U.S.A.'s Practices for Controlling Pathogens in Biosolids

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Abstract

The U.S.A. initially established regulations for the management of sewage sludge in 1979 and updated them in 1993. They were designed to protect human health by minimizing the contact of humans with pathogenic microorganisms. Two types of disinfection processes are employed. Processes like pasteurization are employed to reduce pathogens below their analytical detection limits, while processes like anaerobic digestion are combined with requirements for organic matter reduction and access restrictions. Issues with the present disinfection alternatives such as their only being concerned with the presence or absence of certain pathogens like enteric viruses or *Ascaris* sp. are discussed and remedies suggested. Similarly, several of the current options for measuring vector attractiveness (stability) such as volatile solids reduction are in need of improvement. Work is underway to evaluate bacterial enzymatic activity and biochemical oxygen demand as possible measures of vector attractiveness. Innovative and alternative methods for disinfection are frequently proposed and it is important to understand how the stressors employed by the process contribute to its reduction of pathogenic bacteria, viruses, protozoa and parasites. For example with an alkaline disinfection process it may be possible to utilize the beneficial effects of time, temperature, pH, chemical agents like ammonia, and pressure. A two phase and batch thermophilic anaerobic digestion system, however, is able to utilize the benefits of high temperature, high levels of volatile fatty acids and free ammonia to accomplish a large reduction of pathogens. Vermicomposting and a process that uses a fumigant are currently under evaluation by the US Environmental Protection Agency and briefly discussed.

Background

Fecal matter potentially containing pathogenic microorganisms enters community wastewater collection systems from sources like hospitals, embalming facilities, animal slaughtering operations, and dwellings. While these wastewaters are cleansed with treatment, pathogenic microorganisms largely become concentrated in the sludge. If that sludge is to be beneficially used on land and possibly come in contact with humans, it must be disinfected to protect the public health. To accomplish this task, the U.S. Environmental Protection Agency (EPA) established a rule that put multiple barriers in place (U.S.EPA, 1979).

Technologies for Disinfecting Sludge

The commonly employed disinfection Processes to Significantly Reduce Pathogens (PSRP) and Further Reduce Pathogens (PFRP) are shown in the table below. Details of how these processes must

PSRP	PFRP
Anaerobic Digestion	Heat Drying
Aerobic Digestion	Composting
Lime Stabilization	Thermophilic aerobic digestion

be operated are well described in the literature (U.S.EPA, 1989). The intent of PFRP processes is to reduce pathogenic organisms to below their analytical detection limits, while that of the PSRP processes is only to partially reduce the number of pathogens. Both PSRP and PFRP processes are required to minimize the sludge's attractiveness to vectors like flies, birds, etc. by either reducing the volatile sludge solids by $\geq$ 38% or temporarily stopping putrefaction with the addition of a chemical like lime. Since pathogens are likely to still be present with the employment of PSRP processes it is essential that time be allowed for the sludge once land applied to undergo further pathogen reduction by natural attenuation. Thus public access, crop harvesting and grazing restrictions are applied. They are detailed in the literature (U.S.EPA, 1989).

1993 Rule Improvement

This 1993 Rule added alternatives for achieving disinfection and divided all the alternatives into Class A or Class B; separated out from the PSRP and PFRP descriptions the parts dealing with vector attractiveness; and established acceptable levels of pathogenic and/or indicator organisms for treated sludge intended for beneficial use (biosolids) (U.S. EPA, 1993).

The requirements for sludge to be Class A with respect to pathogens can be met with any one of six alternatives. Common to every alternative is the necessity that the density of *Salmonella* species be reduced to less than three MPN per four grams of dry sludge solids or the fecal coliforms be less than 1000 MPN per gram of dry sludge solids. Since levels of fecal coliforms in the untreated sludge often approach 10^8, it is expected that there will be at least a five log reduction. The four principally employed alternatives, briefly stated, are:

- Alternative 1. Time (D-days) & temperature (t-°C) are related by the equation: $D= 31{,}700{,}000/10^{0.14t}$ or $50{,}070{,}000/10^{0.14t}$. The first equation applies when the total solids are $\geq$ 7%; t $\geq$ 50ºC and time is $\geq$ 20 minutes. If the sludge particles are small and are heated by warmed gases or an immiscible liquid, the minimum time is 15 seconds. This equation also applies when the solids <7%, t >50ºC and time is $\geq$ 15 sec to<30 min. The second equation applies for total solids < 7 %; t $\geq$ 50ºC and D $\geq$ 30 minutes. These requirements were established from FDA requirements for eggnog, data from German sources, and other data collected during composting experiments in the U.S.A. (U.S. EPA 1992). Many facilities approach Alternative 1 without realizing that it was derived from experience with fluids. In fluids it is not difficult to insure that all particles meet the requirements for time and temperature. So when a facility submits a plan to the permitting authority it is shocked when they are asked for a monitoring plan that will insure that all parts of the sludge will meet the appropriate time and temperature requirements. In general these processes are limited to batch or plug flow reactors rather than continuous flow reactors. It is critical that these sludge treatment processes are completed without short circuiting occurring.
- Alternative 2. This alternative is based on disinfection research done by the N-Viro Energy Systems, Inc. in the late 1980s (U.S.EPA, 1999). The pH is raised to above 12 for greater than 72 hours, the temperature is above 52°C, and, after the 72 hours, the treated sludge is air-dried to 50 % solids or greater.
- Alternative 5. The sludge is treated by a PFRP. The three processes most frequently used are composting, pasteurization, and heat drying. With composting it is critical that all parts of the sludge pass through a zone where they can be held for no less that 3 days at 55ºC and then be removed

without contamination. Pasteurization is holding the temperature of a fluid at 70ºC or above for at least 30 minutes. A good example is the way milk is pasteurized. Achieving the same results by mixing a powder, quicklime (or similar reagent), with semisolid material, sludge, is not by any means easy. The mixing has to be very thorough to insure that all parts of the sludge comes into contact with the alkaline material; the temperature gets elevated to 70ºC or above and is held there for at least 30 minutes. Some minimal level of moisture is necessary and critical to insure that thorough mixing can occur. These systems need to be engineered and carefully monitored to insure that they are properly operating.

- Alternative 6. The sludge is treated by a process equivalent to a PFRP. Some technologies found to be equivalent are: two-stage (a thermophilic aerobic digester followed by a mesophilic anaerobic digester) sludge stabilization; autothermal thermophilic aerobic digestion; two-phase thermo-meso anaerobic digestion; OxyOzonation (U.S. EPA, 1999)

Alternatives 3 and 4 are not discussed. They depend on monitoring for the presence of enteric viruses and helminth ova. This is only useful when substantial numbers of enteric viruses and helminth ova are present in the raw sludge and monitoring is done to measure the effectiveness of the treatment process. Otherwise it is meaningless since the presence or absence of enteric viruses and helminth ova says nothing about the presence or absence of other pathogens. It is expected and hoped that the two alternatives will be removed from the regulation.
Requirements for a sludge to be Class B with respect to pathogens are met by employing one of the following three alternatives:

- Alternative 1. The geometric mean fecal coliform density (either MPN or CFU per gram of dry sludge solids) of seven samples shall be less than 2,000,000. Here, since levels of fecal coliforms in the untreated sludge often approach 10^8, at least a two log reduction was expected.
- Alternative 2. The sludge is treated by a PSRP. The commonly employed processes are: aerobic digestion, air drying, anaerobic digestion, composting (less stringent thermal requirements than the PFRP), and lime stabilization (U.S.EPA, 1999).
- Alternative 3. Sludge is treated by a process equivalent to a PSRP.

Development of Innovative and Alternative Technologies

The Pathogen Equivalency Committee (PEC) was created by EPA in 1985 to advise EPA and State managers on the equivalency of innovative and alternative sludge disinfection technologies to either a PSRP or a PFRP (Whittington and Johnson, 1985). It accomplishes its mission through a rigid evaluation program. The PEC consists of eleven members with expertise in microbiology, medicine, veterinary science, environmental engineering, wastewater treatment, and sludge regulations. It includes representatives from EPA's research and development, regional and water offices, and the Centers for Disease Control. The PEC's determinations are not formally binding agency decisions. Rather, they constitute technical guidance and are advisory. The table below broadly shows the requirements for demonstrating equivalency of an innovative or alternative technology.

The PEC must be able to understand how the proposed technology acts to disinfect and know what the key process control parameters are. To demonstrate adequate pathogen destruction, the untreated sludge must contain adequate numbers of organisms. For example, to demonstrate PFRP equivalency the untreated sludge needs to contain at least 1,000 PFU of enteric viruses /4 g TS (dry weight basis); and 100 viable *Ascaris* spp. ova/4 g TS. If the untreated sludge does not naturally contain these density levels, the applicant must spike it to achieve these levels.

PSRP Equivalency	PFRP Equivalency
> 1 log reduction of *Salmonella* sp. or > 2 log reduction of fecal coliforms	≥ 3 log reduction of enteroviruses
> 1 log reduction of enteroviruses	≥ 2 log reduction of viable *Ascaris* sp. ova
Final product contains < 2,000,000 fecal coliforms/g	Final product contains < 1000 fecal coliforms or < 3 *Salmonella* sp./4 g; < 1 pfu/4g of entericviruses and < 1 helminth ova/ 4g

Assessment of Evaluation Criteria

Work by several investigators has shown the danger of relying on only one or two stressors to disinfect sludge. Similarly there have been difficulties associated with using the reduction of a few organisms to demonstrate adequate disinfection for protection of public health. As a case in point if we consider that time and temperature are the critical parameters for operating an anaerobic digester and attaining Class A disinfection, the time and temperature equation provided above gives 24 hours as the time necessary to hold the sludge in the digester at 55°C. In recent testing at the University of North Carolina it was found that *Ascaris* sp., considered by many investigators to be the most difficult organism to kill, could be killed at 53°C in as little a time as 30 minutes, although large numbers of fecal coliforms continued to exist (Aitken et.al., 2005). Other investigators have similarly found that *Ascaris* sp. is not so difficult to kill (Nelson, 2005; Kato et.al., 2003).

It is increasingly apparent that for a disinfection technology to perform adequately it must impose multiple stressors that result in several logs of destruction for organisms including bacteria, viruses, worms, and protozoa. Examples of stressors are time, temperature, pH/oxidation, desiccation, ammonia, solids concentration, and irradiation. Stressors operating with various sludge disinfection technologies are shown in the table below.

Disinfection Processes and Some Stressors that Influence their Effectiveness

Process	# of Stressors	Irrad	Temp	Solids Conc	NH_3	Organic By Products (Volatile Acids)	Drying	Cavitation /Ultrasound
Composting	5	-	+	+	+	+	+	-
Anaerobic Digestion	5	-	+	+	+	+	-	+
Aerobic Digestion	3	-	+	+	-	-	-	+
Lagoon Storage	4	-	+	+	+	+	-	-
Air & Heat Drying	4	+	+	+	-	-	+	-
Alkaline Stabilization	5	-	+	+	+	+	+	-
High Energy Irradiation	5	+	+	-	+	+	-	+

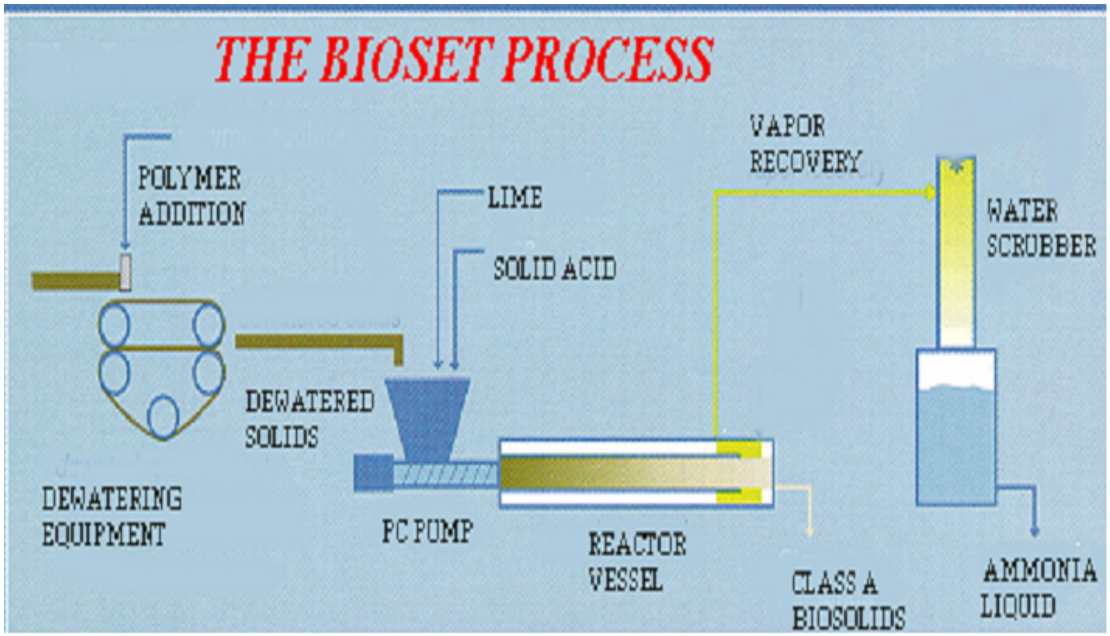
The decay of pathogen density with temperature is known to follow first order kinetics with time. Stern and Farrell (1977) stored digested primary sludge at temperatures of 4ºC and 20ºC for 24 weeks. At 4ºC

in six months fecal coliform densities dropped almost 5 logs, *Salmonellae* dropped 2 logs, and enteroviruses fell about 0.5 log. At 20ºC densities of these microorganisms fell much more rapidly. Fecal coliform densities dropped 3 logs in eight weeks, and *Salmonellae* and enteroviruses fell more than 2 logs. Elevating the pH above 12 and keeping it raised for 2 hours is the basis of the lime stabilization process (U.S. EPA, 2002). This process eliminates viruses and pathogenic bacteria. At this elevated pH, too, ammonia is liberated from sludge and very effective at killing microorganisms. Ammonia as an uncharged molecule is capable of permeating microbial cellular membranes and therefore enhancing pathogen kills. Desiccation alone requires drying to 95% solids to inactivate helminth eggs. Irradiation (Gamma or electron beam) directly damages the DNA of living organisms inducing cross-linkages and other changes that make an organism unable to grow or reproduce. When these rays interact with water molecules in an organism, they generate transient free radicals that can cause additional indirect damage to DNA. Shafer and Farrell (1998) noted that the potential for short circuiting is intrinsic to the use of a continuously fed stirred tank reactor. Technologies such as semi continuous flow or multiple stage processes should be used in place of a single reactor. Farrell et al. (1988) found that draw and fill operation produced much larger reductions in fecal coliform than fill and draw operation. Proper mixing is also critical. The importance of each will depend upon how the process is operated and this will be further discussed in the following case study section.

Case Studies of New Disinfection Approaches

BIOSET

This is an alkaline disinfection process, and its primary stressors are pH, ammonia, exposure time, temperature and pressure (Fitzmorris et.al., 2004). The process, as shown below, comprises mixing dewatered sludge or septage with a solids content ranging from 6% to 35%, calcium oxide, and sulfamic acid with a screw mixer, transferring the mixture into a continuous plug flow closed container reactor, and discharging.



Significant heat is produced as calcium oxide, quicklime, is added at a level of 40-50% dry weight to dewatered sludge. The calcium hydroxide, produced from this reaction, reacts with the sulfamic acid to produce even more heat. Since the calcium oxide to sulfamic acid ratio is approximately 100:1, the pH of

the product material is 12 to 12.3. With the reactor under a pressure of greater than 41 Pa (6 psi) and the sludge at a high pH level and temperature, ammonia contained within the biosolids is released and permeates thoroughly throughout the sludge to further enhance pathogen destruction.

Testing: The procedure was designed to monitor for ammonia content, temperature, and verify disinfection capabilities of the Bioset system at lower temperatures than those required by regulation, e.g. 70°C for 30 minutes. Test runs were performed on aerobically digested (Kingwood, Texas), raw (Morgan City, Louisiana), and anaerobically digested (Sulphur, Louisiana) sludges at temperatures ranging from 40°C to 55°C. The temperatures were monitored by probes located throughout the unit and again checked in the sludge as it came out the end. By controlling the addition of quicklime and sulfamic acid, the temperature within the unit was controlled. The temperature of the influent sludge was consistently at ambient level (25 - 27°C). The untreated sludges were spiked with *Ascaris* eggs to result in a final concentration of 2000 eggs/sample. This was done by adding the eggs (3×10^6) to the sludge cake coming off the belt press at a solids content of between 12-15% and at ambient temperature. 215 Kg (473 lbs) of sludge cake was collected in three containers and the *Ascaris* eggs were then added to provide better mixing. The spiked cake was then added directly into the hopper at the beginning of the system. Test results are shown in the table below for Morgan City (2 temperatures), Kingwood (3 temperatures) and Sulphur (2 temperatures). Each temperature test consisted of one pass through/capture using Styrofoam peanuts as indicators of the beginning and end of the batch. Controls consisted of influent sludge cake plus eggs (3 samples at 0 min). Kingwood, Texas is the focus of the discussion here, since this testing resulted in EPA's PEC issuing a site specific PFRP equivalency recommendation. A 2-meter Ashbrook belt filter press was used to produce a 15% tds aerobically digested sludge. The cake dropped into the Bioset mixing hopper that fed a 9.2 m (30 ft) long 0.3m (12-in) reactor. The Kingwood reactor operated at 207 Pa (30 pounds) of pressure. Note that a 100% kill of the *Ascaris* was achieved in the third run conducted at 55°C. The first two runs were at 45°C (69.9% kill) and 46°C (89.7% kill) respectively. The main difference among them was the ammonia content.

***Ascaris* Inactivation as a Function of Temperature, Time, % Ammonia and Pressure**

LOCATION	DATE	RUN #	TEMP	TIME IN UNIT	% REDUCTION OF *Ascaris*	% AMMONIA	PRESSURE KPa (psi)
Morgan City	28-May-02	1	42°C	85 min	97.4	0.5	103 (15)
	30-May-02	2	50°C	104 min	87.5	0.05	103 (15)
Kingwood	4-Jun-02	1	45°C	25 min	69.9	0.5	207 (30)
	6-Jun-02	2	46°C	25 min	89.7	0.9	207 (30)
	7-Jun-02	***3***	***55°C***	***25 min***	***100***	***1.0***	***207 (30)***
Sulphur	8-Jul-02	1	50°C	14 min	98.6	0.7*	262 (38)
	9-Jul-02	***2***	***55°C***	***11 min***	***100***	***0.8****	***262 (38)***

* Estimated values based on previous research

Two virus spike runs were performed at the Kingwood, Texas plant on February 7, 2003. 70 Kg of biosolids were mixed with 7 tubes of virus concentrate. The results from the run are presented in the table below. As is evidenced by the results, at temperatures as low as 52°C, the Bioset process eliminated all the viruses tested. At temperatures as low as 41 – 43°C, complete inactivation of poliovirus and the male-specific bacteriophage was achieved. EPA believes that the Kingwood, Texas facility is operating as a PFRP equivalent process when the sludge is held at a temperature of 55°C or greater for a minimum of 25 minutes; solids content of the sludge being treated is in the range of 6% to 35%; ammonia content in the reactor is 1% (10,000 mg/L) on a volume basis; pressure in the reactor is 30 psi; and the pH is greater than 12.

Sample	Time (min)	Temperature	Poliovirus (pfu/4g dry wt)	Bacteriophage	
				Somatic (pfu/g dry wt)	Male-Specific (pfu/g dry wt)
Run 1 – Sample A	0	52 – 54°C	3.8×10^4	1.6×10^5	1.0×10^3
Run 1 – Sample B	0	52 – 54°C	8.9×10^4	1.5×10^5	7.8×10^2
Run 1 – Sample C	0	52 – 54°C	7.1×10^4	1.6×10^5	5.5×10^2
Run 1 – Sample A	16.5	52 – 54°C	none detected	none detected	none detected
Run 1 – Sample B	16.5	52 – 54°C	none detected	none detected	none detected
Run 1 – Sample C	16.5	52 – 54°C	none detected	none detected	none detected
Run 2 – Sample A	0	41 – 43°C	3.3×10^4	2.6×10^5	47
Run 2 – Sample B	0	41 – 43°C	7.0×10^4	2.0×10^5	none detected
Run 2 – Sample C	0	41 – 43°C	2.4×10^4	2.5×10^5	none detected
Run 2 – Sample A	20	41 – 43°C	none detected	58	none detected
Run 2 – Sample B	20	41 – 43°C	none detected	1.7×10^2	none detected
Run 2 – Sample C	20	41 – 43°C	none detected	1.5×10^2	none detected

Further testing was performed with aerobically digested, anaerobically digested and untreated sludges and the relevant parameters adjusted as necessary to inactivate bacteria, viruses, and helminth eggs below analytical detection limits. Results are shown in the table below. EPA's Pathogen Equivalency Committee is currently examining all the data it has received from Bioset to see if more is required. If more is not required the committee is seeing if it can define conditions under which the Bioset's process would adequately disinfect any sludge or if conditions need to be sludge specific.

Process Control Settings Bioset to achieve Complete Inactivation

Plant	Sludge	Pressure KPa (psi)	Time	NH^3	Temperature (°C)
Kingwood	aerobic	207 (30)	25 min.	1.1 %	55
Sulfur	anaerobic	262 (38)	15 min.	0.4 %	55
Morgan City	raw	103 (15)	90 min.	0.2 %	55
Kissimmee	raw	103 (15)	50 min.	0.1 %	55
Lakeland	raw	207 (30)	52 min.	0.3 %	55
Hollywood	raw	152 (22)	81 min.	1.0 %	55

BioChem Resources' Neutralizer® Process

The Neutralizer® Process is an acid-oxidative one that treats sludge with chlorine dioxide at an initial dose rate of 50-150 mg/L for two hours (Riemers et.al., 2006). This partially disinfects and raises the ORP of the sludge to greater than 100 mV. It is then acidified to a pH of 2.2-3.0, and nitrite is added. Nitrite (under the specified conditions of pH 2.2-3.0, ORP > 100 mV, and a contact time of 2 hours) forms non-charged nitrous acid, which is able to penetrate the shell of the helminth ova. The stress of chlorine dioxide, pH, nitrous acid, and pressure all work together to completely disinfect the sludge. The process is a sequenced batch process, which ensures that the specified conditions are met before the next phase of the process begins and prevents untreated material from leaving the system. Process characteristics are partially shown in the table below.

Sludge Feed Process	Sequenced Batch
Operating Temperature	≥ 15°C
Operating Pressure	0-103 Pa (0-15 psig) during nitrous acid contact time
pH	pH = 6-8 (ambient) pH = 2.2-3.0 during Nitrous acid contact time
ORP	100 – 500 mV
Chlorine dioxide concentration	50 – 150 mg/l
Nitrous acid concentration	1800 mg/l
Mixing	Continuous

Testing was conducted on three sludge types; aerobically digested from Kenner, Louisiana, anaerobically digested from Lafayette, Louisiana and raw from New Orleans. Sludges ranged from 1.3 to 7.6% solids. Sample size varied from 250 to 750 mL and was designed to yield 4 grams of total solids (dry weight basis). Samples were collected in a 22.7 L (5 gal) pails on the same day that tests were conducted. The ambient temperature at the time of sampling was approximately 21°C (70°F). The samples were taken to the Tulane University laboratories and maintained at a temperature of 4°C until use. In the laboratory, the percent total solids before and after treatment was determined. Also, total suspended solids and volatile suspended solids were determined. Prior to testing the sludges were spiked with *Ascaris* eggs and poliovirus to the levels shown in the table below. Residuals temperature at the start of the treatment process was 10-15°C. By the end of the 4 hour treatment process, sample temperatures had risen to 20 to 22°C. Each 22.7 L (5 gal) sample was mixed by stirring, and three smaller samples were removed from this untreated composite sample for each individual test. *Ascaris*, poliovirus, and fecal coliform samples were tested in triplicate for each municipal wastewater residual matrix (raw, aerobic, and anaerobic). After treatment, the sample bottles were placed in Ziploc bags and stored in the refrigerator at 4°C prior to shipping to Cornell University or BioCheck Laboratories for analyses. Typically, 4 to 6 hours elapsed between sample collection and treatment, and 18 to 24 hours elapsed between the completion of testing and the sample analysis. When operated under the conditions specified above, the Neutralizer® process reduces fecal coliform bacteria, enteric viruses, and helminth egg viability to below detectable limits in treated municipal biosolids. Log reduction of pathogens is listed in the table below.

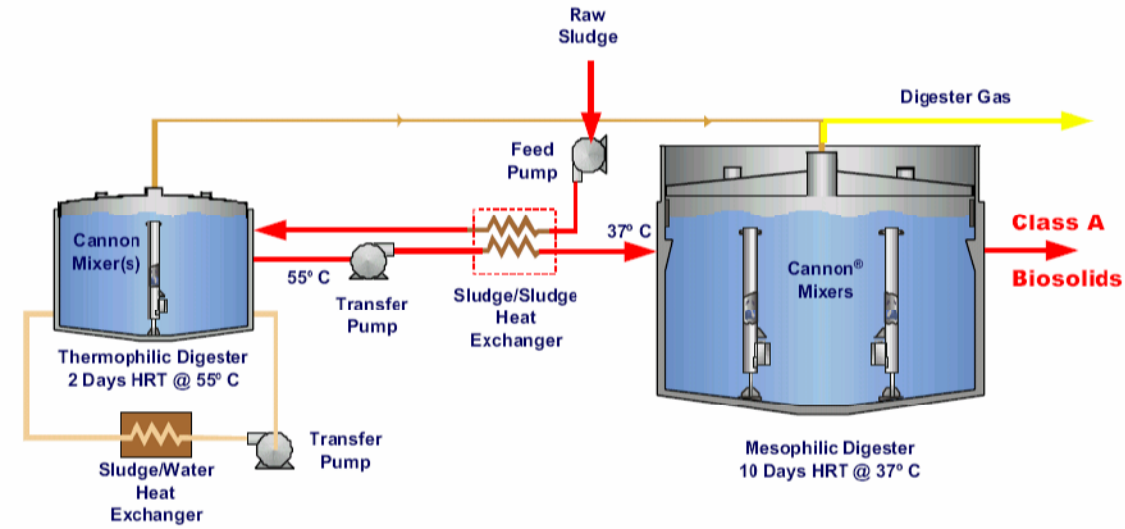
Pathogen	Spike Concentration (per 4 g DWS*)	Recovered from Controls (per 4 g DWS)	Recovered after Treatment (per 4 g DWS)	Log Reduction
Ascaris eggs	5×10^4	4.5×10^4	< 1	4
Poliovirus	1.1×10^5	3.5×10^4	< 1	4
	Raw Concentration (MPN/g)	Recovered from Controls (MPN/g)**	Recovered after Treatment (MPN/g)	Log Reduction
Fecal Coliform***	2×10^9	2×10^9	< 1	9

* Dry weight solids **Most probable number per gram dry weight ***Fecal coliform results are from tests conducted on raw sludge.

Two-Phase Anaerobic Digestion ID 2PAD™ System

USEPA ultimately recommended this process, shown in the figure below, as equivalent to a PFRP one when "Sewage sludge is treated in the absence of air in an acidogenic thermophilic reactor and a mesophilic methanogenic reactor connected in series. The mean cell residence time shall be at least 2.1 days (± 0.05 d) in the acidogenic thermophilic reactor followed by 10.5 days (± 0.3 d) in the mesophilic methanogenic reactor. Feeding of each digester shall be intermittent and occurring no more than 4 times

per day (no less than every 6 hours). The mesophilic methanogenic reactor shall be fed in priority from the acidogenic thermophilic reactor. Between two consecutive feedings temperature inside the acidogenic thermophilic reactor should be between 49°C and 60°C with 55°C maintained during at least 3 hours. Temperature inside the mesophilic methanogenic reactor shall be constant and at least 37°C (U.S.EPA, 2003)."



Lyonnaise des Eaux (ID's ultimate parent company - name is now Suez) worked with EPA's PEC for over four years. They assembled a test plan, constructed a pilot plant, and selected experimental and analytical procedures in consultation with the PEC. Finally the PEC observed some of the testing. The pilot plant testing of their process was conducted at Indianapolis' Belmont Wastewater Treatment Plant using a blend of 60 percent (by vol.) thickened primary sludge and 40 percent (by vol.) thickened waste activated sludge. A 1 m^3 (260 gal) tank was employed for the thermophilic unit and a 3 m^3 (800 gal) tank for the mesophilic one. Performance of the Indianapolis 2PAD™ System pilot plant with 4 feedings per day is shown in the table below (after Huyard et.al., 1999; Huyard et.al., 2000).

The data shows an interesting combination of bactericidal effects. The acidogenic-thermophilic digester operated at temperatures between 48.6°C and 55°C with 55°C maintained for at least 21.6 hours during each detention time of 2.1 days. The combination of a short detention time with thermophilic temperatures enhanced the growth of acidogenic bacteria resulting in high levels of volatile fatty acids, free ammonia and low pH. Additional pathogen removal occurred in the methanogenic-mesophilic digester with the longer detention time and contact with ammonia, residual volatile acids and other chemicals. Lynonnaise noted that other authors reported significant inactivation of heat resistant pathogens during methanogenic-mesophilic digestion after weakening during the previous acidogenic-thermophilic digestion stage. It appears that the hydraulic and feeding mode of the digesters impacted the efficiency of pathogen removal. Semi continuous flow reactors with a 'draw and fill' feeding protocol virtually eliminated the potential for pathogens short-circuiting. Mixing is also critical in achieving optimum pathogen destruction. Proper mixing efficiently dissipates heat within the digester preventing temperature gradients, dead spaces and hot spots. The relatively high level of volatile solids in the raw sludge is likely responsible for the higher levels of volatile fatty acids and free ammonia in both reactors. These chemicals together with the high temperature in the acidogenic-thermophilic digester contributed to the large reduction of pathogens.

The first full-scale 2PAD™ installation will be at the Glendale Wastewater Treatment Plant in Lakeland, Florida, starting up in late 2006 to early 2007.

	Feed sludge		Acidogenic digester		Methanogenic digester		2PAD™ System	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Feeding frequency	-	-	4	-	4	-	4	-
Temperature (^{o}C)	-	-	55 - 56	-	37	-	-	-
pH	5.57	0.69	6.0	0.5	7.2	0.1	-	-
TS (g/L)	38.5	6.1	27.8	4.1	21.2	2.1	-	
VS (g/L)	27.8	4.8	21.3	4.3	12.1	0.87	-	-
VSR	-	-	23.8	10.8	40	10.9	57.2	7.9
VFA total (mgHAc/L)	1,393.3	519.2	2,309.8	1,035	203	115	-	-
Total ammonia (mg/L)	47.7	28.4	552	100	763.5	111.7	-	-
Free ammonia (mg/L)	-	-	2.12	0.4	13.36	1.95	-	-
Fecal coliform Log (MPN/gTS)	> 6.35	0.91	0.9	0.58	0.38	0.43	-	-
Enterovirus Log(PFU/4g TS)	4.04	0.14	BD	-	BD	-	-	-
Viable *ascaris* eggs Log (count/4gTS)	2.61	0.09	BD	-	BD	-	-	-

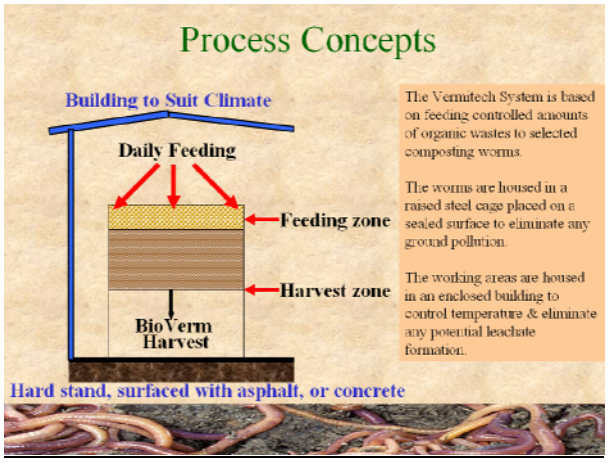
All pathogen densities are shown in $\log_{10}$. TS: Total Solids, VS: Volatile Solids, TSS: Total Suspended Solids, VSS: Volatile Suspended Solids, BD: Below Detection, HAc: Acetic acid, VFA: Volatile Fatty Acids, VSR: Volatile Solids Reduction.

Emerging Technologies

US Filter's J-VAP Process - This technology operates like a traditional filter press process, which dewaters the municipal sludge to a final filter cake at 20 to 30% total solids by weight. However, in addition to the stress of solids concentration, the J-Vap® process incorporates two additional innovative components/stressors: vacuum and heat. These transform the J-Vap process into an innovative vacuum heat drying process. First, hot water is used to hydraulically inflate the filter plate diaphragms to apply mechanical filtration pressure to the biosolids cake. The most cost effective material for filter plates is polypropylene. Because this material softens at temperatures above 93°C, the hot water temperature is maintained at 82°C. Second, a vacuum of 69 cm (27 in) of mercury is applied to the filtrate side of the filter membrane to further facilitate water removal. The combination of applied vacuum and heat enhances and expedites this drying process into an innovative vacuum heat drying disinfection process.

Vermicomposting - Vermiculture is the process by which organic material is fed to earthworms in a controlled environment with the purpose of producing vermicast, and in some cases, more worms.

Vermitech of Australia's concept of the process is shown below (Lotzof, 2001). Vermitech uses an in vessel system which operates as a "semi-continuous reactor". The reactor or bed, is 3.5 meters wide, 1



meter deep and variable in length. Fresh waste is fed daily (5 days per week) to the top surface of the bed. The worms travel to the surface and consume the waste. In the process of digestion and excretion, the waste is transformed in physical, chemical and biological character, including the reduction of human, animal and plant pathogens. The excreta of worms (vermicast), is harvested from the base of the bed on a regular cycle. The worms are found to not work efficiently if the bed temperature rises above 30°C, or if the pH increases above 8.5. From a pathogen standpoint Earthworms are thought to produce peroxidase which has been found to destroy some bacteria. In trials with *E. fetida* and *Perionyx excavatus* it was noted that *Salmonella*, which were present at day 1, were not detected after four days. Fecal coliforms were initially present at over 2 million CFU/g dry solids and decreased to less than 1000 MPN/g between 96 and 103 days. The mechanism for earthworms to kill pathogens or render them inactive appears to be through the process of digestion and the production of enzymes. The enzymes seem effective both in the gut of the worm and extra corporeal. Some work was done on a large scale in Australia indicating that the earthworm is able to kill pathogenic bacteria, viruses, and helminth ova. In the U.S.A. a small full scale installation is operating at Granville, PA and another is planned by Vermitech. PFRP equivalency has not yet been demonstrated.

Magnagro - Magna Management of Houston, Texas is proposing to use a fumigant, approved by the U.S. EPA for use with sludges to disinfect sewage sludge. They describe their process as follows: "..the MagnaGro Process, sewage sludge with a temperature equal to or greater than 15°C and with percent solids equal to or greater than four percent but equal to or less than 30 percent are placed in a closed batch reactor. Rid-A-Vec, a liquid fumigant, is then added to the reactor. The sewage sludge and the fumigant are mixed in the reactor to achieve complete mixing of all materials. After the mixing period, the mixture remains in a closed container for a period of time during which methyl isothiocyanate (MITC), a vapor generated when Rid-A-Vec reacts with water, reduces the densities of the pathogens. After the treatment time, the mixture is exposed to the atmosphere for a period of time to allow MITC to dissipate. This ensures that the treated sewage sludge is not toxic to plants grown on sites where the treated sewage sludge is land-applied." Magna Management claims their process produces Class A biosolids. The PEC is presently reviewing data from laboratory scale studies and has requested some pilot scale work.

Significance of Disinfection Technology Evaluation Work to Date

In showing the effectiveness of a technology/process performance demonstration is critical and in doing so a quality assurance project plan must be followed. This insures that the data will be acceptable. Can't

just consider/follow the fate of one or two organisms, namely enteroviruses and helminth ova. Need to consider other organisms like *E. coli* and spore formers like the bacterial endospores and *C. perfringens*. Male specific phage is another good organism to consider. It is critical to understand the mechanism of organism destruction. Disinfection is most effective when multiple stressors are at work.

Vector Attraction Reduction and Stability

The U.S.A.'s requirements currently only regulate vector attraction reduction and, broadly speaking, do it by specifying requirements for volatile solids reduction, the oxygen uptake test, chemical addition, dry solids concentration, or incorporation. The intent of its 38 % volatile solids reduction number, demonstrating a SOUR at 20°C of 1.5 mg oxygen/hr/g total sewage sludge solids, and aerobically treating sludge for at least 14 d at > 40°C with an average temperature of > 45°C are to indicate removal of all putrescible (biodegradable) organic material from sludge so that it will no longer be attractive to vectors. Not surprisingly these test values are not optimal. Adjustments are needed. For example we know that biological digestion processes can as a function of the sludge being digested achieve volatile solids reductions from 20 to 70 % or higher. Thus what is needed in place of the 38 % value is a formula into which the parameters for a specific sludge are inserted. The SOUR number now can only be used within a narrow temperature range and with a relatively low solids concentration. These conditions need to be expanded and further we need to address the situation of thermophilically digested sludges. Better tests are already available for composted materials such as measuring the evolution of CO_2 and need to be considered.

Within the U.S.A. concerns for more than vector attraction reduction to achieve public acceptance are the responsibility of state and local authorities. It is recognized, though, that if a material is no longer putrescible, it is not likely to be odorous.

Some work is underway in our laboratory to investigate the usefulness of alternative vector attraction reduction measures. The reduction of percent volatile solids is being compared to two indicators of bacterial enzymatic activity, enumeration of two indicator groups of microorganisms, biochemical oxygen demand, and peak oxygen uptake rate. Sludge samples are being taken from five locations within the sludge treatment train at a municipal wastewater treatment plant in Fairfield, OH. All laboratory research is conducted at EPA's Andrew W. Breidenbach Environmental Research Center in Cincinnati, Ohio. Our goal is to develop one or more tests to use with any sludge and determine whether or not it will attract vectors and might be considered stabile.

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