Wastewater Digester Enhancement and Sludge Volume Reduction Through Cell Lysis with Controlled Hydrodynamic Cavitation

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ABSTRACT

The conditioning of biosolids is a growing issue due to extremely large increases in production of this waste, escalating disposal costs and inefficient use of produced methane. One approach to improve biosolids utilization is treating waste activated sludge (WAS) before anaerobic digestion to enhance digestion, increase methane production and lower biosolids production.

Cavitation is the dynamic process of the formation, growth, and collapse of micro-sized bubbles in a fluid. During bubble collapse, extremely high temperature and intensive pressure waves are generated around the bubbles. Controlled hydrodynamic cavitation (CHC) is a process that seeks to optimally produce cavitation and harness the kinetic energy that is imparted to the fluid.

These extreme physical conditions in CHC provide the primary mechanism for the lysing of bacteria cells. Preliminary studies show that by lysing the cells, methane generation can be increased along with reduction in biosolids production.

This paper will describe the technology behind CHC and demonstrate its effect on WAS during a pilot study. The data will show improved dewatering, an increase in soluble COD, and reductions in TSS, VSS, SVI and particle size.

KEYWORDS: anaerobic digestion, biosolids, lysing, cavitation, methane generation, improved dewatering

INTRODUCTION

Wastewater treatment facilities using an anaerobic digestion process can have two potential areas limiting plant efficiency. The first is the efficiency of the biological process itself and the second is the generation of excess sludge. If the biological process is not optimized, methane production can be limited and may not be usable for co-generation purposes. Dewatering, transportation, and disposal may contribute up to 25% of the annual operating budget of the wastewater treatment facility if sludge production is excessive.

A low-cost, environmentally friendly technology that can improve digester efficiency, increase methane production and throughput, and lower sludge generation would be extremely valuable.
A number of different technologies that have been examined can improve biosolids processing. The EPA categorizes Biosolids Management Technologies (USEPA, 2006) into the following categories:

1. Embryonic (lab, bench scale)
2. Innovative (full scale demonstration, available in US < 5 years, < 25 U.S. installations)
3. Established (widely used in U.S. with > 25 installations)

Ultrasonic, where acoustic waves are applied to sludge (Ek, 2005; Wang, 2007); electrical, where an electric field applied to sludge (Stephenson, 2003; Banaszak, 2007); and chemical, where the addition of caustic chemicals such as NaOH is applied to sludge (Rabinowitz, 2006) are considered innovative. However, hydrodynamic cavitation, defined as a fluid under pressure creating cavitation, is considered embryonic. It is this technology that will be discussed in this paper.

**CONTROLLED HYDRODYNAMIC CAVITATION: TECHNOLOGY OVERVIEW**

Cavitation is the dynamic process of the formation, growth, and collapse of micro-sized bubbles in a fluid (Gogate, 2006, Gogate 2005). Controlled hydrodynamic cavitation (CHC) is a process that seeks to produce cavitation and harness the kinetic energy that is imparted to the fluid. CHC has been demonstrated to offer the following properties when applied to a fluid: bacteria eradication, removal of dissolved gases, precipitation of certain inorganic salts, creation of hydroxyl radicals, and the formation of stable emulsions. CHC has found successful commercial application for the past seventeen years in the treatment of cooling water without the use of any chemicals. The bacteria eradication effect of CHC provides consistent control of bacteria, including Legionella, in the warm oxygen rich environment of recirculating cooling water. Scale forming calcium carbonate is removed from the cooling water through the mechanism of gas stripping of CO₂ resulting in a buffered pH of 8.8-9.0 and an excess of CaCO₃ which is removed via precipitation and filtration. Recent research and development work by VRTX Technologies has resulted in several new potential applications for CHC. Sludge dewatering, heavy metal removal from water, TCE removal from groundwater, and phosphate removal from wastewater are all positively enhanced when CHC is applied.

The CHC unit typically consists of a pressure equalizing chamber and a cavitation chamber as shown in Figure 1.
The fluid is first pumped into a pressure equalizing chamber. Then it is channeled into the cavitation chamber where it is forced to rotate at high velocity through truncated nozzles. As the static pressure in the fluid falls below a critical value, cavities start to form and continue to grow. With a sudden increase in pressure at the nozzle outlet, these cavities cannot sustain the surrounding pressure and collapse catastrophically. During the collapse of cavities, extremely high temperature and intensive pressure waves are generated around the cavities. This is illustrated in Figure 2 below.

Figure 3 is a photograph of a clear plastic chamber backlit to see the hydrodynamic cavitation cloud. The gauge in the photo is measuring the vacuum created inside the nozzles.
These extreme physical conditions provide the primary mechanism for the lysing of bacteria cells. During the catastrophic collapse of the cavitated bubbles, it is believed that the collapse tends to be asymmetric resulting in high velocity micro jets (Figure 4). These micro jets, coupled with the extreme localized temperature and pressure, cause the destruction of the cell wall membrane.

The CHC equipment is relatively simple. It consists of the pump, a pressure equalizing manifold, the nozzles, and outlet (Figure 5). During operation, there are virtually no field adjustments, and maintenance requirements are limited to normal pump maintenance. In addition, no nozzle wear has been observed due to the cavitation created. Observations of units applied to cooling water show no wear after 17 years of continuous operation. Examples include Gerdau AmeriSteel, Beaumont, Texas, operating since 1998, Richmond Cold Storage, four locations in Georgia and Virginia operating since 1991, and Maxim in Hillsboro Oregon since...
1995. An area to be studied in applying the technology to WAS will be possible erosion due to the grit that may be contained in the WAS.

1.4 CHC for Digester Enhancement

With the application of CHC technology and the generation of cavitation bubbles, the bacteria cell will be ruptured. The water and other fluid components inside a bacteria cell will be released (lysate).

Lysate acts as a stimulant in the first phase of the anaerobic processes - enzymes cause the lyses of other microbial cells, as well as the hydrolysis of high-molecular soluble (glucose, acetic acid) and insoluble (biomass) organic substrates. Lysate directly stimulates hydrogenotrophic and acetotrophic methanogens, helping increase the rate of removal of propionic and formic acid, which is very important for sustaining the dynamic equilibrium of the process of methanization. The action of lysate is also indirect, in that it represents the source of growth agents, which have a significant stimulating effect on the present anaerobic microorganisms.

Therefore, release of lysate will result in the acceleration of the overall degradation reaction in the anaerobic process. It will also increase the decomposition of organic compounds normally found in wastewater. By increasing the degradation reaction, more methane will be generated and fewer solids will be formed. Overall, there will be an increase in the net energy from the biosolids.

1.5 CHC for Enhanced Dewatering

Sludge dewatering is used to remove as much water as possible from sludge to produce a highly concentrated cake, to reduce the costs of hauling large quantities of sludge long distances to a landfill or other disposal site.
Sludge contains bulk water, which is not bound with solid particles, and bound water. The bound water is the water captured in the interstitial spaces within particle flocs and within the bacteria cells. Water accounts for ~ 80% of bacteria mass. The current dewatering methods used, such as centrifugation, vacuum and belt press can remove the bulk water, but they cannot extract the bound water. After processing, the solid sludge still has 65% to 75% of water.

As described above, the application of CHC technology will rupture the bacteria cell. The water and other fluid components inside of bacteria cell will be released. Also, the floc will be broken so the captured water will be freed. This will facilitate the dewatering process and allow more water to be separated from the sludge. The solid cake will contain less water (40 – 60%). Consequently, the volume of solid sludge is minimized and the related transportation and disposal costs are reduced.

**PILOT STUDT RESULTS and DISCUSSION**

In applying the VRTX technology to WAS, a pilot operation was conducted on a 200,000 gallon per day SBR plant in Michigan. The site was chosen based on the flexibility it allowed to treat different ages of WAS and the ability to study various sludge solids content. The results of the pilot study are shown in Figures 6-10.

Figure 6 indicates that CHC treatment does not have a significant effect on total COD of the sludge. This is expected since there is no significant oxidation occurring and therefore no change in COD is expected. However, as shown in Figure 7, the soluble COD does increase. This is due to the combination of cavitation and high shear that occurs within the VRTX chamber. The treatment clearly showed lysing of the cellular membrane with the associated release of material into the sludge increasing the soluble COD.

![Figure 6. Effects of CHC on Total COD](image-url)
The reduction of approximately 17% in TSS is also a direct correlation to bacteria eradication and a corresponding release of internal cellular constituents into the WAS (Figure 8).
An additional benefit of applying VRTX to WAS was a significant reduction in particle size and a corresponding uniformity in particle size (Figure 9). While not demonstrated in the pilot study, it is believed that this reduction in particle size would contribute to an increase in digestion (more surface area for the bacteria to act on).

![Figure 9. Effects of CHC on Return Activated Sludge Particle Size](image)

Some of the most promising data involved the significant reduction in the sludge volume index (SVI), a measure of the settleability of the WAS. Applying VRTX showed reductions of 45%, depending on the age of the WAS (Figure 10). This should aid in the dewatering of the sludge and has been demonstrated in other reports (Banaszak, 2007).

![Figure 10. Effects of CHC on Sludge Volume Index](image)
CONCLUSIONS

The results of the pilot test have shown that VRTX Controlled Hydrodynamic Cavitation can:

1. Improve dewatering via declumping, thereby releasing water from hydrated inert particles along with destruction of filamentous bacteria via bacteria cell lysis

2. Increase the soluble COD

3. Maintain a relatively stable total COD during treatment

4. Reduce TSS and VSS by 15-17%

5. Reduce SVI by 21% to 47%

6. Reduce the particle size of the WAS (125 to 25 microns) by up to 80% and improve size uniformity

Although it was not demonstrated in this study, the increase in soluble COD and the reduction in particle size will most likely result in an increase in methane generation. Future plans are to demonstrate this technology at a utility with methane capture and co-generation facilities.

REFERENCES


