The effects of iron and system operation for sludge reduction in the Cannibal™ process

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Abstract
A study of a sludge reduction process in the laboratory in which a sidestream anaerobic reactor was used to incorporate with the SBR called the Cannibal™ process was performed to determine the variations of sludge reduction occurred in field installations. Two issues were thought to be important, the iron concentration in the feed and the activated sludge process configuration. Based on field observations, it appeared that processes that had a single stage reactor and a high sludge age would frequently not provide a low organic solids yield. Iron oxidation/reduction cycling was thought to influence the bioavailability of organic matter in activated sludge flocs. Laboratory sequencing batch reactors were operated-one of which was operated as a conventional activated sludge system and the others included a side stream anaerobic reactor (Cannibal system). Initially, the iron content in the feed was varied. Later, the feeding cycles were varied. The "fast feed" system used a 5 minute feed period and the "slow feed" had a 4 hour feed period. It was found that the Cannibal process operated as a fast feed system generated up to 80% less solids than the conventional activated sludge system without any negative effect on the effluent quality or the settling characteristics of the activated sludge. For the system operated under slow feed, solids production was lower than the conventional activated sludge system but remained higher than for the fast feed

Keywords
Cannibal™ process, yield, iron, anaerobic side-stream reactor, activated sludge, combined aerobic-anaerobic processes

INTRODUCTION

Activated sludge has proven to be reliable, efficient, and capable of producing high effluent quality. However, it also produces significant quantities of excess biomass that require additional processing and disposal handling and disposal of the sludge are a large fraction (40-50%) of plant operating costs. Many technologies have been developed to decrease sludge production from wastewater treatment but most of them either add significantly more costs or are inappropriate in practical terms. In this study, we investigated the degradation of sludge generated from a conventional activated sludge system (CAS) by incorporating a sidestream anaerobic bioreactor into the system. This system is called the "Cannibal process". A flow scheme for this process can be found from Novak et al. (2007). A previous study by Novak et al. (2007) demonstrated that the Cannibal process generated about 60% less solids than a conventional activated sludge system without any negative effects on the effluent quality. That study was conducted under a specific operation in which the return sludge was retained in an anaerobic bioreactor for 10 days and the interchange rate (the exchange of sludge between anaerobic and aerobic bioreactor) was 10% per day by mass. However, for some full-scale Cannibal processes, solids reduction does not meet expectations. Observations suggested that for plants operated at high mean cell residence times in a complete mix mode, solids reductions were much less than for plug flow systems. In addition, it was thought, based on studies by Novak, et al. (2007), that an important mechanism in solids reduction by the Cannibal process was iron reduction in the anaerobic (interchange) reactor which released iron-associated organics that could then be degraded. Therefore, this study was undertaken to examine two issues related to the Cannibal process performance:

1. the effect of iron in the feed on solids reduction by the Cannibal process and
2. the effect of the activated sludge process configuration or feeding patterns on the solids reduction by the Cannibal process.

MATERIALS & METHODS

Two operational phases were used. In the first phase, two Cannibal systems and a conventional activated sludge were run. Both Cannibal systems were operated as sequencing batch reactors (SBR) with a sidestream anaerobic bioreactor. The control system was run as a SBR without a sidestream reactor. Sludge was not wasted from the Cannibal system, but it was returned to the main reactor from the anaerobic sidestream bioreactor. For the control system, concentrated biomass was wasted from the settled mixed liquor suspended solid following the settling phase. The volume in the react tank was 3 L, and the feed was 2 liters/day for all systems. The sidestream anaerobic bioreactors had a 10-day hydraulic retention time (HRT) and were fed 10% of the volume of the settled sludge from the SBR. The volume of returned sludge from the anaerobic bioreactors to the main reactors was the same as the feed volume. The HRT for all SBRs was 1.5 days. The SBRs were operated at 4 cycles/day; with a 5 hour react time and a settle time of 40 minutes. All systems were fed with synthetic wastewater with a feed period of 5 minutes. The purpose of the first phase was to evaluate the impact of iron concentration in the feed on the solids yield. For the second phase, two Cannibal systems were operated in the same manner as in the first phase without the control system. The first Cannibal system was fed over a 5 minute time period (fast feed) in order to produce a high initial substrate concentration during the feed cycle. This was to mimic a plug flow system. The second system was fed over a period of 4 hours (slow feed) to provide a consistently low substrate concentration. The slow feeding pattern was to mimic a complete mix reactor. Feed composition and analytical methods can be found from Novak et al. (2007) and APHA, et al. (1999), respectively.

RESULTS AND DISCUSSION

In the first phase, two Cannibal systems were operated-one with a higher iron concentration than the other. A sequencing batch reactor without a side-stream reactor was also run to represent a conventional activated sludge system and serve as a control. The measurement of the soluble chemical oxygen demand (COD) and total suspended solid (TSS) in the effluent and the sludge wasted was used to evaluate the system performance. The mixed liquor suspended solids concentration (MLSS) in the SBR for both Cannibal systems was considerably varied during the first 30 days. However, less variability was observed after day 35. The loss of solids from the Cannibal systems was due to solids in the effluent and solids removed for sampling for measurement. No solids were intentionally wasted from the Cannibal system. However, daily wastage of settled sludge from the control system was performed to maintain the MLSS between 3,500 and 3,800 mg/L. The total suspended solids in the effluent was similar for all systems and remained between 20-24 mg/L once steady-state was reached (after day 35) as evidenced by low variability in soluble COD and total suspended solid in the effluent. The effluent soluble COD was low and less variable as was the total suspended solid after day 35. The soluble COD for the high iron system was lower than that for the low iron and control systems. Iron is known to bind proteins and it was thought that the effect of iron was to reduce the effluent protein concentration slightly. The accumulated solids over time are shown in Figure 1. It can be seen from Figure 1 that the Cannibal systems generated much less solids than the control system, as indicated by lower observed yield for both Cannibal systems. The solids accumulation in the Cannibal system with low and high iron in the influent was approximately 31% and 20% of the cumulative solid in the control, respectively. When the system performance of the two Cannibal systems is compared, the system with higher iron in the influent can be seen to generate less solids than the low iron system. The observed yield for the system receiving lower iron in the influent was 0.14, and that for the high iron system was 0.09. These data indicate that iron plays a role in solids reduction in the Cannibal system. The cumulative solids was calculated by summation of total suspended solid in the effluent, the increase of mix liquor suspended solid in SBRs, and the solid lost due to sampling for the experiments.

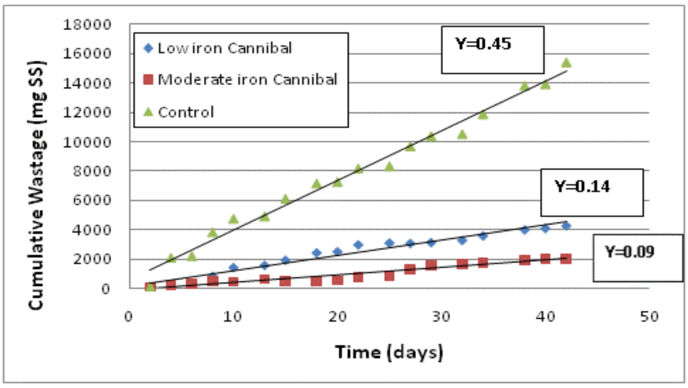

Figure 1 Cumulative Solids for Control, Low and High Iron Systems

In the second phase, two Cannibal systems were operated with different feeding patterns. One system was fed over a period of 5 minutes while the feeding period for the other system was 4 hours. The slow (4 hours) and fast feed (5 minutes) were used to provide low and high substrate pressure for those systems respectively. The concentration of alum and ferric chloride was the same as phase 1 for both systems, one with low iron and one with high iron. The SRT for the fast and slow feed systems was approximately 90 and 58 days while it was 18 days for the control system. The data from Figure 2 illustrate that a higher solid accumulation was found in the Cannibal system with low iron content in the influent compared to the system with the high iron concentration. On day 43, the feeding time for the system with high iron in the influent was increased from 5 minutes to 4 hours. As illustrated in Figure 2, the reduced feed flow rate resulted in an increase in solids generation for the Cannibal system with high iron. However, when fast feed resumed, as shown in Figure 3, the solids generation returned to the lower level. Therefore, it can be seen that the fast feed mode gives better solids reduction than the slow feed mode. It is thought that fast feed operation provides an initial high food to microorganism ratio (F/M ratio) and this makes the system performance similar to a plug flow operation. In contrast, slow feeding provides a low F/M ratio and is similar to a complete mix operation. The data show that the characteristics of the sludge from two Cannibal systems are different. The sludge produced under slow feed does not respond as well to the Cannibal system. However, compared to the control, the slow feed system still provides for solids production that is less than the control or conventional activated sludge system. For the low iron system, a similar response was seen to the conversion to slow feeding. As shown in Figure 4, conversion of fast to slow feed resulted in an increase in the yield from 0.14 to 0.31 mgTSS/mgCOD. These data show that the feed flow rate for the influent is an important factor and should be considered for the design of Cannibal systems. Nevertheless, it can be seen that the yield for the system with slow feed and low iron content is still less than the control system value of 0.45 (the conventional activated sludge) from phase 1. The Cannibal system provides some sludge reduction, regardless of the feeding pattern. The oxidation-reduction potential (ORP) in anaerobic bioreactor of the Cannibal system operated under fast and slow feed was -264 mV and -108 mV, respectively. The much lower ORP in the fast feed system indicated that more iron was reduced, resulting in higher sludge degradation. These data are in accord with the research from Saby et al. (2003). These researchers modified an activated sludge system called the oxic-settling-anoxic process by recycling the settled activated sludge to an anoxic tank. They found that the amount of solid reduction was dependent on the ORP. That is, a lower ORP in an anoxic reactor was associated with a higher solid reduction.

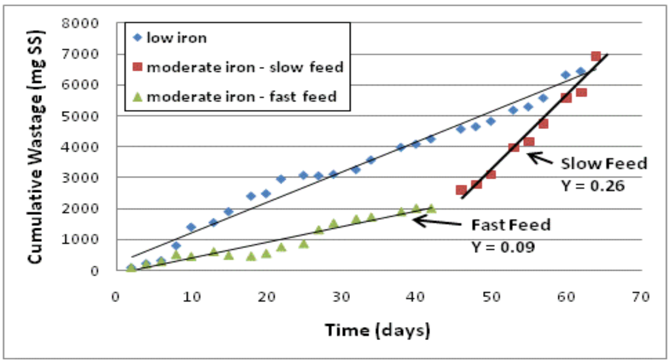

Figure 2 Effect of Feeding Pattern on Solids Production for the System with Moderate Iron in the Feed

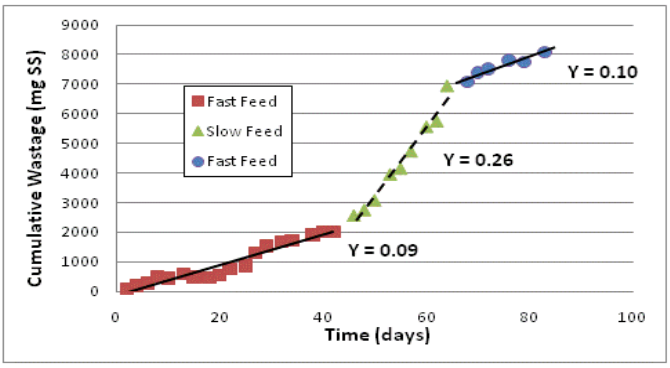

Figure 3 Effect of Feeding Variations on the Yield From a Cannibal System. Data are for Moderate Iron Concentration.

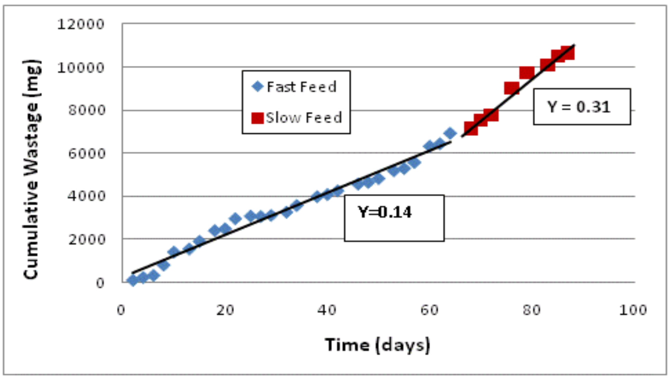

Figure 4. Effect of Feeding Variations on the Yield from a Cannibal System. Data are for the Low Iron Concentration.

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