# Evaluation of influent prefermentation as a unit process upon biological nutrient removal

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Water Science and Technology **Vol 47 No 11 pp 9–15** 

**Abstract** The objective of this NSF sponsored research was to provide a controlled comparison of identical continuous flow biological nutrient removal (BNR) processes both with and without prefermentation in order to provide a stronger, more quantitative, technical basis for design engineers to determine the potential benefits of prefermentation to EBPR in treating domestic wastewater. Specifically, this paper focused upon the potential impacts of primary influent prefermentation upon BNR processes treating septic domestic wastewater. This study can be divided into two distinct phases – an initial bench-scale phase which treated septic P-limited (TCOD:TP>40) wastewater and a subsequent pilot-scale phase which treated septic COD-limited (TCOD:TP<40) wastewater. The following conclusions can be drawn from the results obtained to date.

- Prefermentation increased both RBCOD, SBCOD and VFA content of septic domestic wastewater.
- Prefermentation resulted in increased biological P removal for a highly septic, non-P limited (TCOD:TP<40:1) wastewater. However, in septic, P-limited (TCOD:TP>40:1) wastewater, changes in net P removal due to prefermentation were suppressed by limited P availability, even though P release and PHA content were affected.
- Prefermentation increased specific anoxic denitrification rates for both COD and P-limited wastewaters, and in the pilot (COD-limited) study also coincided with greater system N removal.

**Keywords** Biological nutrient removal; EBPR; prefermentation; wastewater

## Introduction

Prefermentation of wastewater or primary solids is a common practice associated with Biological Nutrient Removal facilities in many parts of the world although it is only used in a few full scale installations in the United States to date. Prefermentation technology is associated in the minds of many engineers exclusively with cold climates as an enhancement solely for Enhanced Biological Phosphorus Removal (EBPR) for non-septic wastewaters. It is true that prefermentation technology is used broadly in Western Canada for that purpose. However prefermentation is practiced widely in Australia (Keller and Hartley, 1997), and to varying degrees in other temperate or even tropical climates, including some parts of the United States.

Prefermenters can be either on-line (the entire wastewater stream is treated) or side-stream (only primary clarifier underflow is treated). The most basic on-line prefermenter is simply a primary clarifier operated with a very high sludge blanket, commonly referred to as a Static Prefermenter. These prefermenters are not very efficient, often elevating influent VFAs less than more sophisticated prefermenters (VanMunch *et al.*, 1996). Static Prefermenters were improved with a recycle to elute VFAs from the sludge blanket and this configuration is referred to as an Activated Primary Tank or APT. Sidestream Prefermenters are reactors which receive the primary clarifier underflow instead of fermenting the entire wastewater flow. They can consist of a single tank which may or may not be completely mixed, or of a complete mix tank followed by a dedicated thickener. BNR facilities may receive both prefermented solids and liquid from a Sidestream Prefermenter, or may receive only the supernatant, depending on which configuration is used.

Traditionally the function of prefermenters has been to convert a large portion of the slowly degradable influent COD into readily available substrate (e.g. VFAs) to drive EBPR in the anaerobic zone. In plants in Western Canada, where prefermentation is very common, consistent effluents of 0.5 mg/L and lower are claimed without chemical polishing for some wastewaters. Reliably going below 1 mg/L without chemical polishing is anecdotally described as routine. However there are obvious disadvantages to prefermentation. One is that the capital costs of primary clarification are incurred while many of the benefits may be lost (i.e. no direct reduction in oxygen demand or secondary waste sludge production although increased denitrification may mitigate this). In addition in countries where there is a phosphate detergent ban such as the US, it is not as difficult to meet effluent standards and chemical polishing costs can be significantly less than in countries with significantly higher influent phosphorus concentrations. Further in the southern US, and seasonally in the north, raw wastewater is often at least partially septic, and in Florida it is very septic and raw wastewater concentrations may routinely exceed 50 mg/L total VFAs even in the winter. As a result it is often presumed that there will be little benefit to prefermentation in a warm climate.

Prefermenters have historically been an unusual unit process because they are frequently used with BNR plants by some design communities, while other design communities have not (at least in the past) seriously considered them as an option. Part of the reason for this is the absence of quantitative information on the process and effluent changes resulting from prefermentation for a variety of wastewaters and climates. Most information is from full scale applications and is anecdotal (e.g. we have a plant with prefermentation that always meets 0.5 mg/L P, we have a plant without prefermentation that always goes below 1 mg/L P, etc…), with only a few direct comparisons existing in the literature (e.g. Danesh and Oleskiewica, 1997).

This portion of the current National Science Foundation (NSF) funded study is being conducted with two basic objectives:

1. to conduct controlled comparisons of BNR processes with prefermentation, and without prefermentation, for a variety of wastewater conditions;
2. to determine if prefermentation might be beneficial in niches for which it has not traditionally been used; i.e. to enhance denitrification kinetics, or for septic wastewaters in warm climates.

## Methods and materials

In order to meet the research objectives listed above, the performance characteristics of an activated sludge train augmented with the effluent of a prefermenter was operated in parallel with a control activated sludge train that did not receive prefermenter effluent. The data presented in this document was collected in two distinct phases; an initial bench-scale phase that treated a septic, P-limited influent wastewater, and a larger pilot-scale phase that treated a septic, COD-limited influent wastewater. The two phases are described in detail below.

In the initial phase of this study, two bench-scale, 15 litre liquid volume, Biological Nutrient Removal (BNR) systems were run simultaneously at a solids retention time of 12 days and an average hydraulic retention time of 8.3 hours in order to determine the effect of influent prefermentation upon the performance characteristics of activated sludge treatment systems (Figure 1). Both systems were three zone (i.e. anaerobic 16.7% of the total volume, anoxic 33.3%, and aerobic 50.0%) University of Cape Town (UCT) systems. One system was preceded by an on-line prefermenter, served as the prefermented activated

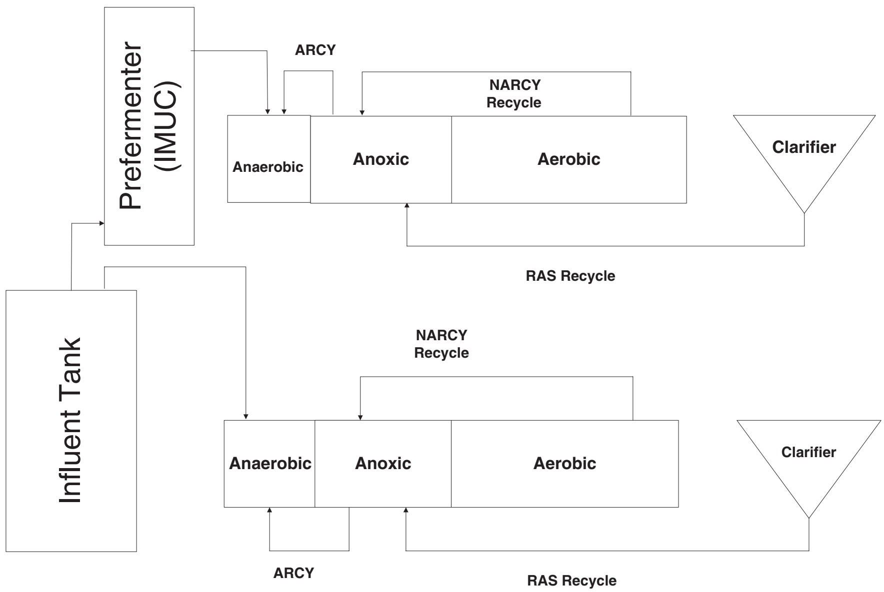


**Figure 1** Schematic of the bench-scale system

sludge (PAS) system. The other system, which did not have a prefermenter, served as the control activated sludge (CAS) system.

During the latter part of the bench-scale phase, both activated sludge trains were operated in a split-feed mode in which the influents to both trains were divided equally between the anaerobic and anoxic zones to shunt more of the VFAs to drive denitrification rather than EBPR. The prefermenter in operation during the bench-scale phase was an on-line intermittently mixed upflow clarifier (IMUC) with a 2.1 to 2.4 hour hydraulic retention time (HRT) and a solids retention time of 4 days was used for the retention and prefermentation of influent primary solids.

Influent wastewater during the bench-scale phase consisted of a strong, septic, phosphorus (P) limited domestic wastewater (TCOD = 428 mg/L; VFA without prefermentation = 46 mg/L; TCOD:TP = 58:1; i.e. phosphorus limited in that TCOD:TP>40; WEF, 1998). However the wastewater had significant influent TSS (121 mg/L) with an associated COD demand of 1.8 mg COD/mg TSS. This meant that significant prefermentation potential remained since relatively unstable primary solids were still present. Early in the study several prefermentation potential tests (Lie and Welander, 1997) using serum bottles confirmed 20 mg/L or more of additional VFA could potentially be produced from the wastewater. The prefermenter increased the average total VFA content of the already septic wastewater by 15.5 mg/L.

The pilot-scale system consists of two parallel 4 stage modified UCT systems. The flowsheet for the pilot-scale system is similar to that shown in Figure 1, with the exception that the anoxic zone was split into two separate reactors. The NARCY recycle line in the pilot plant flowed into the second anoxic zone, while the RAS returned into the first anoxic zone. The purpose of this revised flow configuration was to minimize nitrate loading into the anaerobic zones. Both trains had a total tankage of approximately 35 L, with volume fractions of 9.6% anaerobic, 39.4% anoxic, and 51.0% aerobic. Both trains were operated at solids retention time of 8.5 days and a hydraulic retention time of 3.5 hours, deliberately low in order to test which system would fail first. The prefermented activated sludge system (PAS) was augmented with the effluent from a completely mixed sidestream prefermenter operated at a 10 day SRT, while the control activated sludge system (CAS) received an equal amount of fresh, unprefermented primary solids.

Influent wastewater during the pilot-scale phase consisted of a strong, septic, COD-limited domestic wastewater (TCOD = 381 mg/L; VFA without prefermentation = 55 mg/L; TCOD:TP = 31.8). The prefermenter increased the average total VFA content of the already septic wastewater by 18.2 mg/L. Both influent tanks were also supplemented with 6 mg/L of phosphorus (in the form of $K_2HPO_4$) to increase the $PO_4$-P in the influent to 12.0 mg/L in order to ensure that excess phosphorus was present, ensuring that influent wastewater was COD-limited. Both the pilot-scale and the bench-scale systems were located at a local full-scale BNR plant (a 5 stage Bardenpho plant removing both nitrogen and phosphorus).



**Results and discussion of the septic, P-limited phase**

The results from the bench-scale septic, P-limited phase have been well documented in the literature (Randall *et al*., 2000). The most important differences between the PAS system and the CAS system for the bench-scale septic, P-limited phase are listed below.

- Prefermentation resulted in a greater PHA content for the biomass in the PAS system as compared to the CAS system.
- Prefermentation resulted in significant redistribution of P release and uptake between the anaerobic and anoxic zones, but this did not significantly change either the net P release or the net P removal of the system for this P limited wastewater.
- Prefermentation increased specific denitrification rates for the PAS system as compared to the CAS system.
- A step feed modification to the anoxic zone in which half the influent was routed from the anaerobic zone to the anoxic zone, increasing denitrification rates, was used without detrimental effects to EBPR for both the PAS and CAS systems utilizing this P limited wastewater.

**Results and discussion of the septic, COD-limited phase**

Influent VFAs in the domestic wastewater averaged 55 mg/L during the pilot study. The completely mixed prefermenter utilized during the pilot phase consisted of a hydraulically isolated completely mixed reactor. Primary solids were collected from a full-scale primary clarifier and added to the prefermenter in sufficient quantity to maintain a 10 day SRT. During the daily operation of the pilot plants, 1 litre of solids from the prefermenter was added to the influent tank for the prefermented system. At the same time, an equal volume of fresh primary solids from the full-scale primary clarifier was added to the influent tank of the control system in order to equalize the solids loading to both of the trains. Composite samplers on the influent tanks measured an average total VFA content of 75.0 mg/L in the control influent tank and 93.2 mg/L in the prefermented influent tank.

The impact of prefermentation upon the phosphorus removal characteristics of the activated sludge systems are shown in Tables 1 and 2. Comparison of effluent P shows that prefermentation led to an effluent 2.1 mg/L lower than the control system (CAS; Table 1). Looking at the mass balance data, a significantly higher anaerobic release was observed due to prefermentation, and also a significantly higher release in the first anoxic zone (see Figures 1 and 2). The net P release in the prefermented system (PAS) was over 80% higher than the control system, which was surprising since the influent VFA increase of 18.2 mg/L due to prefermentation was less than a 20% increase in the very high influent VFA levels found in the septic wastewater typical of Central Florida.

Nitrogen data also indicated a significantly higher rate of both nitrification and denitrification in the PAS system (Table 3 and 4). Higher PHA content could explain the higher denitrification rates, but the nitrification results are unexplained. Respirometric data in batch experiments are being conducted to determine: a) if the higher denitrification rate

**Table 1** Pilot-scale phosphorus concentrations

| Parameters (mg/L) | PAS | CAS |
|---|---|---|
| TP influent | 11.6 | 12.4 |
| Anaerobic SOP | 36.7 | 27.3 |
| Anoxic I SOP | 41.7 | 33.0 |
| Anoxic II SOP | 12.7 | 10.5 |
| Aerobic SOP | 4.2 | 6.3 |
| Clarifier SOP | 4.0 | 6.7 |
| % P removal | 64.2 | 49.3 |
| Apparent anaerobic P release | 25.1 | 14.9 |
| Apparent anoxic I P release | 5.0 | 5.7 |
| Apparent anoxic II P uptake | 29.0 | 22.5 |
| Aerobic P uptake | 8.6 | 4.2 |
| Net P uptake (excluding clarifier) | 7.4 | 6.1 |



**Table 2** Pilot-scale phosphorus mass flux values

| Parameters (mg/day) | PAS | CAS |
|---|---|---|
| TP influent | 2794 | 2995 |
| Anaerobic SOP release | 4834 | 2254 |
| Anoxic I SOP release | 9009 | 7349 |
| Anoxic II SOP uptake | 4239 | 4050 |
| Net anoxic SOP release | 4770 | 3299 |
| Net SOP release (anaerobic+anoxic) | 9604 | 5553 |
| Aerobic SOP uptake | 11356 | 7093 |
| Net SOP uptake (excludes clarifier) | 1840 | 1377 |
| %P in MLSS (via mass balance) | 10.5 | 8.8 |

observed in Table 4 is also consistent with a higher rate of nitrate/nitrite respiration when the MLSS is taken from the system and observed in batch mode, and b) if SOUR is significantly different in the aerobic zone MLSS from the two systems and this corresponds to the observed differences in nitrification and simultaneous denitrification (Table 4).

A table showing both glycogen content and PHA concentrations in the two activated sludge pilot-scale trains is shown below in Table 5. There was a 2.5 fold increase in glycogen degradation from the anaerobic zone to the first anoxic zone and a 15.6% increase in glycogen production from the second anoxic zone to the aerobic zone in the PAS train as compared to the CAS train. The greater glycogen consumption (anaerobic, anoxic I) and biosynthesis (anoxic II, aerobic) corresponded to greater PHA formation in the PAS train. PHA concentrations were greater in the PAS train as compared to the CAS train in every reactor. Despite similar PHA concentrations in the anaerobic zones, there was 16.5% greater PHA concentration in the first anoxic zone, with a corresponding 39.1% increase in

**Table 3** Pilot-scale nitrogen concentrations

| Parameters (mg/L) | PAS | CAS |
|---|---|---|
| TKN influent | 41.4 | 35.2 |
| SKN influent | 34.0 | 32.1 |
| Ammonia influent | 30.8 | 28.7 |
| Nitrate influent | 0.27 | 0.19 |
| KN effluent | 7.3 | 9.4 |
| SKN effluent | 6.5 | 7.8 |
| Ammonia effluent | 5.1 | 6.7 |
| Nitrate effluent | 5.19 | 2.10 |

**Table 4** Pilot-scale nitrogen mass flux values

| Parameters (mg/day) | PAS | CAS |
|---|---|---|
| TKN influent | 9987 | 8526 |
| Assimilated N | 1633 | 1484 |
| Available N | 8354 | 7042 |
| Nitrate produced | 6792 | 5178 |
| % Nitrification (available N) | 80.9 | 73.2 |
| Nitrate load to anaerobic zone | 99 | 80 |
| Nitrate load leaving anaerobic zone | 66 | 72 |
| Anaerobic zone denitrification | 33 | 7 |
| Nitrate load to anoxic I | 958 | 434 |
| Nitrate load leaving anoxic I | 96 | 93 |
| Anoxic I denitrification | 862 | 341 |
| Nitrate load to anoxic II | 6116 | 2131 |
| Nitrate load leaving anoxic II | 3891 | 727 |
| Anoxic II denitrification | 2225 | 1403 |
| Specific denitrification rate in the anoxic I (mgNOx/gVSS*day) | 55.1 | 20.4 |
| Specific Denitrification rate in the anoxic II (mgNOx/gVSS*day) | 96.9 | 81.7 |
| Simultaneous denitrification | 1992 | 2900 |
| Clarifier denitrification | 509 | 57 |
| System denitrification (without clarifier) | 5112 | 4653 |
| Total system denitrification | 5621 | 4709 |

**Table 5** Intracellular storage products

| | PAS AN | PAS AX I | PAS AX II | PAS AE | CAS AN | CAS AX I | CAS AX II | CAS AE |
|---|---|---|---|---|---|---|---|---|
| Glycogen (mg glycogen/g MLSS) | 96.0 | 86.0 | 97.3 | 104.7 | 91.8 | 89.0 | 90.2 | 96.6 |
| PHB concentration (mg/L) | 141.4 | 253.4 | 149.8 | 0.0 | 138.5 | 220.5 | 0.0 | 0.0 |
| PHV concentration (mg/L) | 50.7 | 83.2 | 85.9 | 0.0 | 46.6 | 68.5 | 41.7 | 0.0 |

PHA production from the anaerobic zone to the first anoxic zone. In the second anoxic zone, however, there was an over 200% increase in PHA degradation from the first to the second anoxic zones in the CAS train as compared to the PAS train, even though anoxic II P uptakes were similar (Table 2). This observation may be an artifact since the PHA and glycogen data is much more preliminary than the N and P data (fewer repetitions).

Respirometry and other experimental techniques are currently being used to quantify the biokinetic parameters used in dynamic modeling (e.g. ASM1 and 2d) using an OUR meter purchased from South Africa (it was developed by the UCT research group led by George Ekama and is now commercially available). Preliminary data obtained using techniques similar to those of Wentzel *et al.* (1995) indicate that PAS influent contained 10% more of both RBCOD and SBCOD than the influent from the control system. Other biokinetic parameters, including the heterotrophic maximum specific growth rate on RBCOD ($\mu_{maxH}$), the heterotrophic maximum specific growth rate on SBCOD ($K_{MP}$), and the heterotrophic active biomass concentration ($Z_{BH}$) will be discussed during the presentation of this paper at the conference.

## Conclusion

- Prefermentation increased both RBCOD, SBCOD, and VFA content of septic domestic wastewater.
- Prefermentation resulted in increased biological P removal for a highly septic, non-P

limited (TCOD:TP<40:1) wastewater. However, in septic, P-limited (TCOD:TP>40:1) wastewater, changes in net P removal due to prefermentation were suppressed, in spite of elevated PHA content, due to limited P availability.
- Prefermentation increased specific anoxic denitrification rates, and in the pilot (COD-limited) study also coincided with greater system N removal.
- The increased anaerobic P release, aerobic P uptakes, and greater specific denitrification rates correlated with greater PHA formation and glycogen consumption during anaerobiosis of prefermented influent.
- Improvements in biological P removal of septic, non-P limited wastewater occurred even when all additional VFA production exceeded VFA requirements using typical design criteria (e.g. 6 g VFA per 1 g P removal).



## Acknowledgements

This research was funded by the National Science Foundation, Award #9616144. In addition the assistance of the Orange County Utilities Eastern Water Reclamation Facility personnel and the Plant Manager, Tim Madhanagopal, P.E., DEE, QEP, is gratefully acknowledged.

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