Controlling Pathogens and Stabilizing Sludge/Biosolids: A Global Perspective of Where We Are Today and Where We Need To Go

Lucia Sobrados-Bernardos+ and James E. Smith, Jr.*#
+Centro de Estudios Hidrográficos (CEDEX), Paseo Bajo Virgen del Puerto,3 28005 - Madrid, Spain
*USEPA-ORD-NRMRL-Ci (Retired), 5821 Marlborough Drive, Cincinnati, Ohio 45230-3513
#Corresponding author JesmithjrDSc@aol.com. (F) 513-232-5629

ABSTRACT

The paper briefly considers how extensively countries apply treated sewage sludge to agricultural lands, the pathogenic microorganisms that can be present in sludge, and the infectious diseases they cause. A review is made of many of the disinfection and stabilization regulations and guidelines in usage in Europe, North, Central and South America and Australia. Guidance of the World Health Organization is also considered. This assessment includes foremost the hygienic but also the aesthetic and practical concerns with beneficial use of wastewater treatment plant residuals. Prime consideration is given to how the residuals are treated to insure good disinfection and stabilization and how the accomplishment of that can be monitored. Next it assesses the developments (including science) leading to the current national sludge regulations and discusses them & their applications. Ultimately it addresses the questions: Where are nations now headed and what does the future hold?

KEYWORDS

Biosolids, sludge, hygiene, disinfection, stabilization, vector attraction, pathogenic organisms, regulations, guidelines

INTRODUCTION

Fecal material with its beneficial constituents has been used in agriculture since its beginning. That practice continues today for a large amount of the biosolids generated globally. In a 2010 report of the European Commission the total quantity of sludge produced in the European Union (EU) during 2007 was estimated at 10.13 million tons (dry solids). Of this total, nearly 40% is estimated to be spread on land for agricultural use. Denmark, France, Ireland, Spain and the UK were found to use more than half of their sludge production in agriculture (EC, 2010). By comparison with Europe, a 2007 report indicates that the United States (US) was estimated to produce 7,180,000 dry tons of sewage sludge in 2004 (NEBRA, 2007). Of that total, the report found that approximately 55% was applied to soils for agronomic, silvicultural, and/or land restoration purposes following treatment in accord with US federal, state, and local requirements.

Sludge Disinfection Issues

The link between human health and what humans ingest, inhale, or come in contact with by some other means has, perhaps surprisingly, been known since the early ages. One public health text of the early 1900s suggests that untreated residuals not be used on food chain crops (Babbitt and Baumann, 1958). Prior to the early 1970s, sewage sludge in the U.S. was given minimal

treatment if any for hygienic purposes. Treatment was mainly for mass and/or volume reduction and odor control to facilitate its use and/or disposal. In West Germany and Switzerland, pasteurization (heating to 70ºC for 25 minutes) became a requirement in the 1950s when sludge was spread on pastures during summer growth periods. Disease causing organisms or pathogens commonly found in municipal wastewater and sewage sludge and their associated disease/symptoms are shown in Table 1 (U.S. EPA, 2003). You will note there the causes of typhoid, gastroenteritis, cholera, hepatitis A, polio, giardiasis, hook worms, cryptosporidiosis, and amebiasis. If one considers the relative risk to human health from pathogenic organisms, the highest risk of infection and spread of disease is from Helminths *(Ancylostoma, Ascaris, Trichuris, Taenia,* etc.) (Shuval et al. 1986). The medium risk is from entericbacteria *(cholera vibrio, Salmonella enterica,* serovar typhi, *Shigella,* etc.). Low risk is from enteroviruses, hepatitis A virus, etc.

REVIEW OF GLOBAL APPROACHES TO INSURE THE GOOD HYGIENIC QUALITY OF SLUDGE/BIOSOLIDS THAT IS LAND APPLIED

In this section the approaches taken or recommended by the World Health Organization (WHO),

Table 1 - Major Pathogens Potentially Present in Raw Domestic Sludge

PATHOGEN CLASS	EXAMPLES	DISEASE
Bacteria	*Shigella sp.*	Bacillary dysentery
	Salmonella sp.	Salmonellosis (gastroenteritis)
	Salmonella typhi	Typhoid fever
	Vibrio cholerae	Cholera
	Enteropathogenic-	
	Escherichia coli	A variety of gastroenteric diseases
	Yersinia sp.	Yersiniosos (gastroenteritis)
	Campylobacter jejuni	Campylobacteriosis (gastroenteritis)
Viruses	Hepatitis A	Infectious hepatitis
	Norwalk virus	Acute gastroenteritis
	Rotaviruses	Acute gastroenteritis
	Polioviruses	Poliomyelitis
	Coxsackie viruses	“flu-like” symptoms
	Echoviruses	“flu-like” symptoms
Protozoa	*Entamoeba histolytica*	Amebiasis (amoebic dysentery)
	Giardia lamblia	Giardiasis (gastroenteritis)
	Cryptosporidium sp.	Crytosporidiosis (gastroenteritis)
	Balantidium coli	Balantidiasis (gastroenteritis)
Helminths	*Ascaris sp.*	Ascariasis (roundworm infection)
	Taenia sp.	Taeniasis (tapeworm infection)
	Necator americanus	Ancylostomiasis (hookworm infection)
	Trichuris trichuria	Trichuriasis (whipworm infection)

the EU, and several European, South American and other countries are critically reviewed. The approaches typically include a product quality requirement, although some go further and specify methods to be used for disinfection. Only rarely is a requirement noted for stabilization or vector attraction control. Site access and crop harvesting restrictions are also seldom specified. Table 2 shows the actual/recommended value levels of indicator and pathogenic organisms in biosolids

that are intended for land application. The levels provide a means of insuring that the sewage sludge has been adequately disinfected. WHO further recommended a period of one month between the time of biosolids application and that of crop harvesting (WHO, 2006).

In the EU, the use of sewage sludge in agriculture is regulated by Directive 86/287/EEC (EEC, 1986). It does not specify limits for pathogen populations, but specifies general land use, harvesting and grazing restrictions to provide protection against the risk of infection. In this sense, Article 6(a) requires treatment of the sludge before its land application. Untreated sludge is allowed to be used in agriculture only if it is injected or worked into the soil. Processes for sludge treatment are not specified as these are viewed as the responsibility of the Member States. The article does define "*treated sludge*" as "*sludge which has undergone biological, chemical or heat treatment, long-term storage or any other appropriate process so as to significantly reduce its fermentability and the health hazards resulting from its use*" (art. 2(b)).

Table 2. Summary of Some Hygienic Criteria for the Beneficial Use of Biosolids (after Buchauer, 2007 & Updated)

	HELMINTHS		**BACTERIA**			**VIRUSES**
	Total Ova	Viable Ova	Fecal Coliforms	*E. Coli*	Salmonella	Enteroviruses
World Health Organization						
Recommended at 10^{-6} daily (2006)	-	< 1/g (dry)	-	< 1000 /g	-	-
European Union (1986)	No Specific Restrictions					
Norway (1995)						
	-	ND	< 2500 / g	-	ND in 50 g	
United States (1993)						
Class A	-	< 1/4g	< 1000/ g	-	< 3/4g	< 1/4g
Class B	-	-	< 2 x 10^6 /g	-	-	-
Australia						
National Standard (2004)						
P1	-	-	-	<100/g*	<1/50g	
P2	-	-	-	<1000/g*	<10/50g	
P3	-	-	-	<2x10^6/g*	-	
P4	No Specific Restrictions					
New South Wales (1997)**	< 1 / 4g	-	< 1000/g	< 100/g	ND in 50 g	< 1/4g***
Argentina – Santa Fé (2000)						
	-	< 1/4g	-	-	-	-
Mexico (2002)						
Class A	<10 /g	-	< 1000/g	-	<3 /g	-
Class B	< 35/g	-	< 2x10^6/g	-	< 300/g	-
Nicaragua (2006)	-		-			
Class A	< 10/g	-	< 1000/g	-	< 3/g	-
Class B	< 35/g	-	< 2x10^6/g	-	<300/g	-
Class C	< 50/g	-	< 5x10^6/g	-	< 500/g	-

* "E. Coli or thermotolerant coliformns"
** stabilization grade A microbiological standards
*** Initial process verification standards

Since 1999, several draft modifications of this directive were developed by the European Commission. The last one was in 2003 and categorized sludge into two groups as a function of how it was treated (CEC, 2003). Advanced treatment status would require a treatment process to:

- Achieve a 99.99% reduction in *E. Coli* and to less than $1x10^3$ cfu/g (dry weight) of treated sludge
- Produce a sludge containing $< 3x10^3$ spores of *Clostridium perfringens*/g (dry weight)
- Produce a sludge containing no *Salmonella sp.*/50 g (wet weight).

Advanced treatments were mostly the same as the ones required by U.S. EPA to obtain a Class A sludge (see Table 4), although the minimum time required in composting and thermophilic aerobic and anaerobic digestion was 4 h at 55ºC.

Conventional treatment of the sludge was intended for biosolids that would be used in agriculture with restrictions (CEC, 2003). These are necessary because untreated sludge could be added into the process and the sludge therefore not be adequately treated. Pathogens could still be present in the biosolids. Further the use of these biosolids was prohibited in public parks and forests as well as areas where fruits and vegetables grow close to the ground. Sludge would achieve a conventionally treated status when it was subject to any type of treatment (physical, chemical, biological or other) which achieved a 99% reduction in *E. Coli* and to less than $5x10^5$ cfu/g (wet weight) of treated sludge.

At this time it seems that no modification of the actual Directive will take place in the near future (personal communication from the Sludge Working Group of EUREAU, 2011). In this sense, EC reports (EC, 2010) that in Europe the only clear evidence for transfer of disease from sewage sludge has been in a few instances where its requirements have not been properly implemented or where operators may have been using unhygienic practice es. The requirements of Directive 86/278/EEC have been implemented by the Member States differently, based on specific local conditions and circumstances. Some of these countries or regions have developed stricter regulations since 1986 Directive was implemented. A review of the different national legislations is summarized in Table 3.

The United States (US) requires use of the processes shown in Tables 4 and 5 for achieving the values given in Table 2 (U.S.EPA, 1993). Class A processes are expected to reduce pathogenic organisms to below their analytical detection limits. Class B processes are expected to reduce pathogens by one log and indicator organisms by two logs (USEPA, 2003). Class B processes have access and cropping restrictions.

Norway has biosolids treatment requirements similar to the US. Somewhat different requirements are for composting (Odegaard et al. 2001). It requires a temperature of > 55°C in either naturally or artificially aerated piles for more than 3 weeks; or if done in a vessel, it requires a temperature of > 55°C for more than 10 days; or if done at a temperature of > 65°C it requires > 2 days. Subsequent curing needs to occur during at least 2 weeks. Norway also specifies that thermophilic aerobic stabilization should occur in at least two reactors that are connected in series and at a temperature of 50°C for > 23 h; or at a temperature of 55°C for more than 10 h, or 60°C for more than 4 hours. The minimum detention time should be 7 days.

Table 3. Product and Disinfection Process Requirements of Some European Countries (modified from Sede and Anderson, 2001)

Country	Recommended treatments	End product standards
Denmark	- Thermal treatment at 70ºC during 1h or equivalent combinations of time and temperature. - Composting at 55ºC during at least 15d. - Liming - aerobic and anaerobic treatments	Salmonella: No occurrence Fecal streptococci <100/g
France (Decree 97-1133, 1987)	Treatment by physical, biological, chemical or thermal process, for long storage, or by any other appropriate process, in order to reduce its fermentation capacity and the correlated sanitary risks by using it.	Salmonellae:<8 MPN/10 g DM Enterovirus: <3MPCN/10 g DM Viable Helminths eggs: <3/10 g DM Thermo-tolerant coliforms: none
Austria:		Salmonella: none/g DM Enterobacteria: <1000/g DM Viable Helminths eggs: none/g DM
Switzerland		For the agricultural land producing fodder or vegetables: Enterobacteria: <100/g DM Infectious parasite eggs: none/g DM
Italy		Salmonella: <1000 mpn/ g DM
Luxemburg		Enterobacteria: <100/g DM no eggs of worm likely to be contagious
Poland		Sludge cannot be used in agriculture if it contains Salmonella
Ireland (FTC, 2000)*	- Mesophilic anaerobic digestion (> 12 d at 35ºC±3ºC or > 20 d at 25ºC ±3ºC) with pre or post pasteurization (> 1h at T≥ 70ºC or 2 h at T≥55ºC). - Thermphilic anaerobic digestion (> 48 – 72 h at 50 – 55ºC including > 1h at T > 70ºC followed by ≥2 h at T ≥55ºC or ≥4 h at T ≥50ºC). - Thermophilic aerobic digestion (7 d with all sludge at T≥ 55ºC for ≥4 h. Reduction of VS ≥ 38%). - Composting: Windrows (15 d at T≥55ºC with 5 turnings) or in vessel (3 d at T≥55ºC). - Alkaline stabilization. - Thermal drying (T > 80ºC and ≥ 90% dry material)	Faecal coliforms < 1000 NPM/g DM Salmonella sp. < 3 NPM/4g DM

* Mandatory Code

Table 4 – US Class A and Processes to Further Reduce Pathogens (PFRPs)

1. Composting a) Using the within-vessel composting method or the static aerated pile composting method, the temperature of sewage sludge is maintained at 55°C (131°F) or higher for 3 consecutive days. o**r b)** Using the windrow composting method, the temperature of the sewage sludge is maintained at 55°C (131°F) or higher for 15 consecutive days or longer. During the period when the compost is maintained at 55°C (131°F) or higher, there shall be a minimum of five turnings of the windrow.
2. Heat Drying Sewage sludge is dried by direct or indirect contact with hot gases to reduce the moisture content of the sewage sludge to 10% or lower. Either the temperature of the sewage sludge particles exceeds 80°C (176°F) or the wet bulb temperature of the gas in contact with the sewage sludge as the sewage sludge leaves the dryer exceeds 80°C (176°F).
3. Heat Treatment Liquid sewage sludge is heated to a temperature of 180°C (356°F) or higher for 30 minutes.
4. Thermophilic Aerobic Digestion Liquid sewage sludge is agitated with air or oxygen to maintain aerobic conditions and the mean cell residence time (i.e., the solids retention time) of the sewage sludge is 10 days at 55°C (131°F) to 60°C (140°F).
5. Pasteurization The temperature of the sewage sludge is maintained at 70°C (158°F) or higher for 30 minutes or longer.
6. Alkaline treatment 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.
7. Other Methods Other methods or operating conditions may be acceptable if pathogens are reduced to an extent equivalent to the reduction achieved by any of the above add-on methods.

In Australia the biosolids guidelines are referred to in other environment legislation and take on legal significance as a result. There are different guidelines for the different States, even though, in case a State does not have its own, the national standards (NWQMS, 2004) are used. It could be said that the national standards and New South Wales and Western Australia guidelines have regulations very similar to those of the US (NSWEPA, 1997), although with a larger numbers of grades according to changes in the coupled time-temperature.

Table 5 – US Class B and Processes to Significantly Reduce Pathogens (PSRPs)

1. Aerobic Digestion Sewage sludge is agitated with air or oxygen to maintain aerobic conditions for a specific mean cell residence time (i.e., solids retention time) at a specific temperature. Values for the mean cell residence time and temperature shall be between 40 days at 20°C (68°F) and 60 days at 15°C (59°F).
2. Air Drying Sewage sludge is dried on sand beds or on paved or unpaved basins. The sewage sludge dries for a minimum of 3 months. During 2 of the 3 months, the ambient average daily temperature is above 0°C (32°F).
3. Anaerobic Digestion Sewage sludge is treated in the absence of air for a specific mean cell residence time (i.e., solids retention time) at a specific temperature. Values for the mean cell residence time and temperature shall be between 15 days at 35°C to 55°C (131°F) and 60 days at 20°C (68°F).
4. Composting Using either the within-vessel, static aerated pile, or windrow composting methods, the temperature of the sewage sludge is raised to 40°C (104°F) or higher and remains at 40°C (104°F) or higher for 5 days. For 4 hours during the 5-day period, the temperature in the compost pile exceeds 55°C (131°F).
5. Lime Stabilization Sufficient lime is added to the sewage sludge to raise the pH of the sewage sludge to 12 for > 2 hours of contact.
6. Other Methods: Other methods or operating conditions may be acceptable if pathogens are reduced to an extent equivalent to the reduction achieved by any of the above methods.

Discussion of Product Quality Requirements

The infestation with worms is presently so low (non-detectable levels of ova) in industrialized nations that they can no longer be considered useful indicators of the hygienic quality of sewage sludge (Buchauer, 2007). There appears to be a preference for bacteria. Some countries use bacteria in combination with helminths and may even further use them in combination with viruses. Culturable enteric viruses also frequently occur in very low numbers and have difficult analytical methodologies. A review of the product quality requirements in Tables 2 and 3 shows for:

- Helminths – Total ova values ranging from < 50 /g dry solids to < 1/ 4g and viable ova values ranging from non detectable to < 1 viable ova/ 4g
- Bacteria: Fecal coliforms – Values were from < 100 MPN / g dry solids to < 2500 MPN /g. A lesser quality material could have up to < $2x10^6$ MPN/ g or even $5x10^6$ MPN/g.
- Bacteria: *E. coli* – Values were from < 100 MPN/ g to < 1000 MPN/ g. A lesser quality sludge could have up to < $2x10^6$ MPN/ g.
- Bacteria: Fecal streptococci – One value given and that was < 100 MPN/ g dry solids
- Bacteria: *Salmonella spp* – Values ranged from non detect in 50 g dry solids to < 1MPN / 50 g and even < 1000 MPN/g.
- Viruses – Value in one case given as < 1 pfu / 4 g.

Pillai studied raw sewage sludges from across the US to identify those pathogens and surrogate indicator organisms that are at the highest density and determine their time-temperature-pH relationships in the laboratory under controlled conditions (Pillai et al. 2011). He found surprisingly low numbers of culturable enteric viruses (median values shown) (< 1 PFU/g), *Salmonella* spp (< 8 MPN/g), and helminth ova (< 1 ova/g) in the untreated sludge samples. Other pathogens, such as *Shigella* spp (25 MPN/g), *Legionella* spp (10^8 CFU/g), *Aeromonas* spp (10^8 CFU/g), were, however, present in larger numbers. Other organisms such as aerobic spores (10^6 CFU/g), *Clostridia perfringens* spores (10^6 CFU/g), fecal coliforms (10^8 MPN/g), *E.coli* (10^6 MPN/g), Enterococci (10^6 MPN/g), somatic coliphages (10^5 PFU/g) and male-specific coliphages (10^5 PFU/g) were present in large numbers.

E. coli was the most resistant of the target bacteria to temperature stress and was abundant in raw sludge with concentrations averaging about 10^7 MPN/g. This indicates that treatment of *E. coli* to

levels nearing or below detection would suggest that more sensitive pathogens initially present at much lower levels (*Salmonella* spp., *Shigella* spp., enteric virus, etc) would be reduced to acceptable levels. Another good option for treatment indicators included coliphages. Coliphages demonstrate potential as treatment indicators because of their resistance to heat-treatment as demonstrated during time-temperature trials. (Pillai et al. 2011). A review of the main indicators used in the different regulations reveals that *Salmonella sp.* is almost in all of them. However, its detection in treated sludge might be difficult due to the low numbers present (Skanavis and Yanko, 1994; WERF, 2009).

Differences in analytical methods used for detecting and quantifying microorganisms among nations, states, localities, and even laboratories make comparison of data very difficult. It is uncertain how to change this situation. Some nations like the US specify in their regulations that certain analytical methods be employed for some microorganisms but not all.

Discussion of Treatment Requirements to Achieve Disinfection

Several technologies or treatment processes were principally called out in the literature. These include:

- Drying – Heating to a temperature of >80ºC and drying to > 90% solids; or 80-90ºC for 30 minutes
- Pasteurization – Heating to a temperature of $\geq$ 70ºC for 30 minutes or up to 1 hour.
- Composting – In an enclosed system – heat to 55ºC for > 10 d or at > 65ºC for 2 d; In an aerated static pile system require 3 d at 55ºC; In windrows heating to 55ºC for 15 d to 3 weeks with up to 5 turnings in the 15 d period.
- Lime/Alkaline Treatment - pH >12 for > 72 hours, temperature >52°C, and, after the 72 hours, the treated sludge is air-dried to 50 % solids or greater; pH > 12 and T > 55°C for more than 2 h; or pH > 12 for > 3 months.
- Thermophilic Aerobic Digestion – 2 reactors in series with a HDT of ~ 10 d, during which the temperature is 50ºC for > 23 h, or 55ºC for > 10 h, or 60ºC for > 4 h.
- Thermophilic anaerobic stabilization is included in one standard in a temperature range 50 - 55°C for > 48 - 72 h including > 1 h at >70ºC followed by > 2 h at 55ºC or 4h at >50ºC.
- Liquid sewage sludge is heated to a temperature of 180^{o}C (356^{o}F) or higher for 30 minutes

Essentially all the treatments for disinfection rely totally or partially on the achievement of a temperature for a period of time. Figure 1 shows the relationships of time and temperature for the US Regulation (USEPA, 1993). The relationships are considered conservative and benefited from studies done in the US, UK, and Germany. Innovative and alternative processes for pathogen reduction frequently surface and question arises, how do we know they will adequately safeguard the public health when their product biosolids is land applied in agricultural applications? The US has developed the testing protocol shown in Table 6 (USEPA, 2003). Basically a new process must demonstrate its ability to inactivate helminth ova, enteroviruses, *Salmonella*, and/or fecal coliforms to the levels shown. When adequate numbers of viable helminth ova or enteroviruses are not present in the raw sludge for testing, it is necessary to add them. Detailed information on testing can be found at: http://www.epa.gov/nrmrl/pec/

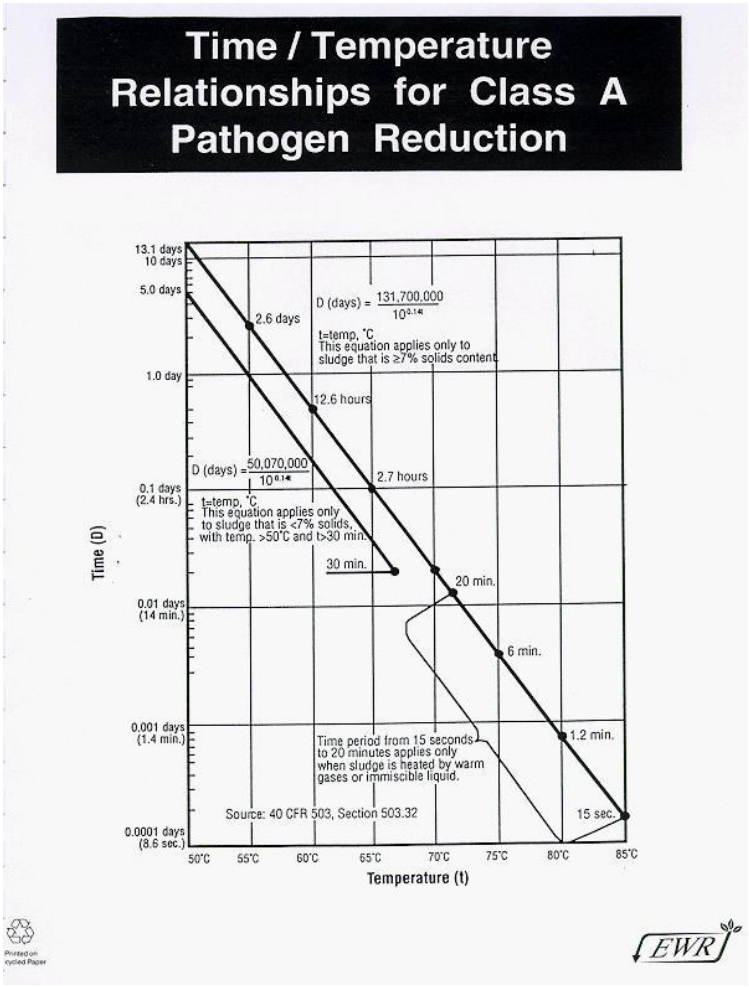

Figure 1. Time / Temperature Relationships for Optimum Removal of Pathogens

Table 6 – Requirements for Demonstrating Pathogen Reduction

PSRP (Class B) Equivalency	**PFRP (Class A) 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

Recent research by Higgins at several full-scale facilities with thermophilic anaerobic digestion followed by high speed centrifugal dewatering showed that culturable densities of indicator bacteria, mainly fecal coliforms and *E. coli*, significantly increased following dewatering (Higgins et al. 2008). Increases of up to five orders of magnitude were measured. One plant sampled did not show increases immediately after dewatering and after storage. This plant was different from the others in that it utilized thermophilic anaerobic digesters in series. An

important fact is that sampling of several thermophilic Class A plants and a thermophilic Class B plant showed that bacterial pathogens, such as *Salmonella*, do not appear to increase after dewatering and storage (Higgins et al. 2008).

STABILITY CONSIDERATIONS

As the definition of the word "stabilize" implies, the goal of stabilizing sludge is to prevent any further change. Sludge odors and putrescibility should be minimized and as such attractiveness to vectors and possible spread of disease. Although all the regulations previously mentioned are conscious about the necessity of treating sludge in this sense, not all of them include clear parameters for this purpose. European Directive 86/276, in its definition of "treated sludge"only touched upon the concept of stabilization.

Autralian Guidelines completely link the concept of stabilization and hygenization. The simplest concept is found in the Western Australian Guidelines (Department of Environmental Protection Water and Rivers Commission, 2002). They recommend achieving stability by:

- reducing the moisture content of the biosolids;
- reducing the organic content of biosolids by either aerobic or anaerobic digestion;
- adding alkalis (e.g.: lime) and/or heating;
- composting; or
- incorporation or injection of biosolids into the soil.

New South Wales Guidelines (New South Wales EPA, 1997) establishes that a biosolids product must meet at least one pathogen reduction requirement and at least one vector attraction reduction requirement in a similar way at is done by the U.S. EPA.

These approaches are very much in agreement with the options required by the US Regulation and shown in Table 7. Obviously reducing vector attractiveness is an approach to stability but does not guarantee that a material is *completely* stabile.

Table 7. U.S. Vector attraction reduction options (US EPA, 1993; 2003)

Option	Requirement
1	Minimum of 38% mass reduction of volatile solids
2	For anaerobically digested biosolids not meeting option 1, demonstrate vector attraction reduction by bench-scale anaerobic digestion (less than 17% reduction of volatile solids over 40 days at 30–37ºC)
3	For aerobically digested biosolids not meeting option 1, demonstrate vector attraction reduction by bench-scale aerobic digestion (less than 15% reduction of volatile solids over 30 days at 20ºC)
4	For aerobically treated biosolids, the specific oxygen uptake rate should be equal or less than 1.5 mg/h/g DS at 20ºC
5	Aerobic treatment of biosolids at temperatures greater than 40ºC (average of 45ºC) for 14 days or longer
6	Increase of the pH to above 12, followed by maintaining the pH at 12 or higher for 2 hours and at 11.5 or higher for an additional 22 hours
7	Reduce moisture content of biosolids that do not contain unstabilized solids to at least 75% solids
8	Reduce moisture content of biosolids that do contain unstabilized solids to at least 90% solids.
9	Injection of biosolids beneath the land surface
10	Incorporation of biosolids into the soil

Unfortunately sludge stability cannot be determined by a universally accepted standard test. The situation is complicated because the best measure varies with the type of stabilization process employed. It could be said that VAR (or odor, as one is a consequence of the other) is the most

relevant and reasonable criterion. However, quantification is difficult, subjective and expensive. In addition to the above methods for determining the degree of stabilization achieved, others that have been suggested are:

- Gas production during anaerobic digestion
- Presence of volatile fatty acids or nitrate
- Evolution of hydrogen sulphide or carbon dioxide
- Biological activity (measured for example with fly paper)

These methods have been widely described by Bruce and Fisher (1984), US EPA (2003) and Switzenbaum et al. (2002). The reduction of VS by 38 % is the most widely used measurement with processes like anaerobic digestion and aerobic stabilization to show adequate VAR. It is followed in employment by the specific oxygen uptake rate (SOUR) test, alkaline addition, dry solids concentration, and injection or incorporation. The intent of the biological treatment processes is to reduce the biodegradable organic material to a level where odors are no longer produced and vectors are no longer attracted. 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. Most designers today would expect to obtain at least 50 % VSR and often much 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 extent of VSR during thermophilic digestion of sludges. Better tests are already available for composted materials such as measuring the evolution of CO_2 and the use of such techniques for evaluation of product stability need to be considered.

WHERE DO WE GO FROM HERE

To be able to consider future requirements for controlling pathogenic microorganisms and how sludge is stabilized, beyond public health issues, it is important to reflect on the signals that are being given by the public, regulators, and users of biosolids. This can partially be done by looking at the findings of a 2007 NEBRA report, the findings of a 2010 Expert Meeting of the Water Environment Federation's National Biosolids Partnership (NBP), UK's Safe Sludge Matrix, the draft EC product quality and treatment recommendations, and recent action of Canada's Quebec Province.

Figure 2 highlights the pressures that a 2007 survey of US practices identified for biosolids programs (NEBRA, 2007). The numbers across the top show the number of individuals/groups surveyed and which, out of 250, identified the subject area as a priority. Highest priority was attributed to public involvement. Another very high priority was nuisance issues which included items like odors, truck traffic, and dust. These concerns were reinforced by the findings of a December, 2010 meeting of experts that the NBP held (WEF, 2011). Participants focused substantially on the persistence of public perception (of health) issues. These in turn have driven local and state regulatory and policy actions limiting biosolids management options including land application bans and the introduction of more restrictive management practices such as

fence line setbacks and incorporation requirements. Perception that Class A treated sludge is healthier than Class B treated sludge by the public has led to more Class A product production.

Figure 2. Pressures on Biosolids Programs (After NEBRA, 2007)

Closely tied by participants to persistent public perception problems were odors associated with biosolids processing, handling, and end use/disposal. Some localities are taking a "zero tolerance" approach to odor (WEF, 2011). Since some evidence exists that malodors may trigger health effects, the Ministry of Sustainable development, Environment and Parks in Quebec, Canada (MDDEP) developed an odor classification system for biosolids and other fertilizing residuals (FRs) that are applied on farm land (NEBRA/Beecher, 2010). It uses the system in its regulations of biosolids and other FRs. Specifically, 38 different types of typical biosolids and FRs are given a default odor designation. As the odor level increases, increasingly stringent management requirements, such as increased setbacks, are required. "Out of category" biosolids / FRs cannot be land applied without further treatment for odors. The regulatory system has proven effective in reducing odor complaints. However, it has led to elimination of land application in the province of some biosolids that were deemed too odorous (NEBRA/Beecher, 2010).

The UK's Safe Sludge Matrix of practices which was agreed upon by the UK's Sewage Treatment Plant Operators and National Farmers Union, Country Landowners Association, food manufacturers and food processors essentially eliminated the land application of conventionally treated sludge in the growing of fruits, vegetables, salads and horticulture as well as surface spreading on grazed grasslands (ADAS-UK, 2003). Enhanced treatment of sludge became

necessary for biosolids to be used in agriculture. This meant adoption of advanced hygienization practices like:

– Thermal drying and ensuring that the temperature of the sludge particles is higher than 80°C with a reduction of water content to less than 10% and maintaining a water activity above 0.90 in the first hour of treatment;
– Thermophilic aerobic stabilization at a temperature of at least 55°C for 20 hours as a batch, without admixture or withdrawal during the treatment;
– Thermophilic anaerobic digestion at a temperature of at least 53°C for 20 hours as a batch, without admixture or withdrawal during the treatment;
– Thermal treatment of liquid sludge for a minimum of 30 minutes at 70°C followed by mesophilic anaerobic digestion at a temperature of 35°C with a mean retention period of 12 days;
– Conditioning with lime and reaching a pH of 12 or more and maintaining a temperature of at least 55°C for 2 hours;
– Conditioning with lime reaching and maintaining a pH of 12 or more for three months.
–

A process shall be initially validated through a 6 Log_{10} reduction of a test organism such as *Salmonella Senftenberg W 775*. Further the treated sludge shall not contain *Salmonella spp* in 50 g (wet weight) and the treatment shall achieve at least a 6 Log_{10} reduction in *E. coli* to less than $5 \cdot 10^2$ CFU/g (Godfree, 2005).

A Suggested Direction

Biosolids applied to land must have:

Passed through a treatment (disinfection) process with demonstrated capability of reducing pathogens below the detection level. Recommended processes follow.

- Drying – Heating all the sludge particles to a temperature of >80ºC and drying to > 90% solids.
- Pasteurization – Heating a fluid sludge in a well mixed container to a temperature of ≥ 70ºC for ≥ 30 minutes
- Composting – In an aerated static pile system require 3 days at 55ºC; in windrows heating to 55ºC for 15 days to 3 weeks with up to 5 turnings in the 15 day period.
- Thermophilic Aerobic Digestion – Must operate in a batch mode and have 2 reactors in series with a HDT of ≥ 10 d, during which the temperature is 55ºC for > 20 h, or 60ºC for > 4 h.
- Thermophilic anaerobic stabilization at 55°C for > 20 h without addition of untreated sludge.
- Other processes which demonstrate their capability to remove pathogenic microorganisms (including helminth ova, enteroviruses, and *Salmonella spp.*) to a similar level that the above processes can are permitted.

Been tested for indicator organism levels to insure that adequate disinfection has taken place. Recommended organisms and levels follow.

- *E. coli* – < 100 MPN/ g dry solids
- *Salmonella sp* – Non detect in 50 g dry solids

Add where significant levels of helminths and/or enteroviruses are known to be present and where further there are questions concerning the disinfection process.

- Helminth ova – Total ova of < 1/ 4g dry solids and non detectable levels of viable ova
- Viruses - Entero viruses of < 1 pfu / 4 g dry solids

Been stabilized by a treatment process to the point where a) any odors still present in the biosolids are non offensive and b) biodegradable material remaining is minimal enough that vectors are not attracted. Recommended methods follow.

- Reducing the moisture content of the biosolids to ≤ 25 % (Note: This is only acceptable when some assurance can be given that the dried material will not be rewetted.
- Reducing the biodegradable organic content of biosolids by biological treatment as follows:
    - Aerobic digestion with effectiveness measured by:
        - Specific oxygen uptake rate should be equal or less than 1.5 mg/h/g DS at 20ºC
        - A leveling off of volatile solids destruction with time
    - Anaerobic digestion with effectiveness measured by:
        - A leveling off of volatile solids destruction with time
        - A leveling off of gas production with time
    - Composting with effectiveness measured by:
        - A leveling off of oxygen uptake rate
        - A leveling off of carbon dioxide evolution
        - Allowance for adequate curing of product – this can be from 40 to 90 days.
- Incorporation or injection of biosolids into the soil.

Notes: It is recognized that several of the measures included above will require testing to determine the best values for a particular biosolids

Recommendation

- Measure odor in a field setting of the applied biosolids using an olfactometer. See Beecher (2010).

Concluding Remark

Does the above "Suggested Direction" mean there is no future for conventional sludge treatment? No. Conventional sludge treatment will continue to be used in situations where biosolids will be applied to animal feed crops, grass and forage areas where grazing is not occurring, reclamation sites and possibly forests.

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