3.31 (2.7-3.8)	3.39 (3.0-3.8)	0.40 ^a (0.06-0.66)	0.30 ^a (0.07-0.76)
Total Kjeldahl Nitrogen (mg N/L)	9	20.1 (16.6-26.1)	20.2 (16.8-25.8)	3.3 (1.5-6.5)	3.3 (1.4-7.5)
Ammonia (mg N/L)	9	14.0 (9.8-24.4)	13.4 (9.3-25.4)	0.40 ^a (<0.01-4.5)	0.91 ^a (<0.01-5.0)
Total Suspended Solids (mg/L)	8	60 (51-68)	76 (64-85)	17 (10-31)	16 (11-29)
Five Day BOD (mg/L)	4	96 (77-115)	105 (100-114)	11 ^a (6-18)	10 ^a (5-14)

Percent Phosphorus by Weight in Dried Process Suspended Solids	9	Mean % Phosphorus (Range)	
		A Side	B Side
		4.2 (3.5-4.7)	3.9 (3.5-4.3)

^a Filtered Sample

The results of a batch test simulation of the SGR train conducted in early February, 1993, are shown in Figure 2 (this pattern has been reproduced for both process trains in the current operational mode). During the first 20 minutes of the anaerobic phase, a sharp increase in PO_4^{3-} concentration was observed, together with the removal of simple carbon substrates (measured as total volatile fatty acids) from solution. After removal of the volatile fatty acids (VFAs), the rate of PO_4^{3-} release slowed considerably. The batch test results suggest that the actual HRT in the anaerobic reactor could be reduced to as little as 20 minutes, with minimal effect on the degree of PO_4^{3-} release-VFA uptake.

During the initial 20 minutes of the anoxic phase of the batch test, NO_x introduced with the return biological sludge was eliminated from solution, with coincident PO_4^{3-} uptake (Figure 2). As soon as NO_x was removed, PO_4^{3-} release resumed at a similar rate to that observed during the latter 25 minutes of the anaerobic phase. It therefore appears that the process actual anoxic HRT could be reduced to as little as 20 minutes, without affecting the degree of denitrification. Further, reducing the anoxic HRT should suppress P release, thereby lowering the PO_4^{3-} loading to the aerated phase. Alternatively, nitrified mixed liquor could be returned from the reaeration reactor to the anoxic reactor, to increase the degree of denitrification- PO_4^{3-} uptake under anoxic conditions.

During the aerated phase, virtually all PO_4^{3-} was removed from solution within the first 80 minutes (Figure 2). If PO_4^{3-} release in the anoxic phase were

suppressed, the required aeration time for PO_4^{3-} removal might be less than 80 minutes. Production of NO_x under aerated conditions also ceased after 80 minutes (Figure 2), probably due to the oxidation of all available NH_3 . Nitrifying organisms are present in the mixed liquor by virtue of both sloughing of fixed growth from the FGRs and growth of suspended organisms in the reaeration reactor. In the pilot-scale process, some PO_4^{3-} uptake and almost all nitrification occurs in the FGRs. Filtered PO_4^{3-} and NH_3 concentrations in the mixed liquor leaving FGR Cell 2 are generally in the range 2-5 mg P/L, and less than 1 mg N/L, respectively.

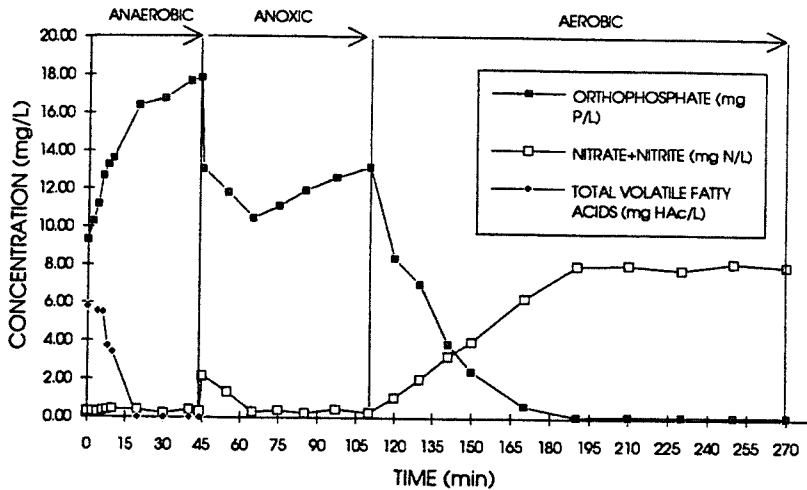


Figure 2 - Batch Test Simulation of SGR Train

Conclusions

Preliminary results have confirmed the phosphorus removal capabilities of the FGR-SGR process first demonstrated at the full-scale plant at Salmon Arm. It is expected that work completed during this study will yield useful information to be used in developing predictive models for design purposes, aimed at optimizing biological phosphorus and nitrogen removal in the FGR-SGR process.

The results of bench-scale batch tests suggest that the total nominal HRT for the SGR component (i.e. the total suspended growth process volume divided by the plant influent flow rate) might be reduced to as little as five hours for the current conditions, without compromising either bio-P removal or nitrification.

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References

- Comeau, Y., W.K. Oldham and K.J. Hall (1987), "Dynamics of Carbon Reserves in Biological Dephosphatation of Wastewater," Proc. IAWPRC Specialized Conference, Rome, Italy, 1987, pp 39-55.
- Gibb, A.J., H.G. Kelly, F.A. Koch and W.K. Oldham (1989), "A Full-Scale Evaluation of Biological Phosphorus Removal Using a Fixed and Suspended Growth Combination," Proc. 12th Int. Symp. on Wastewater Treatment, Montreal, Canada, Nov. 20-21, 1989, pp 185-204.
- Kelly, H.G. (1987), "Bio-P Treatment Using a Fixed and Suspended Growth Combination: A First Year Appraisal," Proc. EE Div./ASCE, Orlando, Florida, July 3-6, 1987, pp79-91.
- Kelly, H.K. and A.J. Gibb (1989), "Biological Phosphorus Treatment Using a Fixed and Suspended Growth Combination," Proc. Specialty Conf./EE Div./ASCE, Austin, Texas., July 10-12, 1989, pp 453-456.
- Rabinowitz, B. and W.K. Oldham (1985), "The Use of Primary Sludge Fermentation in the Enhanced Biological Phosphorus Removal Process," Proc. Int. Conf: New Directions and Research in Waste Treatment and Residuals Management, June 23-28, 1985, University of British Columbia, Vancouver, Canada, pp 347-363.
- Wentzel, M.C., R.E. Lowenthal, G.A. Ekama, and G.v.R. Marais (1988), "Enhanced polyphosphate organism cultures in activated sludge systems - Part 1: Enhanced Culture Development," Water SA, Vol. 14, No. 2, April 1988, pp 81-92.