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The effect of iron dosing on reducing waste activated sludge in the oxic-settling-anoxic process

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HIGHLIGHTS

- High iron concentrations in the wastewater enhances the sludge reduction.
- Reduced observed yield and suitable sludge volume index with fast feeding regime.
- Simultaneously occurring sludge reduction mechanisms.

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ABSTRACT

This study evaluates the biological solid reduction in a conventional activated sludge system with an anoxic/anaerobic side stream reactor receiving 1/10 of return sludge mass. Influent iron concentrations and feeding modes were changed to explore the consistency between the influent iron concentration and yield values and to assess the impact of feeding pattern. The results indicated that sludge reduction occurs during alternately exposure of sludge to aerobic and anoxic/anaerobic conditions in a range of 38–87%. The sludge reduction values reached a maximum level with the higher iron concentrations. Thus, it is concluded that this configuration is more applicable for plants receiving high iron concentrations in the wastewaters.

1. Introduction

Traditionally, excess sludge production has been regarded as one of the most vital issues of activated sludge systems. Recently promulgated stringent regulations significantly increased the cost of sludge handling and disposal as they practically prohibited conventional and economically feasible approaches such as disposal to landfill (Wei et al., 2003); in fact, recent studies provided conclusive evidence that, technically, the organic carbon content of sludge could not be reduced to meet the new regulatory requirements (Orhon, 2014). Consequently, research is now focused on exploring different strategies that would potentially reduce the magnitude of sludge generation in the face of more expensive technologies such as drying, incineration, etc.

Separate handling of activated sludge has been historically tested and implemented for more effective stabilization; it was initially promoted as different *re-aeration* systems that basically involved aerating settled activated sludge in side-stream stabilization reactors prior to mixing with wastewater (Orhon, 2014). Later, more effective sludge stabilization was also reported to occur under anoxic/anaerobic conditions (Wanner, 1994; Eckenfelder, 1998). The *oxic-settling-anoxic* (*OSA*) *process* – also commercialized as the *Cannibal process* – is one of the promising process configurations recommended for sludge minimization (Saby et al., 2003; Chon et al., 2011). Basically, it involves a side-stream anoxic/anaerobic reactor designed to stabilize and reduce the excess sludge generated in the main activated sludge unit. The principles and performance of this system are well covered in different review papers on sludge minimization (Guo et al., 2013; Wei et al., 2003; Liu and Tay, 2001; Semblante et al., 2014).

Related research generally utilized the observed yield values for the assessment of sludge reduction achieved. Novak et al. (2006) found that the observed yield values were about three times lower

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and argued that the *Cannibal* system was likely to generate up to 60% less solids as compared to the conventional activated sludge process. This result was in agreement with the finding of other studies reporting similar sludge reductions in the range of 37–58% (Saby et al., 2003; Wang et al., 2007). Low et al. (2000) further postulated that decreased biomass yield per unit mass of substrate removed indicates uncoupled metabolism in biological wastewater treatment processes.

The function and the positive impact on the biochemical mechanisms associated with the Cannibal process were also explored: Iron is reduced from ferric to ferrous ions under anaerobic conditions and this reduction promotes the release of protein into solution (Novak et al., 2003, 2007); this mechanism was also supported by *the floc model* suggested by Park and Novak (2007), where the released iron-associated protein is recycled to the aerobic activated sludge reactor and becomes available for microbial metabolism (Park et al., 2006).

Studies also suggested a similar effect of the substrate feeding regime, which was empirically called substrate pressure, on the rate of solids generation by the Cannibal system (Khanthongthip et al., 2015). Khanthongthip (2010) reported that a 64% reduction could be achieved with the fast feeding regime compared with the slow-feed system, presumably due to higher production of easily biodegradable floc structure with high substrate pressure. Different mechanisms such as lysis–cryptic growth, uncoupling metabolism, maintenance metabolism, and predation on bacteria were proposed based on experimental results obtained (Low and Chase, 1999; Liu and Tay, 2001; Chen et al., 2003; Guo et al., 2013).

In this context, the objective of the study was to provide experimental support for the effect of iron and feeding regime on the sludge generation mechanism in the OSA process and, particularly, to assess the experimental correlation between the iron content and the observed sludge yield under fast and slow feeding regimes.

2. Methods

2.1. Experimental set-up

The experimental study involved parallel operation of two OSA systems with identical design except for their feeding patterns. The survey period was continued for 115 days (excluding the sludge acclimation phase at the beginning of the total operation period). The sludge from Blacksburg Wastewater Treatment Plant, VA USA, was used to start up the systems. Each system consisted of an aerobic sequencing batch reactor (SBR) coupled with side-stream anaerobic bioreactor as described by Chudoba et al. (1992); the reactor system was sustained at room temperature (22 ± 1 °C).

The sludge was not wasted intentionally from the SBRs during the entire study. The overall sludge loss from the SBR was the daily sludge interchange between SBR and anaerobic bioreactor and a low amount of sludge escaping the system with the treated effluent. The interchange rate was selected as 10% based on the previous study by Easwaran (2006). It was maintained by recycling 1/10th of the settled sludge from the SBR through the anaerobic reactor. Thus, the hydraulic retention time (HRT) and sludge age were maintained at 10 days in the anaerobic bioreactor.

The SBR reactor was designed with a working volume of 7.5 L and an initial volume of 3.75 L before feeding. The total cycle time was 8 h. Thus, the SBR operated with a hydraulic retention time (HRT) of 16 h and a ratio of the initial volume to the fill volume (V_0/V_F) of 1.0. The operation cycle of each SBR consisted of 6 h of reaction (only aerobic) phase and 45 min of settling phase, 15 min of decanting phase, 15 min of interchange phase and 45 min of idle phase. Simultaneous feeding, mixing and aeration were initiated at the beginning of reaction phase of each sequence. Both systems were fed with synthetic wastewater with short and long feeding periods, to provide low and high substrate pressures. The feeding periods of each system were started simultaneously with the aeration phase at the beginning of each cycle and continued for 5 min and 120 min for short and long feeding, respectively.

Once a day within the operation scheme of each SBR, a 5 min mixing period was devoted to provide complete mixing before feeding of settled sludge from the SBR to the anaerobic bioreactor following the withdrawal phase. Then, the same volume of sludge was interchanged between SBR and anaerobic bioreactor to provide 10 days of hydraulic retention time in the anaerobic bioreactor.

2.2. Synthetic wastewater

Both systems were fed with the same synthetic wastewater containing a total COD of 400 mg/l. The synthetic wastewater was composed of peptone (300 mgCOD/L), acetate (65 mgCOD/L) and propionate (35 mgCOD/L) as organic carbon sources. The feed solution was prepared daily using tap water by completely mixing of carbon sources with macro- and micronutrients according to a previous study by Novak et al. (2007). The change in the influent characteristics was only limited to changes in the concentrations of ferric iron in the range of 2.7–16.0 mgFe/L by addition of $FeCl_3$. The iron concentration range is justifiable based upon typical measured iron content of wastewaters of domestic and mixture of domestic and industrial sewage (higher for industrial contributions).

Each phase of the experiments performed with a different concentration of ferric iron in the influent will be described herein as runs. Consequently, iron concentrations in the synthetic wastewater were adjusted to 10.7, 5.35, 2.68 and 16.05 mgFe/L in Run-1, Run-2, Run-3 and Run-4, respectively.

2.3. Batch anaerobic tests

Anaerobic digestion tests were performed using sludge from the SBRs fed with high iron (16.05 mg/L) concentration. Two digesters were initially fed with approximately 750 mL of settled sludge produced in fast feed and slow feed SBRs and tightly sealed to prevent gas leakage and monitored daily for 10 days. The reactors were purged with nitrogen gas to establish and maintain anaerobic conditions in the batch test vessels initially and after every sampling.

2.4. Observed yield

Observed yield is accepted as a suitable marker for the sludge reduction by researchers (Saby et al., 2003; Wang et al., 2007; Low et al., 2000; Troiani et al., 2011; Khanthongthip et al., 2015). In this study, the observed biomass yield values were determined for slow and fast feed SBRs receiving different influent iron concentrations by using the mixed liquor solids data. The observed yield values were calculated based upon the cumulative increase in solids (in term of VSS) divided by the corresponding removal of COD as given by Zhou et al. (2014). The amount of cumulative solids was estimated by the sum of the solids increased in the SBRs, the solids lost in the effluent and the solids removed from the reactors for sampling.

A reduction in the observed yield was demonstrated sludge reduction in the OSA system compared to reference system. And, reduction of sludge production was calculated by using calculated observed sludge yield data from reference and OSA systems.