Office of Water Programs
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The Effects of Solids Retention Time on Effluent Ammonia Concentration in Mesophilic Anaerobic Digestion of Municipal Wastewater Solids:

a Literature Review

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Introduction

Anaerobic digested sludge creates a reject water stream that can contribute 15 to 20 percent of the ammonia load to a wastewater treatment plant, (Constantine 2006). At Plant A (name redacted), return flow from the post anaerobic digestion Solids Storage Basin (SSB) and Biosolids Recycling Facility (BRF) contribute approximately 25% of the plant influent ammonia. Between 1994 and 2007, the Plant A influent and effluent Ammonia-N concentrations increased from 18 mg/L and 15 mg/L, respectively, to 28 and 25 mg/L (Redacted 2008). This review focuses on the contribution of the anaerobic digestion process to the ammonia concentration in the plant influent with the goal of developing an understanding of the effects of changes in anaerobic digester retention times on the ammonia concentrations in digested sludge.

Interestingly, despite widespread use of the anaerobic digestion process for stabilization of residual solids from municipal wastewater treatment, published research on the effects of solids retention time on anaerobic digestion performance is limited. Even fewer published studies report the effects of retention time on ammonia concentrations in digested sludge.

Ammonia as a function of SRT in anaerobic digestion:

Ammonia is formed in the anaerobic digestion process as a reduction product of the microbially mediated biochemical breakdown of proteins or non-protein nitrogenous compounds (Hobson and Wheatley, 1993). Cacho (2005) investigated optimization of solids destruction in anaerobic digestion of excess municipal sludge and found that a key factor in anaerobic digestion of wastewater solids is the solids retention time (SRT). Cacho's studies were conducted using selected SRTs (5, 10, 20 and 40 days). Twelve bench scale reactors were used in the experiment. The reactors were divided into the four different SRTs (three reactors for each SRT) and all were operated under mesophilic conditions. Digester effluent ammonia, TKN (Total Kjeldhal Nitrogen), COD (chemical oxygen demand), pH, and VFA (Volatile Fatty Acids) were analyzed and evaluated in response to SRT variation.

Ammonia concentrations were analyzed and were found to correlate directly to SRT and to solids destruction. Ammonia concentration increased and organic nitrogen concentration decreased as the SRT increased in Cacho's experimental reactors. At a SRT of 5 days the ammonia-N concentration was in the range of 1,200-1,400 mg/L and at a SRT of 40 days the ammonia-N concentration was in the range of 1,800-2,000 mg/L. Cacho reported that TKN concentrations were not affected significantly by changes in SRT. In anaerobic digestion, TKN, the combined concentrations of organic nitrogen and ammonia, is expected to remain constant as organic nitrogen is converted to ammonia.

Hindin and Dunstan (1960) conducted a study on the effect of detention time on anaerobic digestion. Digesting sludge was obtained from the Pullman, Washington, Sewage Treatment Plant, and was used in bench scale digesters operating under mesophilic conditions at SRTs of 5, 10, 15, 20, 30, 60, and 90 days. After the digesters reached "dynamic equilibrium" the supernatant, digested sludge, and digester gas were analyzed. Analyses of supernatant samples from the anaerobic digesters showed that the concentration of ammonia increased as the SRT increased. The ammonia concentration increased from about 500 mg/L to about 1,200 mg/L at SRTs of 5 and 90 days, respectively.

Kiyohara et al. (2000) performed a comparative study of thermophilic and mesophilic anaerobic sludge digestion. The study compared the characteristics of substrate degradation and bacterial activities under thermophilic and mesophilic conditions. Five bench scale anaerobic digesters were used and the SRTs for the five reactors were 2.5, 5, 10, 20, and 40 days. The results showed an increasing trend in the ammonia concentration as the SRT increased. The concentration of ammonia-N in the mesophilic process increased from 553 mg/L to 1,340 mg/L as the SRT increased from 2.5 to 40 days (Kiyohara et al. 2000).

Sawyer and Roy (1955) conducted a study that evaluated high-rate sludge digestion. Five bench scale digestion units were operated in the study. All were fed with sludge twice a day from the Nut Island Sewage Treatment Plant, Boston, Mass. The SRTs used were 6, 8, 10, 15, and 20 days and the temperature in the digesters was maintained between 33° and 40° C. Sawyer and Roy analyzed different parameters with respect to SRT; ammonia nitrogen was one of those parameters analyzed. The results of the study showed an increasing trend in ammonia nitrogen as SRT increased. The measured ammonia concentrations were 400, 418, 434, 464, and 465 mg/L, as N,

for retention times 6, 8, 10, 15, and 20 days, respectively. The alkalinity, pH, and ammonia nitrogen all increased with increasing detention time, indicating a continued degradation of protein matter, the principal source of ammonia nitrogen, as the digestion reactions progressed (Sawyer and Roy, 1955).

Moen et al. (2003) studied the effects of retention time on the performance of thermophilic and mesophilic digestion of combined municipal wastewater sludges. In this study the steady state performance of thermophilic and mesophilic anaerobic digestion was analyzed as a function of solids retention time (4 to 15 days). The investigators analyzed selected parameters and evaluated the effects of SRT on each of the parameters. Ammonia nitrogen was measured in samples of digested and undigested sludge. The ammonia concentration in the digesters was analyzed at 4, 6, 10, and 15 day SRTs; however, no results were reported for the 4 day SRT. Ammonia concentration in both thermophilic and mesophilic anaerobic digesters generally increased at longer SRT; however, 10 day SRT values were anomalously high, perhaps because of changes in feed sludge, or to sampling or analytical errors (Moen et al. 2003).

Ammonia in anaerobic digestion: Related studies

Ammonia is usually formed in the anaerobic treatment process from the degradation of wastes containing proteins or urea (McCarty, 1964). McCarty created a table with ammonia values that might have an adverse effect in the anaerobic treatment process:

Ammonia N concentration	Effect on anaerobic Process
50-200 mg/L	Beneficial
200-1,000 mg/L	No adverse effect
1,500-3,000 mg/L	Inhibitory at higher pH values (7.4-7.6)
Above 3,000 mg/L	Toxic

Ammonia can be present in anaerobic digestion in the form of ammonium ion (NH4+) or as ammonia gas (NH_3): $NH_3 + H_2O \leftrightarrow NH_4^+ + OH^-$ (Parkin and Owen, 1987). Parkin and Owen claimed that as SRT is increased, more ammonia nitrogen is released by decomposition of nitrogenous organics. With highly proteinaceous sludges like waste activated sludge, enough ammonia-nitrogen may be released to cause inhibition (Parkin and Owen, 1987).

Plant A ammonia studies

All residual solids from the Plant A primary and secondary treatment processes, including scum, are anaerobically digested. Recent digester capacity addition provides in excess of 15 days solids retention time (SRT), even in peak two week periods (Carollo, 2006). In the Technical Memorandum (TM) Meeting Ammonia Limits in the Next NPDES Permit, the fate of ammonia at Plant A was analyzed. Ammonia concentration in the effluent and influent in November- December 2007 averaged 25.64 and 25.82 mg/L, respectively (*Redacted*, 2008). The results of the Ammonia Fate, Treatment and Treatability study indicate that the SSB supernatant and BRF return flows contribute about 25% of the ammonia in the influent. The SSB supernatant and BRF return flow concentrations in November-December 2007 averaged 318 and 358 mg/L, respectively. The results from the 2004 Ammonia Fate, Treatment and Treatability study showed an ammonia concentration of 170 mg/L in the sludge digesters (*Redacted,* 2008).

Conclusion

Several studies on the effects of solids retention time on anaerobic digestion were reviewed. Some of those studies included investigations of the effects of SRT on ammonia concentration in the mesophilic anaerobic digestion process. The studies presented in this paper (Cacho 2005, Hindin and Dunstan 1960, Kiyohara et al. 2000, Moen et al. 2003, and Sawer and Roy 1955) conclude that ammonia concentration increases as SRT increases in the anaerobic digestion process.

Staff at Plant A is currently assessing the level of urgency for cleaning digesters to restore digester capacity currently lost to accumulated grit and debris in the tanks. One of the concerns is that the reduced capacity is contributing to the ammonia load returned with the SSB supernatant and BRF return flow to the plant headworks. The conclusion of this literature review is that ammonia load to the SSBs and BRF will increase with increased digester capacity because the digestion reaction will be more complete in reactors with more reaction time. Therefore, decreasing the return ammonia load to the plant headworks can be eliminated as a reason for urgency in cleaning the digesters.

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