World Academics Journal of Engineering Sciences **Research Paper**
Vol.7, Issue.3, pp.20-23, September (2020) **E-ISSN:** 2348-635X

The Effect of an Aluminum Addition to the Single-Stage Thermophilic and Mesophilic Anaerobic Digestion Systems

Jongmin Kim

Civil Engineering Department, University of Texas Rio Grande Valley, TX, USA

Author's Mail id: jongmin.kim@utrgv.edu, Tel.: +00-1-956-882-6661

Available online at: www.isroset.org

Received: 10/Jul/2020, Accepted: 22/Aug/2020, Online: 30/Sept/2020

Abstract— Aluminum is widely used to remove soluble phosphorus in wastewater streams. However, its impacts on the performance of the anaerobic digestion systems are largely unknown. The recent Water Environment Research Foundation study (Document No. 03CTS9b) indicated that aluminum addition to the activated sludge system might improve the quality of the anaerobically digested sludge downstream. This study aimed to evaluate the benefits or drawbacks of additional aluminum to the performance of two anaerobic digestion systems that were operated under thermophilic (55 degrees Celsius) and mesophilic (37 degrees Celsius) conditions, respectively. The results indicated that aluminum addition up to 100 mg/L to the feed sludge could enhance solids removal in the mesophilic anaerobic digestion system while the solids removal in the thermophilic anaerobic digestion was adversely impacted by additional aluminum. Excess aluminum up to 300 mg/L did not deteriorate the stability of both digesters. Also, improved dewaterability was observed from the digested sludges of both systems with aluminum addition up to 300 mg/L to the feed sludge.

Keywords—Aluminum, anaerobic digestion, volatile solids reduction, dewaterability

I. INTRODUCTION

Excess phosphorus (P) in the effluent from wastewater treatment plants can cause eutrophication and devastating fish kill in the watershed, so the concentration of P in the treated effluent is strictly regulated. To accomplish the required removal of P from the wastewater, chemical precipitation with aluminum (Al) or iron (Fe) is widely used in the primary or secondary treatments [1]. Al was reported as a better P removing chemical than Fe since aluminum phosphate does not dissociate in a wider range of pH than iron phosphate [2].

Anaerobic sludge digestion system is one of the most widely adopted biological waste sludge treatment technology that utilizes the biological breakdown of organic contaminants without oxygen [3]. Its final products are carbon dioxide, methane, and stabilized residue. Methane and residue are viewed as reusable commodities nowadays.

There have been two lines of the investigation carried to understand the impact of Al to anaerobic sludge digestion systems, which were Al in raw sludge floc and additional Al to the digestion system.

Al contents in the undigested sludge and its effect on volatile solids reduction (VSR) after anaerobic digestion were studied but no correlation was found [4]. It was also reported that much less solution biopolymer (protein and polysaccharide), thus lower effluent COD was observed from the waste activated sludge containing more Al in the sludge floc [5]. In the recent Water Environment Research Foundation (WERF) study [6], high aluminum contents in the raw sludge slightly lowered VSR in the anaerobic digestion system.

There are a few pieces of literature that introduced the effect of Al addition to the mesophilic anaerobic digestion systems operated at 37 degrees Celsius. It was observed that more than 200 mg/L alum could deteriorate the sludge digestion capability of the anaerobic digestion systems [7]. Since a decrease of digester performance was immediate and the recovery was observed right after the chemical addition was ceased, the cause of inhibition was thought to be the reduction of the available substrate by binding with added Al. The effect of a much greater amount of Al to the anaerobic sludge digestion system was also studied [8]. About 1000 mg/L of Al was observed to inhibit methanogenesis in the mesophilic anaerobic digestion system and the inhibition became more persistent if more than 150 mg/L of sulfate was present in the system. On the other hand, the dewatering properties of anaerobically digested sludge were improved by mixing with alum sludge [9]. The recent WERF study [6] indicated that aluminum addition to the activated sludge system decreased VSR in the anaerobic digestion system in downstream while significantly less odor was detected from dewatered digested sludge cakes.

The paper is structured as follows, Section I contains the introduction of the impact of Al on anaerobic digester performance, Section II contains the objectives of the study, Section III contains the methodology to draw answers for research questions as laid out in Section II, Section IV contains the findings from the research along with deduced ideas from them, and section V concludes research work with the lesson learned from the study.

II. OBJECTIVES

In this study, 0 to 300 mg/L Al was directly added to the single-stage anaerobic sludge digestion systems operated under two different temperatures, 55 and 37 degrees Celsius. Effluent from each digester setup was tested for solids reduction efficiencies and dewatering properties, and results were compared. Six different digestion conditions in this study are listed below:

- A thermophilic system without Al addition (ThAl0);
- A thermophilic system with 100 mg/L Al (ThAl100);
- A thermophilic system with 300 mg/L Al (ThAl300);
- A mesophilic system without Al addition (MeAl0);
- A mesophilic system with 100 mg/L Al (MeAl100);
- A mesophilic system with 300 mg/L Al (MeAl300).

III. METHODOLOGY

A schematic of the experimental setup is presented in Fig. 1. Two anaerobic sludge digesters were built with 24.6 L plastic brewer tanks (f6.5, The Hobby Beverage Equipment Company, Los Angeles, California). These tanks were completely sealed with rubber gaskets, rubber covers, and metal fasteners so a good anaerobic condition was maintained throughout the study. Digesters were placed in 37 degrees Celsius constant temperature room. During the thermophilic digestion study, a heating tape (BSAT 101-100, Thermolyne, Dubuque, Iowa) was used to heat the digester to 55 degrees Celsius while no heat was applied during mesophilic digestion. Aluminum foil was placed under the heating tape for even heat distribution. A thermometer was placed in the middle of each reactor to monitor sludge temperature. Digesters were mixed by continuously circulating headspace gas to the bottom of the tank. Peristaltic pumps (7553-70, Cole Parmer, Vernon Hills, Illinois) were used for mixing. Gasbags were attached to the top of each reactor to measure generated gas volume and prevent excess gas pressure build-up in the tanks. The solids retention time (SRT) was 10 days, which was maintained by wasting 1 L of digested sludge and injecting 1 L of feed sludge daily. The inocula for thermophilic systems were a thermophilically digested anaerobic sludge from the previous successful thermophilic digestion study at Virginia Tech, USA. Seed sludge was not introduced to the mesophilic system since it was converted from the thermophilic systems and responded well without seeding. The steady-state of each digestion system was assumed if the standard deviations of solids removal data were less than 10% of the average. Usually, the stable condition was observed after digesters were operated for 2 to 3 SRTs.

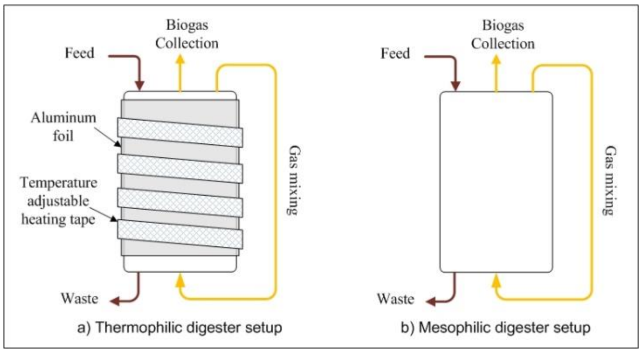

Figure 1. Digester setup schematic

The feed sludge was prepared by mixing primary and secondary sludge from a local wastewater treatment plant in VA, USA. The total solid (TS) of feed sludge was maintained at about 3%. Aluminum chloride was used to make desirable Al concentration (100 and 300 mg/L Al) in the feed sludge. It was used instead of aluminum sulfate to prevent any effects associated with high sulfate [8].

The acidity of the sludge sample was measured by a pH probe (13-620-287, Accumet, Petaling Jaya, Malaysia) and a pH meter (910, Accumet, Cambridge, Massachusetts). Sludge solids and alkalinity were measured following standard methods [10].

Solution phosphate was measured by ion chromatography (DX120, Dionex, Sunnyvale, California) equipped with the AS9-HC column (051786, IonPac). The carrier was 9.0 mM Na_2CO_3 flowing at 1.0 ml/min. Each liquid sample was prepared by collecting filtrate after passing sample sludge through a 0.45 um membrane filter (09 719 2D, Fisher Scientific, Pittsburgh, Pennsylvania).

Dewatering properties of digested sludge were determined by a capillary suction time (CST) apparatus (W.R.C type 165, Triton Electronics Ltd., Essex, United Kingdom). Higher CST implies poorer dewaterability of digested sludge.

IV. RESULTS AND DISCUSSION

4.1. P removal

Al addition of 100 and 300 mg/L removed more than 98% of solution P in both thermophilic and mesophilic anaerobic sludge digestion systems, leaving 0 to 2 mg/L solution P in the effluent sludge. Effluents from both sludge digestion systems without Al addition (ThAl0 and MeAl0) still held 20 mg/L or greater solution P. This result reconfirmed the excellence of Al as a P removing agent in the anaerobic sludge digestion systems regardless of digester temperature.

4.2. Digester stability

Although some decrease of alkalinity was observed from both digestion systems as more Al was added to the feed sludge, the neutral condition was observed in all digesters throughout the study (Table 1). Also, the alkalinity of each digestion system was still above 2000 mg/L, which was high enough to provide a good buffer against pH changes. In the study, Al addition up to 300 mg/L did not deteriorate digestion stabilities of the anaerobic digestion systems operated at different temperature conditions.

Table 1. Digester pH and alkalinity

Digester	pH	Alkalinity (mg/L as $CaCO_3$)
ThAl0	7.4 ± 0.2	3712 ± 351
ThAl100	7.0 ± 0.2	2776 ± 31
ThAl300	7.1 ± 0.2	2506 ± 874
MeAl0	7.0 ± 0.2	2986 ± 1074
MeAl100	6.9 ± 0.2	3115 ± 156
MeAl300	6.8 ± 0.1	2157 ± 203

4.3. Solids reduction and biogas production

More volatile solids (VS) were removed in the thermophilic system with Al addition of 0 to 300 mg/L (Fig. 2). Among the mesophilic systems, the highest VSR was observed from MeAl100 while direct Al addition decreased VSR of the thermophilic systems.

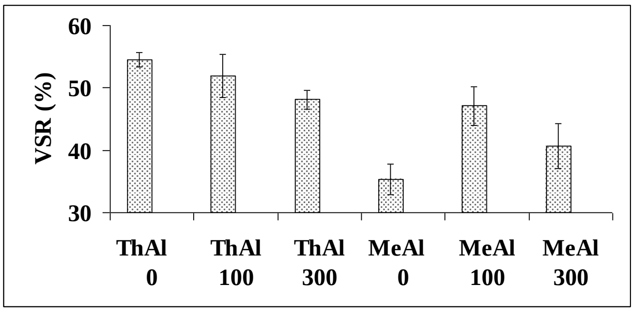

Figure 2. Volatile solids reduction (VSR)

Methane producers in all digestion systems performed well since the biogas yields were between 0.6 and 1.6 L/g VSR that was agreeable with previous research data [11]. Methane in the generated biogas was also 55% or greater. Biogas generations from all thermophilic systems were much greater than those of mesophilic systems (Table 2), which reflected greater VSR in thermophilic digesters.

Table 2. Biogas and methane generation

Digester	Biogas (L/day)	Biogas yield (L/g VSR)	% Methane
ThAl0	13.7± 0.3	1.3	60.7
ThAl100	13.2 ± 0.7	1.3	58.2
ThAl300	14.1 ± 0.6	1.4	54.9
MeAl0	7.3 ± 1.3	1.0	62.8
MeAl100	7.5 ± 1.4	0.9	62.6
MeAl300	6.5 ± 1.5	0.8	65.0

4.5. Dewaterability

Al addition enhanced dewatering properties of both thermophilically and mesophilically digested sludges (Fig. 3). Notably, MeAl0 sludge was much easier to dewater than ThAl0 sludge. Poorer dewatering properties in the thermophilic system were recovered by adding more Al to the feed sludges.

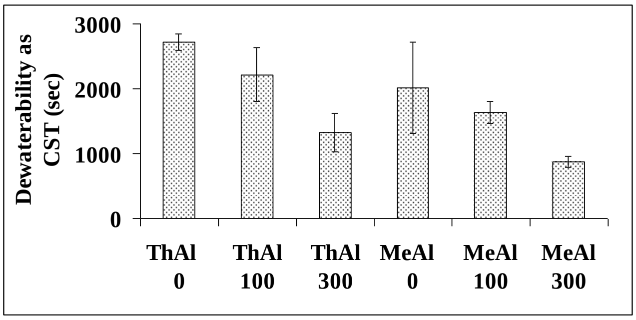

Figure 3. Dewaterability of digested sludge

Discussion

Direct addition of 0 to 300 mg/L Al to the feed sludge did not cause any signs of anaerobic digester upset in the study. This result contradicts the study result reported elsewhere [7]. They observed that more than 200 mg/L alum could deteriorate the sludge digestion capability of the anaerobic digestion systems by binding soluble substrates thus reducing their availability in the digestion system. It might be sulfate in alum that stimulated sulfate reducers in the anaerobic digestion system and these microbes might have outcompeted methanogens in a sulfate-rich environment by consuming more readily available substrates. If binding to the substrate was the mechanism that deteriorated digester stability, similar unhealthy digestion performances should be observed for the anaerobic digestion systems digesting alum or aluminum chloride added feed sludges. However, feed sludge characteristics of both cases should be investigated to support this reasoning.

Direct Al addition up to 100 mg/L improved solids reduction efficiency of the mesophilic anaerobic digestion systems only. The mechanism of decreased VSR in the thermophilic systems by direct Al addition was not in the scope of the study.

Dewatering properties were greatly improved for both digestion temperatures when either 100 or 300 mg-Al/L was added to the feed sludge. It seems that a negatively charged biopolymer was neutralized by positively charged Al, which resulted in less resistance to dewatering in the sludges digested under high Al condition [9]. Overall data showed that the mesophilic sludges were easier to dewater than the thermophilic sludges. Poorer dewatering properties associated with high solution biopolymer contents in the sludge digestion system have been reported by other lab studies [5], [12].

This study may provide anaerobic digester operators valuable information regarding the impact of direct Al addition to the performance of anaerobic digestion systems operated at different temperatures. Direct Al addition to the feed sludge has been widely practiced reducing solution P in the digester effluents. The beneficial impact may be observed from the mesophilic systems with direct Al addition to the feed sludge up to 300 mg/L while solids reduction efficiency may be deteriorated in the thermophilic system with direct Al addition to the feed sludge greater than 100 mg/L.

V. CONCLUSION

This study showed the benefits and drawbacks of Al addition to the anaerobic digestion systems under different temperature conditions. Al has been used to suppress soluble P in the wastewater stream. However, its impact on the anaerobic digestion system was not fully studied yet. Findings in the study may provide guidelines for the wastewater treatment facilities where chemical P control is practiced, and anaerobic digesters are in use. The study concludes:

- Direct Al addition of 100 to 300 mg/L to the feed sludge removed most of the solution phosphorus in the feed sludge regardless of digestion temperatures.
- Direct Al addition of 100 to 300 mg/L to the thermophilic and mesophilic digestion systems did not deteriorate their digester stability.
- Improved dewatering properties were observed for the digesters with more Al addition up to 300 mg/L.
- Direct Al addition to the feed sludge deteriorated solids removal capability of the thermophilic anaerobic digestion system. Increased VSR was observed from the mesophilic system with Al addition up to 100 mg/L.

ACKNOWLEDGMENT

The author thanks to Dr. John T. Novak from Virginia Tech for supporting this study.

REFERENCES

[1] B.E. Rittmann, P.L. McCarty, “Environmental Biotechnology: Principles and Applications,” *McGraw-Hill*, USA, pp. **537-539**, **2001**.

[2] D.R. Smith, P.A. Moore, C.L. Griffis, T.C. Daniel, D.R. Edwards, D.L. Boothe, “Effects of alum and aluminum chloride on phosphorus runoff from swine manure,” *Journal of Environmental Quality*, Vol. **30**, pp. 991-998, **2001**.

[3] A.E. Isiyaku, M. Godfrey, “Experimentation and Design Analysis of Anaerobic Sequencing Batch Reactor for Kano Abattoir,” *International Journal of Scientific Research in Multidisciplinary Studies*, Vol. **6**, No. **2**, pp. 21-28, **2020**.

[4] J.T. Novak, N. Verma, C.D. Muller, “The role of iron and aluminum in digestion and odor formation,” *Water Science and Technology*, Vol. **56**, No. **9**, pp. 59-65, **2007**.

[5] C. Park, C.D. Muller, M.M. Abu-Orf, J.T. Novak, “The effect of wastewater cations on activated sludge characteristics: Effects of aluminum and iron in floc,” *Water Environment Research*, Vol. **78**, No. **1**, pp. 31-40, **2006**.

[6] J.T. Novak, C. Park, “Effect of aluminum and iron on odors, digestion efficiency and dewatering properties Phase IV, Water Environment Research Foundation document No. 03CTS9b,” *Water Environment Research Foundation*, USA, **2010**.

[7] J.M. Gossett, P.L. McCarty, J.C. Wilson, D.S. Evans, “Anaerobic digestion of sludge from chemical treatment,” *Journal of Water pollution Control Federation*, Vol. **50**, No. **3**, pp. 533-541, **1978**.

[8] N. Cabirol, E.J. Barragan, A. Deuran, A. Noyola, “Effect of Al and sulfate on anaerobic digestion of sludge from wastewater enhanced primary treatment,” *Water Science and Technology*, Vol. **48**, No. **6**, pp. 235-240, **2003**.

[9] Y. Yang, Y.Q. Zhao, A.O. Babatunde, P. Kearney, “Co-conditioning of the anaerobic digested sludge of a municipal wastewater treatment plant with alum sludge: Benefit of phosphorus reduction in reject water,” *Water Environment Research*, Vol. **79**, No. **13**, pp. 2468-2476, **2007**.

[10] American Public Health Association (APHA), “Standard Methods for Examination of Water and Wastewater 20th Ed.,” *American Public Health Association*, USA, **1998**.

[11] M.H. Gerardi, “The microbiology of anaerobic digesters,” *Wiley*, USA, pp. 73-76, **2003**.

[12] J.T. Novak, C. Park, “Chemical conditioning of sludge,” *Water Science and Technology*, Vol. **49**, No. **10**, pp. 73–80, **2004**.

AUTHORS PROFILE

Jongmin Kim, Ph.D. is an assistant professor of civil engineering department at the University of Texas Rio Grande Valley, Texas, USA. He is an expert in water and wastewater treatment processes and renewable biogas energy technologies. He has 16 years of experience in the environmental engineering field including 4 years of teaching, 6 years of research, and 6 years of industry.