SLUDGE MINIMIZATION TECHNOLOGIES- DOING MORE TO GET LESS

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ABSTRACT

Sludge minimization technologies have been available for several decades; however recent developments have brought some sludge minimization technologies to the forefront. All of the technologies utilize one or more of three basic approaches to minimize the amount of waste activated sludge produced by an activated sludge process: cell lysis, cyclic oxic environments, and long solids retention time. This paper will discuss the three basic mechanisms, will review the development of several sludge minimization technologies, and will report on the current viability of each technology as well as current research needs for each.

Sludge minimization refers generally to the optimum reduction of the mass of sludge or biosolids produced at a wastewater treatment facility. The sludge minimization technologies that have emerged perform their main solids reduction mechanisms within the activated sludge process, prior to sludge stabilization and conversion to a biosolid. These are the technologies that are of interest in this paper. A fundamental understanding of the basic mechanisms available to minimize sludge production is needed prior to evaluating the various sludge minimization technologies that are emerging onto the market. From that understanding, each technology can be evaluated.

Early attempts at sludge minimization focused on long solids retention times within the activated sludge process, and the reduced sludge production was seen as a benefit of extended aeration plants. Ultrasonic cell lysis was first developed through laboratory-scale research in the 1960s, but was initially uneconomical due to limitations of the ultrasound equipment available at that time. Advances in ultrasound technology in the last decade have enabled commercial application of the technology for wastewater applications. Ultrasound can be used for sludge minimization in the activated sludge process or in digestion. The Cannibal™ process has shown recent success, and is marketed by Siemens USFilter. IDI has developed a competing process, know as Biolysis® 'O'. Both of these technologies emphasize cyclic alternation between aerobic, anoxic and anaerobic environments. The MicroSludge™ homogenization process is another recent development for sludge minimization, relying on chemical pretreatment and mechanical shear forces to lyse bacterial cells.

Each of the technologies discussed briefly above, will be more fully described with information on the history of the technology development, the basic mechanisms of sludge reduction, installations and performance information, economic considerations, and the identification of

research needs for each technology. Other technologies in earlier stages of development will also be identified.

KEYWORDS

Sludge reduction, waste activated sludge, minimization, hydrolysis, cell lysis, cyclic environments.

INTRODUCTION

Sludge minimization technologies have been available for several decades; however recent developments have brought some sludge minimization technologies to the forefront. All of the technologies utilize one or more of three basic approaches to minimize the amount of waste activated sludge produced by an activated sludge process: cell lysis, cyclic oxic environments, and long solids retention time. Sludge minimization refers generally to the optimum reduction of the mass of sludge or biosolids produced at a wastewater treatment facility. The sludge minimization technologies that have emerged perform their main solids reduction mechanisms within the activated sludge process, prior to sludge stabilization and conversion to a biosolid. A fundamental understanding of the basic mechanisms available to minimize sludge production is needed prior to evaluating the various sludge minimization technologies that are emerging onto the market. From that understanding, each technology can be evaluated.

Early attempts at sludge minimization focused on long solids retention times within the activated sludge process, and as an example the reduced sludge production was seen as a benefit of extended aeration plants. Ultrasonic cell lysis was first developed through laboratory-scale research in the 1960s, but was initially uneconomical due to limitations of the ultrasound equipment available at that time. Advances in ultrasound technology in the last decade have enabled commercial application of the technology for wastewater applications. Ultrasound can be used for sludge minimization in the activated sludge process or in digestion. The Cannibal™ process has shown recent success, and is marketed by Siemens USFilter. IDI has developed a competing process, know as Biolysis® 'O'. Both of these technologies emphasize cyclic alternation between aerobic, anoxic and anaerobic environments. The MicroSludge™ homogenization process is another recent development for sludge minimization, relying on chemical pretreatment and mechanical shear forces to lyse bacterial cells.

There are other technologies in earlier stages of development. These include pulse power, which uses electronic pulses to lyse the cells, the lysate centrifuge which uses the discharge force of the centrifuge to lyse cells against a lysate ring that is integrated into the centrifuge and milling equipment to lyse cells.

Each of the technologies discussed briefly above, will be more fully described with information on the history of the technology development, the basic mechanisms of sludge reduction, installations and performance information, economic considerations, and the identification of research needs for each technology.

MECHANISMS OF SLUDGE MINIMIZATION

In the activated sludge process, biodegradable organic material in the influent wastewater is used by microbes, with some converted to cellular material for growth and reproduction of the microbes, some used as energy sources to maintain the microbes' metabolism, with byproducts, such as carbon dioxide and water. In activated sludge systems the waste activated sludge (WAS) yield is between 0.7 and 0.8 kg/kg BOD. The treatment process therefore produces an increase in the biomass, although the yield is less than the value of the influent organic load. The organic material contained in the biomass is slowly biodegradable, largely due to the time required to break down the cell walls. In mesophilic digestion this may take 8 days or more. All types of sludge minimization technologies operate by increasing the consumption of the biomass as a food source, thus reducing the overall production of biomass. This consumption may take place within the activated sludge process, in a downstream digester, or in an additional secondary treatment stage.

Extended aeration is a proven process for reducing sludge yields, and has been implemented at many wastewater treatment plants (WWTPs) worldwide. This process operates by allowing sufficient solids retention time (SRTs) in the activated sludge process to allow for natural cell death and breakdown of cell walls. Extended aeration processes can operate at SRTs of 20 to 25 days, and some plants have operated at significantly longer SRTs up to 60 days. High mixed liquor suspended solids (MLSS) concentrations are required to provide these long SRTs without excessive tankage and this can affect the stability of the secondary treatment process and impact performance of the secondary clarifiers.

The newer generation of sludge minimization technologies aims to increase the biodegradability and the rate of degradation of the biomass produced in the wastewater secondary treatment process. The authors have been actively involved in the development and testing of these new technologies, working with academic institutions, municipalities and some of the vendors mentioned in this paper.

Hydrolysis has long been held as the rate limiting step in the decomposition of biological sludges. Cell lysis technologies aim to increase the rate of hydrolysis by lysing the cellular material, releasing the organic material into the substrate. Some technologies rely primarily on physical lysis, such as ultrasound, while others such as Microsludge™ combine chemical and physical processes.

Other technologies rely on changing reactor environments and availability of oxygen to affect the biological processes and biodegradability of sludge. This is accomplished through cyclic environments that alternate oxic, anoxic and facultative conditions, such as in the Cannibal™ process. The Biolysis® 'O' process creates an extreme oxidation condition through contact of solids with ozone, improving biodegradability of the biomass when it is returned to the activated sludge system. The mechanisms by which changing reactor environments and causing microbial stress affect the biodegradability of sludge is an emerging area of scientific development.

HOMOGENIZATION - MICROSLUDGE

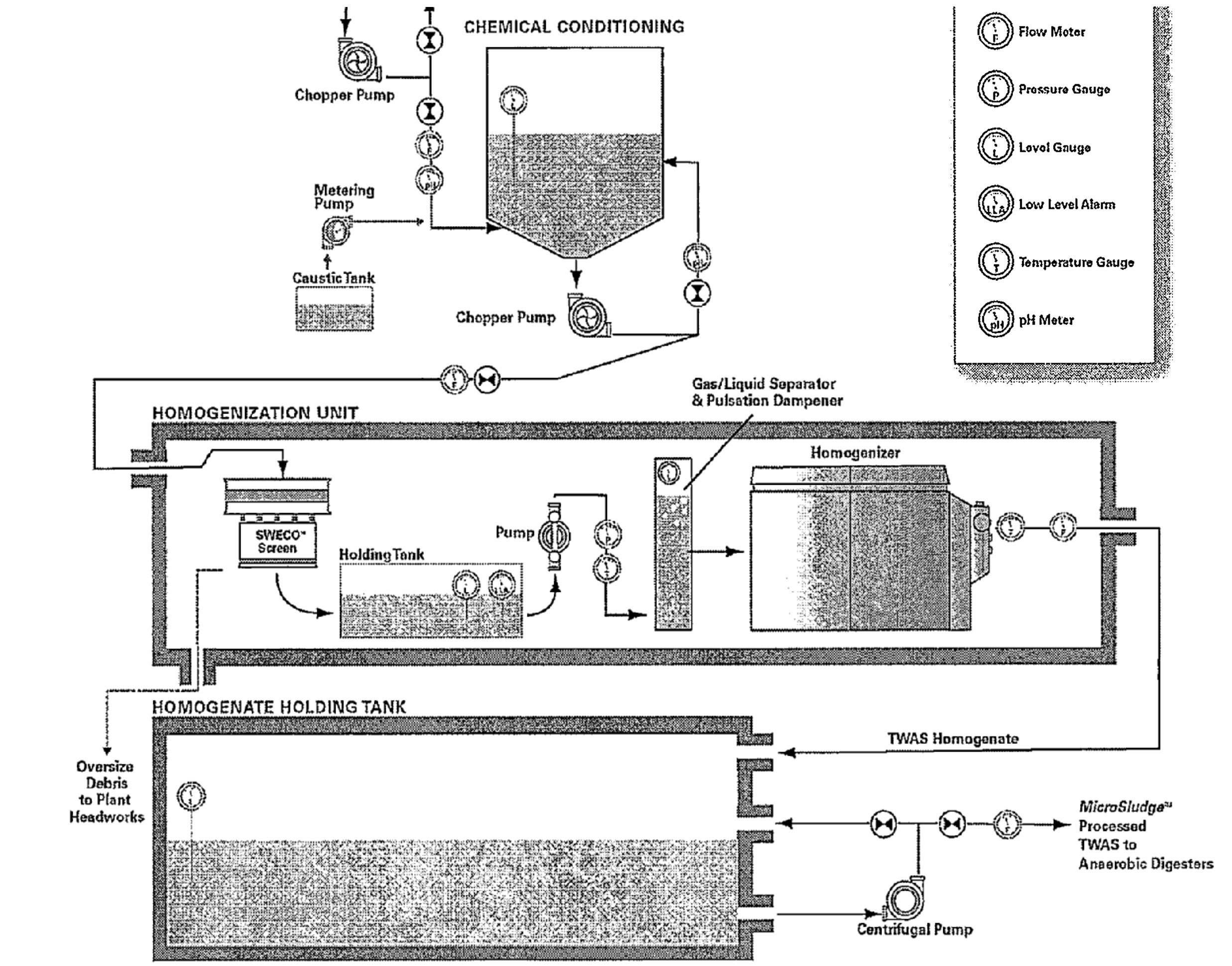
Homogenizers are used in a wide range of industrial applications, particularly in the food industry. In North America, this technology has been brought from the dairy industry to wastewater treatment by Paradigm Environmental through the patented MicroSludge™ process. This is a chemical and pressure pre-treatment process that increases both the rate and extent that thickened WAS is degraded in a conventional mesophilic anaerobic digester. The process uses alkaline pre-treatment to weaken cell membranes and reduce viscosity, and a high-pressure homogenizer to provide an enormous and sudden pressure change to burst the cells. The liquefied WAS is more readily converted to biogas in the digestion process.

The chemical step uses sodium hydroxide to raise the pH to between 9 and 10. Chopper pumps are used to break up large particles and a fine 800 µm screen is used to remove particles that could damage the homogenizer. A gas/liquid separator and pulsation dampener is also required prior to the homogenizer to prevent gas-locks occurring. The homogenizer itself is essentially a valve with a narrow passage-way of less than 1 mm, through which the sludge is pumped at 82,700 kPa (12,000 psig). The pressure drop across the homogenizer liquefies the sludge, and also provides a net increase in sludge temperature of 20 to 25ºC (68 to 77ºF). The principal O&M costs of the process are chemicals and power. The principal benefits of the process are the increased biogas production associated with the increased volatile solids reduction (VSr), a reduction in the digester hydraulic retention time (HRT), and the reduced quantity of digested biosolids that requires dewatering and disposal. To date this process has been tested for WAS pre-treatment for enhanced anaerobic digestion. It is conceivable that the process could equally be applied on a sidestream of return activated sludge (RAS) to provide reduced sludge production from the activated sludge process.

Installations

The first full-scale demonstration of the process was carried out in 2004 at the Chilliwack WWTP in Canada (Rabinowitz and Stephenson, 2005). The Chilliwack plant had two anaerobic digesters operated in sequence treating primary sludge and trickling filter/solids contact sludge in a ratio of 65:35, with total digester HRT of 13 days. As one digester was approximately twice the size of the other, the setup was not amendable to the use of one digester as a test digester, with a parallel control digester. The test was therefore conducted with Microsludge™ testing May through July 2004, followed by monitoring of performance without Microsludge™ August through October 2004. As part of the test the WAS was thickened in a rotary drum thickener to 4 percent TS. Thickening and homogenization was conducted 10 hours per day. The homogenate was stored in a holding tank and fed to the digesters over each 24 hour period. Figure 1 provides a process flow schematic for the Microsludge™ process as tested at Chilliwack. The Chilliwack test had some shortcomings. The control test could not be conducted in parallel with the Microsludge™ test. Digester gas production was not measured as the gas meters were not reliable, and total biosolids hauled from the plant were not measured, which did not allow for checks on the digester mass balance calculations used to measure digestion performance.

Figure 1 – Microsludge™ Process as Tested at the Chilliwack WWTP



Since late 2005 a full-scale demonstration of the MicroSludge™ process has been operating at the 400 MGD Joint Water Pollution Control Plant in Los Angeles County, California. The plant has 24 mesophilic anaerobic digesters, each with a volume of 14,500 m^3 (3.8 million gallons) and an HRT of approximately 19 days. The digesters are fed with a 68:32 mix by mass of primary sludge and WAS from a pure oxygen activated sludge process. As part of the full-scale demonstration, two 4,000 L/h homogenizer modules have been continuously operated for 24 hours per day to process approximately 192 m^3/day (50,000 USGPD) of thickened WAS at a nominal solids content of 6 percent. Primary sludge and pre-treated WAS have been fed to a dedicated experimental digester. A parallel control digester has also been monitored to provide side-by-side performance comparison. It was anticipated that this test would address the shortcomings of the Chilliwack test. One critical difference between the setup of the Los Angeles test compared with the Chilliwack test is the absence of the homogenate holding tank, as the Microsludge™ units were sized to operate and feed the digester continuously. Other differences inherent between the two installations are the type of secondary process, the HRT in the digesters and the difference in scale.

Performance

The Chilliwack test showed significant digester performance improvement, based on the solids mass balances calculated across the digesters. The MicroSludge^{TM} pre-treatment of the thickened WAS resulted in an average VSr of 78 percent despite an HRT of only 13 days (Rabinowitz and Stephenson, 2005). An extrapolation of data from the demonstration suggests that the VSr in the WAS alone was over 90 percent. This compares with typical WAS VSr of 35 to 40 percent in typical mesophilic digestion systems. Further, the process appears to liquefy both the volatile and fixed solids fractions of the sludge. During the control test, the VSr at the plant was 60 percent. This is higher than VSr performance typically seen across North America (low to mid 50 percent), particularly given the very short HRT. As noted above, the mass balance calculations could not be verified by digester gas production or total dewatered biosolids volumes. Work is ongoing as part of the Los Angeles trial to confirm the impacts of Microsludge^{TM} on sludge reduction through the digestion process, and in particular to evaluate the role of homogenate storage as an acid fermentation reactor and the importance of this step.

Economics

Microsludge^{TM} intends to manufacture units in self-contained modular units up to 24,000 L/hr (576 m^3/d or 152,000 gpd) capacity. The systems include the caustic system, chopper pump, screen and homogenizer, housed within a shipping container. Costs quoted in 2005 ranged from around \$2 million for an 8,000 L/hr unit (190 m^3/d or 50,000 gpd) to \$4.4 million for the largest module of 24,000 L/hr and future costs will change to reflect changing commodity and labor prices. Installation of a Microsludge^{TM} system would entail other costs, including storage of thickened WAS (TWAS) or homogenate, piping, pumping to or from the system, electrical, instrumentation and control costs, site preparation, utilities, screenings handling, construction costs and costs for an alternative building if a shipping container is not the preferred means of housing. Larger units would not be modularized and would require customized on-site construction. The life cycle cost-benefits will be more favorable for thicker sludges. Electricity, natural gas and biosolids handling costs will also affect the economic balance and pay back period. The heat produced through the homogenization process raises the temperature of the sludge by approximately 20ºC, which reduces the heat required for digestion. Actual economics and payback periods will be site specific. Table 1 presents an example of operation and maintenance (O&M) costs for Microsludge^{TM} with digestion, comparing potential economic differences between TWAS with a solids concentration of 4 percent and 6 percent. The estimates assume that there is existing excess co-generation capacity at the plant to utilize all the increase in gas production. The economic benefits of MicroSludge^{TM} pretreatment are greater for plants facing higher unit power and biosolids disposal costs. Other site-specific aspects that may impact maintenance costs for the Microsludge^{TM} equipment include the presence of abrasives and chlorides in the sludge, both of which will reduce the life of metal components.

The economics for installation of a Microsludge^{TM} system on a RAS recycle for reduction of WAS production from the activated sludge process would be considerably different. Gas production from the digesters may be reduced due to the reduction in quantity of WAS produced. The heat produced through the homogenizer would not have a direct natural gas heating offset, but may have some benefits for reaction rates within the activated sludge plant, particularly in colder climates. The addition of caustic may also be a benefit in nitrification in plants that may be alkalinity or pH limited. Aeration requirements in the activated sludge process may also increase, with a corresponding increase in electricity consumption. However, there would be potential savings in O&M and future expansion capital costs for digester and dewatering facilities and biosolids management. Testing of the Microsludge™ system would be required to ascertain the benefits of this system for secondary treatment.

Table 1 – Example O&M Costs for Microsludge™ for WAS Pre-treatment for Anaerobic Digestion

Item	Unit Cost	Unit	Cost/dry ton TWAS (4% TS)[1]	Cost/dry ton TWAS (6% TS)[2]
Electricity	$0.06	/kWh	($46)	($30)
Caustic	$0.60	/L	($13)	($9)
Maintenance			($15)	($10)
Total O&M			($73)	($50)
Natural gas offset	$8.50	/GJ	$78	$78
Heat from homogenization	$8.50	/GJ	$18	$12
Biosolids Management Savings	$120	dt	$49	$49
Total Savings			$145	$139
Net O&M Value			$72	$90

[1] Based on data from Chilliwack WWTP trial. Assumes CH_4 at 64%, biosolids management at $30/wt, 25% TS cake. Does not include cost of handling screenings. Performance assumptions to be adjusted based on final data from Los Angeles trial.
[2] Estimated

ULTRASOUND

The application of high intensity ultrasound has significant potential for minimizing secondary treatment process WAS production, or improving solids reduction in the digestion process. Ultrasound is sound above the range of human hearing, with frequencies between 20 kHz and 10 MHz. At the lower end of this range the compaction and rarefraction waves generated by ultrasound lead to the formation of cavitation bubbles in the fluid, which implode creating high mechanical shear forces. The implosions create localized hot spots with conditions similar to the sun, reaching temperatures up to 5,000ºK and pressures up to 500 bar (7,250 psig). Jet streams caused by the implosions can have speeds up to 400 km/hr (250 miles/hr). These forces can be used for disintegrating solids in the fluid. For wastewater applications it has been shown that ultrasound is most beneficial when applied on biological secondary solids, where rapid hydrolysis can be induced, releasing the nutrients in the cells for consumption in the activated sludge or anaerobic digestion process.

Installations

Ultrasound is used in a wide range of industrial applications, in many different frequencies and forms. There are, therefore, an extensive list of ultrasound manufacturers in North America and Europe. However, the number of manufacturers with equipment designed for wastewater treatment applications and with experience in this field is limited. The two main suppliers are Ultrawaves, represented in North America by Dorr Oliver Eimco's Sonolyzer™ equipment, and Sonico with the Sonix™ system. Ultrawaves is a German company that was established as a spin-off from ultrasound research conducted at the Technical University of Hamburg-Harburg, which purchases the ultrasound equipment from Sonotronic, a local manufacturer. Sonico is a U.K. company that was established as a joint venture company between Purac, an equipment supply company, and Atkins, an engineering consulting company that conducted applied research in ultrasound wastewater applications. Sonico purchases the ultrasound equipment from Branson, a company based in the U.S.A. These two companies have the largest number of installations in wastewater applications, with over 30 installations in Europe, Asia and Australia. The largest installation is the Sonico installation for WAS pre-treatment for enhanced digestion at the 400 MLD (106 mgd) Mangere WWTP in New Zealand. Two smaller companies also have a few smaller wastewater installations, Ultrasonus from Sweden and VTA from Austria. IWE Tec was a German company that had acquired representation in North America in 2003; however this company has since ceased operation.

Ultrasound may be generated by two different methods, magnetostrictive and piezoelectric. The former uses electric energy, passing through a magnetic coil attached to the vibrating piece to produce the mechanical energy, or vibration. The latter uses electrical energy, converted to high frequency electric energy, which is applied to piezoelectric crystals that vibrate at the same frequency. The crystals are attached to the vibrating piece (known as the sonotrode, probe or horn), causing the vibration to be transferred to the liquid. Magnetostrictive systems typically have a longer life, but lower energy efficiency as the electrical energy applied is converted to magnetic energy prior to being converted to mechanical energy. For wastewater applications it appears that the economics favor the use of piezoelectric systems due to the high energy intensity required to lyse the cellular material in the sludge.

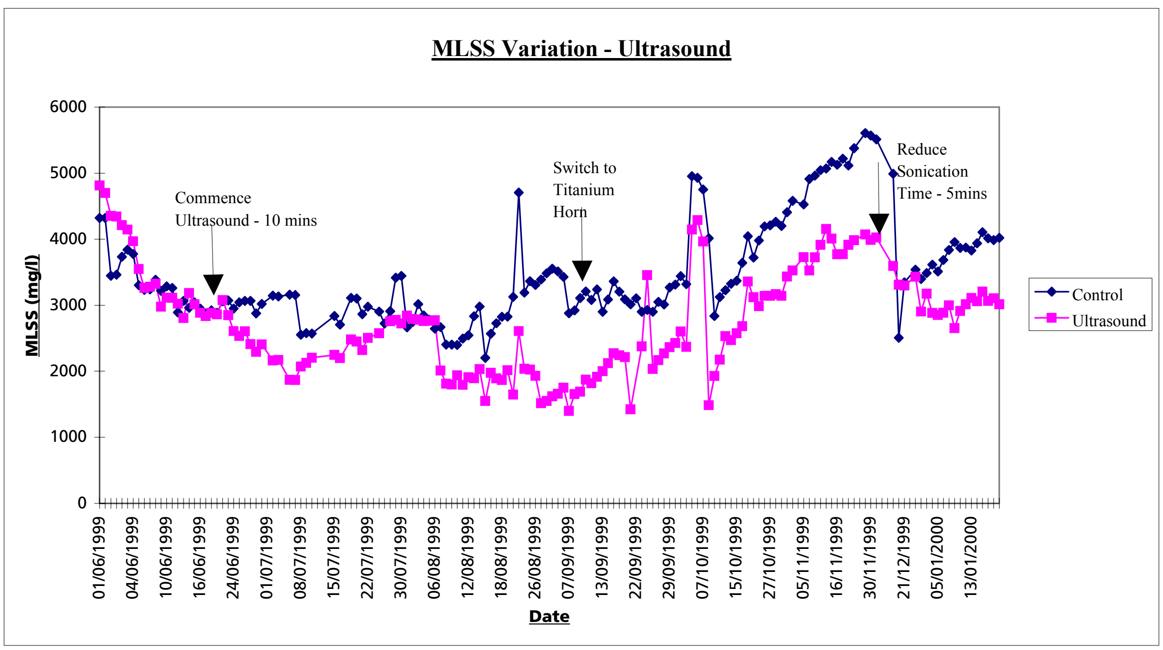
There are differences in the ultrasound systems available for wastewater treatment. Each manufacturer uses a unique shape for the vibrating ultrasound piece, for example UltraWaves uses short rod shaped sonotrodes that project into the flow path, while Sonico uses ring shaped horns that sit within a pipe spool. Ultrawaves treats a smaller portion of the flow for a longer retention time, while Sonico typically treats a greater portion of the sludge flow for a considerably shorter retention time. Each probe in the Ultrawaves system is rated for 2 kW power input, but typically operates at 1 kW. Sonico has 3 kW and 6 kW horns, with the latter as their standard unit, operating at 50 to 60 percent of rated power.

The majority of ultrasound applications to date have been for WAS pre-treatment prior to anaerobic digestion. However, both Ultrawaves and Sonico have European installations on RAS streams within the waste activated sludge process.

Performance

Ultrasound installations in Europe show that treating a sidestream of the RAS flow can reduce WAS production from the secondary treatment process by 25 to 50 percent, depending on characteristics of the sludge, operation of the secondary treatment process and the amount of power input to the system. Sludge minimization tests were conducted by Anglian Water in the UK to compare bioaugmentation (addition of a fermented bacteria and nutrient solution) with a Sonico ultrasound system in parallel activated sludge lanes (Griffiths, 2001).

Figure 2 – MLSS Reduction During Ultrasound Test at Anglian Water Cambridge WWTP Pilot Activated Sludge Plant



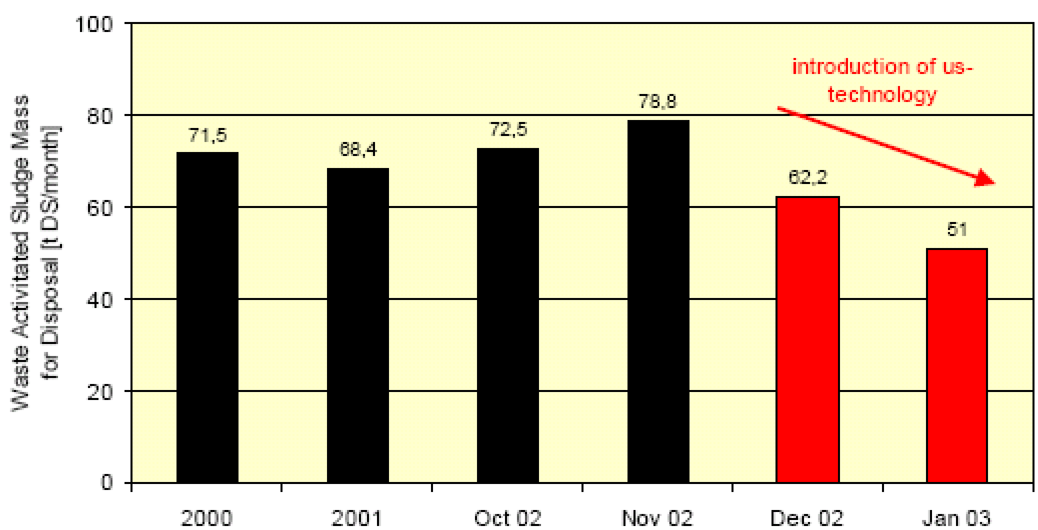
(Griffiths, 2001)

The control lane was operated at a solids retention time (SRT) of 12 to 15 days and a mixed liquor concentration of 3,500 mg/L. The test showed that a titanium ultrasound horn system treating approximately 1/6th of the RAS flow provided up to 30 percent reduction in WAS production, compared with 5 to 9 percent reduction with the bioaugmentation process. Figure 2 compares the MLSS concentration in the control and ultrasound lanes. The ultrasound system was also found to have an additional advantage in reducing the impact of filamentous foaming and maintaining good settleability (95 ml/g) during a period when filamentous organisms reduced the settleability of the control lanes (140 ml/g). No increase in aeration demand was noted during the test.

The Leinetal WWTP in Heiligenstadt, Germany tested an Ultrawaves ultrasound system prior to full-scale installation. The activated sludge process was operated as an extended aeration process, with an SRT of 18 days and experienced problems associated with bulking sludge. The ultrasound system was installed to treat 30 percent of the thickened secondary sludge flow, which was then returned to the aeration basins. The test showed that the ultrasound system reduced WAS production by 30 percent, improved settleability of the secondary sludge and increased the dewatered cake dryness by 2 percentage points. Foaming and bulking problems were also eliminated. The full-scale installation has been operational since June 2003 and the plant has been able to avoid construction of a new aeration tank.

Treating a thickened sludge stream, rather than unthickened RAS, may improve the cost-effectiveness of ultrasound installations for activated sludge applications, as the ultrasound systems are designed to maintain a specified hydraulic retention time within the sonication chamber to achieve cell lysis.

Figure 3 - Leinetal WWTP Impact of Ultrasound on Waste Activated Sludge Production



Ultrasound applications for WAS pre-treatment prior to anaerobic digestion have shown that with appropriate levels of sonication WAS will achieve similar digestion rates to primary sludge, typically increasing the VSr of the WAS from 40 percent to 60 percent. The overall improvement in digester VSr will depend on the ratio of primary to WAS in the digester feed, as well as other site-specific conditions, such as baseline performance of the digesters and sludge characteristics. As ultrasound increases the hydrolysis rate, the impact will be greatest for digesters at short HRTs where cell lysis was rate limiting. Excess polymer dosing for WAS thickening will reduce the effectiveness of ultrasound as particles may re-agglomerate if there is active polymer still present.

Economics

Ultrasound systems are typically manufactured in modular units, with different suppliers providing different configurations and sizes. Ultrasound systems are sized to treat a unit flow for a certain retention time. Therefore, the systems will be more cost effective on thicker sludges. However, over around 6 to 7 percent solids concentration the energy required to overcome the sonication threshold or cavitation attenuation caused by higher viscosities and solids concentrations will rise. Ultrawaves systems are provided in modular units, each with five probes, as shown in Figure 4. Flow through one unit will vary depending on the level of sludge reduction required. Treating 30 percent of the WAS through the unit at approximately 30 m^3/d (8,000 gpd) would typically provide a 15 percent improvement in sludge reduction while a flow rate of 15 m^3/d (4,000 gpd) would typically provide a 30 percent improvement in anaerobic digestion. To accommodate higher flows, additional units would be installed in parallel or in sequence.

Figure 4 – Ultrawaves Sonolyzer™ Unit

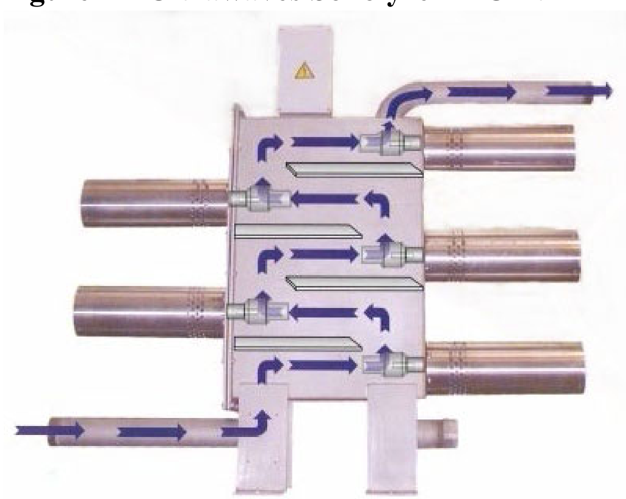
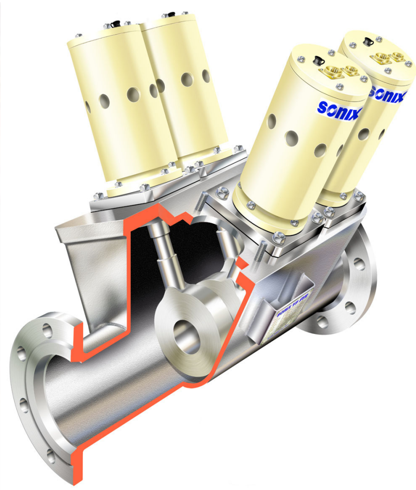


Figure 5 – Sonico Ultrasound Unit



Sonico's ultrasound systems are manufactured to fit in a 6 inch diameter pipe, as shown in Figure 5. Systems can be customized to provide the required number of horns required, either in series or in parallel. The Sonico system supply typically includes the feed pumps, system instrumentation, ultrasound hardware, control cabinet and automated SCADA system with PC, housed within a shipping container. Costs quoted in 2005 ranged from around $500,000 for an 4,000 L/hr unit (96 m^3/d or 25,000 gpd) to $900,000 for a 15,000 L/hr (360 m^3/d or 95,000 gpd) and $2.2 million for a system to treat 37,000 L/hr (888 m^3/d or 235,000 gpd). Future costs will change to reflect changing commodity and labor prices among other factors. Alternatively the units can be installed within pipe galleries or existing buildings, as the units are designed to connect directly to 6 inch flanged pipes. Sound enclosures are important for such installations as all ultrasound systems create sub harmonics that are within the range of human hearing.

Installation of an ultrasound system would entail other costs, including storage of TWAS, piping, additional pumping to or from the system, electrical, instrumentation and control costs, site preparation, utilities, maceration or pre-screening (if fine screens are not used at the headworks), construction costs and costs for an alternative building if a shipping container is not the preferred means of housing. The life cycle cost-benefits will be more favorable for thicker sludges. Electricity, natural gas and biosolids handling costs will also affect the economic balance and pay back period. Actual economics and payback periods will be site specific. Table 2 presents an example of operation and maintenance (O&M) costs for ultrasound with digestion, comparing potential economic differences between TWAS with solids concentrations of 4 percent and 6 percent. The estimates assume that there is existing excess co-generation capacity at the plant to utilize all the increase in gas production. The economic benefits of ultrasound pretreatment are greater for plants facing higher unit power and biosolids disposal costs.

Table 2 – Example O&M Costs for Ultrasound for WAS Pre-treatment for Anaerobic Digestion

Item	Unit Cost	Unit	Cost/dry ton TWAS (4% TS)[1]	Cost/dry ton TWAS (6% TS)[1]
Electricity	$0.06	/kWh	($3)	($2)
Maintenance			($7)	($5)
Total O&M			($10)	($7)
Natural gas offset	$8.50	/GJ	$30	$30
Biosolids Management Savings	$120	dt	$19	$19
Total Savings			$50	$50
Net O&M Value			$40	$43

[1] Based on digester VSr improvement to 60 percent, CH_4 at 64%, biosolids management at $30/wt, 25% TS cake and equipment maintenance data from Sonico. Does not include pre-screening or maceration costs.

The economics for installation of an ultrasound system on a RAS recycle for reduction of WAS production from the activated sludge process would be considerably different. Gas production from the digesters would be reduced due to the reduction in quantity of WAS produced. However, there would be potential savings in O&M and future expansion capital costs for thickening, digestion, and dewatering facilities and biosolids management. As shown in the Anglian Water trial, the ultrasound system allowed the activated sludge system to operate effectively at lower MLSS concentrations and minimized the impact of filamentous organisms on sludge settleability. This could provide an advantage at WWTPs where the secondary clarifiers may be solids overloaded. As noted at the Leinetal WWTP test, the facility was able to avoid construction of another aeration lane by installation of the ultrasound system, as well as reducing WAS production by 30 percent.

CANNIBAL

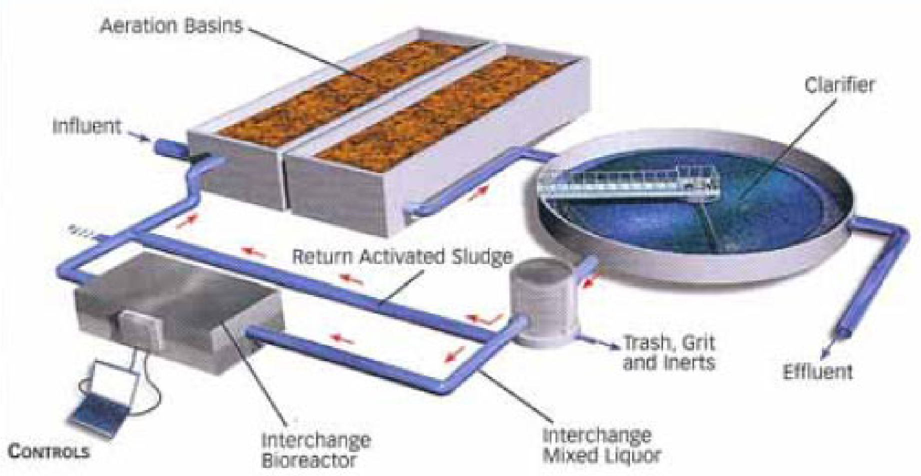
US Filter has developed a package of technologies they market as the Cannibal™ process. Unlike homogenization and ultrasound technologies that use physical cell lysis to promote rapid hydrolysis and release of organic material within cellular material, the Cannibal™ process uses cyclic environments to reduce the production of WAS from a secondary treatment system. The Cannibal™ system also differs from the previous two technologies in that it is a process tied in with the secondary treatment process to prevent production of WAS for digestion, whereas homogenization and ultrasound can be used to reduce WAS in either the secondary process or in the digestion process. Versions of the Cannibal process have been in operation since the late 1990s at municipal and industrial wastewater treatment plants.

The Cannibal™ process consists of two primary processes, a physical separation step, and a biological treatment step, as depicted in Figure 6. The physical separation step, or solids separation module (SSM), consists of a very fine drum screen (250 µm perforations) that removes inert organic matter from the bioreactor. The screens treat approximately 50% of the RAS flow rate on a continuous basis.

The second part of the SSM is a set of hydrocyclones that are intermittently operated on the RAS, generally on a monthly basis. The underflow from the hydrocyclones is discharged into a classifier similar to that used for grit washing in the headworks. These remove heavy organic material, grit and dense inorganic particles that will accumulate without wasting of sludge. The material produced by the SSM steps is a stabilized material that does not require digestion.

The biological treatment part of the Cannibal™ process is the heart of the process and consists of an additional biological tank, called the interchange reactor. The flow which would normally be considered WAS is wasted to this additional reactor on a daily basis, using a conventional calculation of the MLSS inventory in the main activated sludge process and a typical SRT of 8 to 15 days. The interchange reactor is sized for a 10 to 12 day SRT, with a solids concentration no greater than 1 percent. Air is intermittently applied to maintain the tank at the cusp between anoxic and anaerobic conditions and allow the growth of facultative microbes. These conditions are maintained by monitoring oxidation reduction potential (ORP) and intermittently applying coarse bubble aeration to produce nitrates. In between aeration events, the solids are allowed to settle. Each day a portion of the material in the interchange reactor is returned to the main bioreactor system. A mixer is activated prior to returning mixed liquor from this tank back to the activated sludge plant. The process continues in the closed loop cyclic interchange between oxic and facultative conditions, with no sludge wasting from the process. However, it is recommended that one inventory of solids be purged on an annual basis.

Figure 6 – Flow Schematic of the Cannibal Process Integration with an Activated Sludge Plant



(Sheridan and Curtis, 2004)

The cyclic environments support the growth of different microbial communities, while microbes not adapted for that environment are stressed. This leads to changing the biodegradability of the cellular material and each community of microbes utilizing the other as a carbon source in their respective reactors. The end result of this process is that the amount of traditional WAS from the secondary process is reduced significantly. These savings are offset by the production of the screenings from the SSM, but the net benefit is a reduced solids production from the plant.

Installations

There are a number of municipal and industrial installations with versions of the Cannibal™ process, with more currently in design or construction. The concept was first implemented in 1998 at a small 3.8 MLD (1 mgd) Sequencing Batch Reactor plant in Georgia. A 60.6 MLD (16 mgd) facility is currently under startup and another is due to start construction this year in Albany, Oregon. The technology was commercially introduced by US Filter in 2003. The Solids Separation Module has been implemented at the newer installations, including installations in southern California and Illinois that have been operating since late 2004.

It has also been reported that a Mr. Boris Khudenko had a similar process with three installations, of which one is no longer operational due to industrial reuse and one pilot plant that is also not operational. His process is reportedly the basis for the design of the 56.8 MLD (15 mgd) Cartersville Plant in Georgia, which is currently under construction. Patent disputes will likely need to be resolved through the legal process.
Other work is being conducted, including bench scale tests under the guidance of Dr. John Novak at the Virginia Polytechnic Institute and State University to further understand the mechanisms of the process and verify empirical data from pilot and full-scale installations.

Performance

Installations with the fine screening and hydrocyclone steps show that this inert organic material is produced at a rate of approximately 0.2 to 0.3 kg TSS/kg BOD (±10%) applied to the bioreactor at a plant without primary clarification. The material is similar in form to paper pulp and dewaters fairly easily to 30 percent solids, is generally inert, 90 percent volatile and can be disposed of with the conventional screenings.

Annual purging of the system produces a WAS quantity that is equivalent to less than 0.1 kg/kg BOD treated. US Filter provides a two year guarantee that the observed yield will be less than this, supported by performance at existing installations that have run in excess of two years with the Cannibal™ process and produced solids quantities significantly less than the guaranteed level.

Currently one disadvantage is that biological phosphorus removal cannot be integrated with the Cannibal™ system as there is no wasting. Continuous addition of metal salts to the secondary process would also require frequent wasting and is therefore not compatible with the process. Phosphorus can be removed chemically in tertiary treatment steps, such as filters. Some of the authors of this paper are working on a method to overcome this disadvantage, but this has not been tested to date.

Odor generation from the interchange reactor is another potential disadvantage. At the start of the aeration cycle in the interchange reactor, a noticeable odor is normally discernable. It is recommended that the interchange reactor be covered and odor control provided at plants where odor is a sensitive issue.

Economics

The economic advantages of the Cannibal™ process will be site-specific and is most likely to be favorable for small to medium plants, particularly those below the threshold for anaerobic digestion systems. The cost of constructing the interchange reactor to provide a 10 day SRT at ≤1 percent solids concentration can be a significant capital expense. Covers and treatment for odor control, if required, will add to the capital cost. Capital and O&M costs for pumps, interchange reactor aeration system, screens, hydrocyclones and classifiers will also need to be included in the economic evaluation. Costs for the SSM portion are usually no lower than $ 1 million. However, savings in the construction, operation and maintenance of aerobic or anaerobic digestion systems, thickening and dewatering as well as significant reductions in solids disposal costs will provide offsets against the costs of the Cannibal™ system. For plants that have aerobic digester tanks that could be converted for use as Interchange Reactors for the Cannibal process, the economics would be particularly favorable, as this approach would use existing facilities, minimizing capital costs, while reducing energy costs associated with the high aeration demand for aerobic digesters. For larger plants that have existing digesters and co-generation equipment the cost benefit analysis and footprint requirements may not favor the Cannibal™ process over other available technologies, such as enhanced digestion processes.

IDI BIOLYSIS®

IDI through Ondeo-Degremont in France (now owned by Suez) has commercialized the Biolysis® process. It was developed as a process for improving sludge settleability while also reducing the quantities of WAS produced by activated sludge treatment plants. Chemical and enzymatic stressing are used to make cellular material biodegradable, limit microbial growth and increase the energy requirements for metabolism of bacteria. It is claimed that WAS production can be reduced by 30 to 80 percent. Two versions of the process have been developed.

The Biolysis® 'O' process uses ozone for chemical oxidation to stress the bacteria. The process consists of bringing mixed liquor from the activated sludge process, injecting ozone and passing it through a specially designed contact tower. The ozonated stream is then returned to the activated sludge process. The ozone stresses and oxidizes the biological material making it more readily biodegradable when it is returned to the activated sludge process, and reducing the reproducibility of a portion of the bacteria. The ozone is produced in a standard on-site generator.

The Biolysis® 'E' process uses a biological enzymatic process to achieve a similar effect. Mixed liquor from the activated sludge process is thickened and passed through a thermophilic enzymatic reactor operating at 50 to 60ºC (122 to 140ºF). This causes hydrolysis and enzyme release that prevents reproduction of the bacteria. The treated sludge is sent through a heat exchanger for heat recovery and returned to the activated sludge system. No external enzymes are used in this process. This process was originally developed in partnership with the Japanese company Shinko Pantec.

Installations

Full-scale demonstration testing of the Biolysis® 'O' process has been carried out in the United Kingdom and Lebanon, Oregon. Testing in 2004 at the Broomhaugh STW (Northumbrian Water Ltd) in the United Kingdom showed that Biolysis® O reduced biological sludge by 78 percent in one phase of the test and up to 100 percent in a second phase. Percent reduction was measured relative to a reference train of the plant. The representative ozone dosage for the test was established at 0.13 kg O_3/kg dry solids removed. It was also shown that the oxygen requirement of the activated sludge increased as the returned mixed liquor was oxidized with a mean increase of 41% as compared to the reference train. Sludge settleability was also measured during the test with SVI improvement from an average of 200 – 250 mL/g before the trial to 70 mL/g following.

A full-scale demonstration of the Biolysis® O process was also conducted at the Lebanon WWTP, Lebanon Oregon. The Lebanon facility is sized to treat 50,000 P.E (18.9 MLD or 5 mgd). Pretest average annual sludge production was 1,533 kg dry solids/day. The sludge reduction objective for the demonstration was 80% on a total solids basis at an ozone dose of at 0.13 kg O3/kg dry solids removed. The sludge SVI improvement objective for the test was to maintain a value of less than 100 mL/g.

Performance

Data from test installations of the Biolysis® 'O' process support the target reduction of up to 80 percent in WAS total solids, without removal of inert solids as is conducted in the US Filter Cannibal™ process. Design for a facility in France was based on a target 70 percent reduction in sludge. An ozone dose of 0.13 kg O_3/kg dry solids removed has also been shown to be practicable. However, the return of this highly degradable stream may increase the oxygen requirement of the activated sludge by up to 40 percent. Lower sludge volume index (SVI) values have also been shown, although the level of improvement will depend on the baseline SVI and the presence of filamentous bacteria prior to installation of the Biolysis® process.

Economics

The main capital costs for the Biolysis® 'O' process are the ozone generator, the MLSS sidestream pumping system and the injection system and contact tower. The principal O&M costs of the process are energy demand for pumping, increased aeration demand, and ozone generation. The capital costs for the Biolysis® 'E' process include the enzymatic reactor, heating and heat recovery system, as well as the MLSS sidestream pumping system. O&M costs would include energy for heating the process side stream to thermophilic temperatures.

The principal benefits of the process are the potential for improved performance and capacity of the secondary clarifiers due to consistently low sludge volume index (SVI) values and benefits due to the reduced quantity of residuals that require conveyance, treatment and disposal. The Biolysis® process may also have an important benefit over the Cannibal™ process, namely the lower footprint required. However, similar to the Cannibal™ system, savings in the construction, operation and maintenance of aerobic or anaerobic digestion systems, thickening and dewatering as well as significant reductions in solids disposal costs will provide offsets against the Biolysis® process costs. For larger plants that have existing digesters and co-generation equipment the cost benefit analysis requirements may not favor the Biolysis® process over other available technologies, such as enhanced digestion processes. Initial reviews for a facility in the U.S. indicates that the costs of the ozone system are significant and may not, depending of site specific factors, be as cost effective as alternative options.

OTHER EMERGING TECHNOLOGIES

There are other WAS reduction technologies that have not reached similar levels of commercialization for various reasons including financial constraints of the developer, slow market response to new technologies, changes in company structure or ownership, technical limitations at the time of development, or newness of the technology. Some of the more promising technologies are briefly discussed below.

Kady Bio-lysis System

Not to be confused with the IDI Biolysis® systems described above, the Kady Bio-Lysis System (BLS) was developed as an off-shoot application by Kady International, which manufactures mills for industrial applications. The physical shearing action provided by the Kady high speed rotor-stator mill can be used to promote cell lysis of biological sludge, although it appeared that the mill itself did not lyse cells, but reduced particle size and broke up filaments. A number of tests were conducted at different locations in the treatment process, including activated sludge recycle streams, WAS pretreatment for enhanced digestion and digester recirculation loops, with varying success.

The system was tested for almost a year at the 253.6 MLD (67 mgd) Springfield Regional Wastewater Treatment Facility, Massachusetts as part of a process to improve economics of the wastewater treatment process (Borgatti, 2004). The activated sludge system was changed to an extended aeration system, with a SRT of 18 to 22 days and a MLSS concentration increase from 2,000 to 5,000 mg/L. The Kady process was installed on two of the four trains, with thickened sludge pumped through the mill and returned to the secondary treatment basins. The trial results indicated that the extended aeration process provided a 30 percent reduction in WAS production compared with the lower SRT activated sludge process, while addition of the Kady process to two of the extended aeration trains increased the WAS reduction to 42 percent, providing a 40 percent improvement over the extended aeration system. The extended aeration process increased the aeration demand for the activated sludge process, but the demand in the Kady process trains was 8 to 9 percent lower than the other two trains. There were associated cost reductions in downstream solids processing and handling. However, the Kady process did not appear to improve the SVI and appeared to be susceptible to settling problems due to spring wet weather flows and these issues were not resolved at the time.

The Kady Bio-Lysis System was also tested on the digester heat recirculation loop at the 20.8 MLD (5.5 mgd) Caldwell WWTP, Idaho (Basu et. al, 2004). The digester was fed primary and secondary sludges. A grinder and basket strainer were installed upstream of the mill. Sludge loading to a test digester was increased in increments during the trial. A similar digester was used as the 'control', but was maintained at the baseline loading rate. However, the average VSr in the control digester appeared to be uncommonly low at 32 percent given a nominal HRT close to 24 days. This VSr was lower than the US EPA CFR 503 regulation VSr of 38 percent for Class B biosolids. VSr in the test digester averaged 60 percent. Gas production from each digester was not monitored, therefore the difference in VSr cannot be verified by this means.

Due to some restructuring within the company and a decision to focus on core business areas, the Kady wastewater process was withdrawn from the market. Recent communications appear to indicate that new supply agreements may bring the system back on the market.

Pulsed Power/Electron Beam Systems

Pulsed power or electron beam systems use pulsed electric currents within the sludge stream to cause shock waves and induce cell lysis. The technology was initially developed in Germany in 1997, and licensed to Scientific Utilization Inc (SUI), a U.S. company founded in 1992. The process operates by immersion of two electrodes into the sludge stream. Initial tests in Germany for WAS pretreatment prior to anaerobic digestion indicated that a gas production increase of 12 to 20 percent could be achievable. The process was tested using the SUI PulsePower® submerged plasma arc technology at a number of installations in the U.S., including Orange

County Sanitation District, California. Results indicated that the input energy was not sufficient to provide significant improvements in WAS reduction through the digestion process. In part due to lack of funding to further develop the technology, this application was not pursued further by SUI.

The technology appears to have given rise to recent interest from new companies that are seeking to develop similar processes, including OpenCEL, based out of Chicago, U.S.A and EB-Tech based in South Korea. OpenCEL performed a small scale 38 m^3/d (10,000 gpd) pilot test for treatment of a RAS sidestream on an activated sludge plant at the Lancaster WWTP, Ohio, using high voltage micropulses. Initial results appear to be promising. A larger scale trial is being implemented to test improvements in anaerobic digestion at the Lancaster WWTP with WAS pretreatment using the OpenCEL technology.

Lysate Thickening Centrifuge

The lysate centrifuge was developed in Germany and was known as the Baker Process, as mergers between German company and Baker Hughes in the U.S. led to the process being assigned to the Baker Hughes environmental division. The technology incorporates a lysate ring in the thickened sludge discharge of the centrifuge to shear cellular material, using the energy inherent in the discharge stream. A number of pilot tests were conducted in Germany and the Czech Republic in the late 1990s and early 2000's. These tests focused on sludge pretreatment for enhanced anaerobic digestion. Results showed digestion improvements, with up to 25 percent increase in digester gas production. However, Baker Hughes has since sold or dissolved its environmental division. The Bird Humboldt centrifuge business was bought by Andritz, but the Baker Process was not included in the sale. Dr. Dohanyos at the Institute of Chemical Technology in Prague conducted research into cell lysis technologies including lysate centrifuge. However, the authors are not aware of any company currently attempting to commercialize this technology.

Other Enhanced Digestion Technologies

The focus of this paper has been on technologies for WAS minimization. Some of these are technologies that are primarily suited for integration into the secondary treatment system, such as the Cannibal™ process. Others, such as MicroSludge™ and ultrasound, can be used to reduce WAS production from the secondary treatment process and/or from the digestion process. Other technologies exist that are primarily suited for reduction of biosolids generation through the digestion process rather than secondary treatment process applications. These include enhanced digestion processes such as staged or phased digestion processes, and the CAMBI thermal hydrolysis system. When considering overall solids reduction from WWTPs these technologies should also be included for evaluation of their role in the suite of processes available.

CONCLUSIONS

There are a number of technologies in early commercialization or pre-commercial testing that show significant promise in improving WAS reduction through the activated sludge and anaerobic digestion processes. In particular, cyclic environments technologies, as employed by the Cannibal™ and the IDI Biolysis® processes, appear to practically eliminate production of waste organic solids from the activated sludge process, with inert solids production in the range of 0.2 to 0.3 kg/kg BOD.

Cell lysis technologies appear to provide 30 to 40 percent reduction in total WAS production from activated sludge processes when treating a sidestream of the return activated sludge. Treating thickened sludge, increasing the proportion passed through the cell lysis process and increasing the input energy could potentially result in better performance. With the increased interest in WAS minimization and increasing biosolids management costs, vendors of these technologies may re-consider operating parameters for their systems. Cell lysis technologies can alternatively be implemented for WAS pretreatment to enhance sludge reduction through anaerobic digestion, typically increasing WAS digestibility 50 percent to a level similar to primary sludge. The Microsludge™ trials indicate that implementation of an acid or fermentation tank prior to digestion of lysed WAS may provide added improvements in the digestibility of WAS.

Selection of the most appropriate technology will depend on a number of site-specific factors, including existing facilities (secondary treatment, process air, thickening, digestion, dewatering, co-generation etc), capacity, baseline performance, available footprint, costs of electricity and natural gas, biosolids management costs. However, it is clear that there are a number of viable options to do more to get less sludge. As these technologies gain acceptance and are implemented, it provides opportunities to further our understanding of the processes involved, while also providing opportunities for improving the economics of these technologies as designs are refined and manufacturing reflects growing economies of scale from increased equipment demand.

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REFERENCES

Basu, S.; Abu-Orf, M.; Laquidara, M.; Boe, O.; Sanchez, G.; Law, G.; Muller, C.; Novak, J. (2004) High Rate Anaerobic Digestion with Mechanical Shear – A Case Study at the Caldwell, ID WWTP. *Proceedings of the 77th Annual Conference of the Water Environment Federation*, New Orleans, LA.

Borgatti, D. (2004) *Evaluation of the KADY Biolysis System at the 67-MGD Springfield Regional Wastewater Treatment Facility*. Seminar presentation, University of Massachusetts.

Rabinowitz, B.; Stephenson, R. (2005) Improving Anaerobic Digester Efficiency by Homogenization of Waste Activated Sludge. *Proceedings of the 78th Annual Conference of the Water Environment Federation*, Washington, DC.

Sheridan, J.; Curtis, B. (2004) Revolutionary Technology Cuts Biosolids Production and Costs. *Pollution Engineering*, May.