IS TIME-TEMPERATURE REALLY IMPORTANT?

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INTRODUCTION

Class A Lime Stabilization is quickly gaining popularity as one of the more cost-effective methods for complying with the 503-Class A Requirements. There are many facilities in operation, with more coming on-line, that operate in an open pile mode of operation. These plants typically utilize a very simple operation that consists of a sludge/lime mixer that discharges into an open pile. Sufficient quicklime is added to raise the temperature of the product to 70°C / 158°F. This product is then discharged into an open pile or a truck where it cools rapidly due to ambient conditions, during cold winter months heat loss may be rapid.

This problem is compounded by a false sense of security because the biosolids are testing favorable for less than 1,000 MPN fecal coliform. Operators feel their process complies with the requirements of Class "A" because they are meeting their fecal coliform limits of 1,000 MPN. therefore, they can give the sludge away without any of the restrictions of the management practices specified in the 503 Regulations. Insufficient time-temperature, however, will not effectively stabilize the sludge as required by the 503 Regulations.

Helminth ova, for example, are extremely resistant to all but the most adverse processing and environmental conditions at temperatures below the mesophilic range of 50°C. In this temperature range bacterial indicator organism testing is inaccurate and can not be used to indicate reduction in Helminth ova. The fecal coliform test assumes the predescribed time-temperature regimes have been met. If the time-temperature requirement has not been achieved, the fecal testing is not appropriate or accurate.

The 503 Regulations outline specific Time-Temperature Regimes that must be met in order to qualify under Class "A" for Alternatives 1 & 2. Many facilities are actually operating outside of the prescribed time-temperature with lower temperatures for shorter periods of time. They are considering the end product to be Class A material under the assumption that the Regulations are unnecessarily stringent and what they are doing is "good enough". This raises the issue of whether time and temperature is really important.

HOW PREVALENT ARE HELMINTHS?

During the early 1980's the EPA funded a research project to assess the types and densities of parasites in municipal wastewater sludges in the southern United States (5). Samples were examined during each of the four seasons at 27 treatment plants. The study documented;

a) viable eggs of <u>Ascaris</u> and <u>Toxocara</u> were found at every plant,
b) viable eggs of <u>T.vulpis</u> and <u>T.trichiura</u> were observed at least once from 26 and 15 plants, respectively;
c) additional viable eggs of at least 10 other helminths and cysts of a few protozoa were also found at the plants studied, albeit in fewer numbers and at lower frequencies.

Since the early part of this century, public health workers in the United States have been concerned about the presence of resistant stages of human and animal parasites in domestic sewage effluents and sludges as a possible source of disease. However, until recent years, there were relatively few published reports of studies concerning this problem.

During the 70's and 80's, changes in regulations concerning the treatment of municipal wastewaters have resulted in a magnitudinal increase in the production of domestic sewage sludges. The problems related to the disposal of these sludges have increased accordingly. Among the alternative methods of sludge disposal, those that "recycle" the sludge through land applications have attracted increasing interest. A number of studies have been initiated in the past few years to determine the potential risks due to the presence of infectious agents in sludges (i.e., viruses, bacteria, parasites and fungi). (5)

Fox and Fitzgerald (9, 10) conducted a comprehensive study of parasites in raw sewage, anaerobically digested sludges and effluents from Metropolitan Sanitary District of Greater Chicago. They reported finding eggs of Ascaris, Toxascaris, Trichuris trichiura, Taenia, Hymenolepis, and Enterobius vermicularis. Hays (11) examined raw and digested sludge samples from four sewage plants in Allegheny County, Pennsylvania and found eggs of Ascaris, Trichuris trichiura, Capillaria hepatica, Enterobius vermicularis Hymenolepis nana, and H. diminuta.

In a study supported by the Environmental Protection Agency, the East Bay Municipal Utility District of Oakland, California and the Sacramento Regional Sanitation District, Thies et al., in 1978 (12), examined municipal sludges (raw, digested and composted) from 12 areas of the United States. They reported Ascaris and Toxocara eggs in sludges (raw, digested or composted) from Oakland, Los Angeles and Sacramento, California; Macon, Georgia; Springfield, Missouri; Hopkinsville, Kentucky; and Frankfort, Indiana. Trichuris, Toxascaris and Hymenolepis diminuta eggs were found in raw digested or composted sludges from Los Angeles. Helminth eggs were not found in samples from Las Virgenes, California; Kendalville, Indiana; Columbus, Indiana; Wilmington, Ohio; or Chippewa Falls, Wisconsin.

Jackson et al. (13) reported that in a 1975 study supported by the United States Food and Drug Administration, Chaney and Burge found Ascaris eggs in liquid sludge samples from 16 municipalities in the United States. Viable Ascaris eggs were present in samples from 13 of the 16 cities.

The resistant free-living stages of the intestinal parasites of man, domestic animals, pets and wild animals (i.e., the eggs and larvae of helminths and the cysts of protozoa) are the stages of parasites that are most likely to enter sewage systems. Several authors have provided lists of parasites that might be encountered in municipal sewage sludges (11, 14); however, in these lists of relative importance of different parasites in sludges was not evaluated.

THE NEED FOR THE REGULATIONS

Municipal wastewater general contains four major types of human pathogenic (disease-causing) organisms.

1. Bacteria
2. Viruses
3. Protozoa
4. Helminths (Parasitic Worms)

The Helminths of the greatest concern to humans are roundworms and tapeworms. Light infestations are asymptomatic, presenting no symptoms of the disease, but heavy infestations can be life threatening (1). The groups at the highest level of risk are infants and the elderly. A single helminth egg is infective to humans. The magnitude or period of infection is dose - related because most of the worms do not multiply in man (1). An infection may frequently sensitize an individual so that subsequent light infections will cause allergic reactions. Because the infective dose is low, exposure should be minimize. The potential for ingestion is highest with Class "A" materials that are distributed and marketed without any of the management practices of 503 and therefore it is necessary that all such biosolids be devoid of viable Helminth ova.

Parasitic infections present a potential health risk associated with agricultural and home use of sludge derived products due to the existence of highly-resistant stages of the organisms in low infective doses. Ascaris ova are the most commonly isolated ova in sludge (Reimers, et al. 1981). In 1973, Ascaris was estimated to affect 4,000,000 people in the United States (Kowal, 1983). Therefore, reasonably thorough helminth inactivation is necessary for home use of sludge products. Once destroyed, enteric viruses and

Helminth ova cannot re-establish themselves in sludge; regrowth is not a concern (Ward, et al. 1984). Farrell, 1986 and WHO, 1981 address the question of risk to health from the use of sludge on land. Both concluded that appropriate measures are available to manage the risk. In short, this requires strict compliance with the requirements of the 503 Regulations in order to assure public health and safety is protected.

Helminth ova are not a problem nor should they be an area of concern if the predescribed time-temperature regimes are met. On the other hand, if a processor is operating outside of the known art, then this raises an issue which should be of concern to all professionals in the industry.

DEVELOPMENT OF 503 STANDARDS

The 503 Regulations describe several techniques for achieving a Class A level of Pathogen Reduction. Two of the most popular options are Alternative #1 & #2, Thermally Treated Sewage Sludges (503.32A [3]). These Alternatives describes different Time-Temperature Regimes that must be met in order to effectively reduce pathogens. The 503 Regulations clearly and specifically state that the time-temperature requirements specifically apply to every particle of sewage sludge processed under Alternative #1 and #2 (1) (8). This section of 503 presents a time-temperature requirement for several sludge regimes with solids concentration at 7% or higher.

The thermal conditions required under Alternative #1 is similar to Thermal Requirements of 40 CFR, Part 257. Part 257 contains two time-temperature conditions which, if met, are expected to reduce pathogens of concern below detectable limits. These two requirements are:

1. Pasteurization by treatment at 70°C/158°F for 30 minutes and;
2. Composting at 55°C for three days.

The pasteurization condition of 70°C for 30 minutes is based on German Recommendations and Practices. Recommended values (IRGRD [1968]) for 20 to 25 minutes at 70°C, but practice settled on 30 minutes at 70 °C (Barker, 1970). The use of the Time-Temperature equation is restricted to times greater than or equal to 20 minutes and the temperatures greater or equal to 50°C. The reason for the minimum time of 20 minutes is that it is difficult to heat sewage sludge with solids higher than 7% uniformly. Sewage sludge, which has a solid concentration greater than 7%, typically has an inherent internal structure which inhibits the thermal and hydraulic gradients that contribute to uniform distribution of temperature (1).

The restriction to temperature of at least 50°C is imposed because information on the temperature-time relationships at lower temperatures is uncertain. For example, Brannen et al. (1975) reports that Ascaris ova are destroyed quickly at temperatures above 51°C, but are unaffected by long exposures to 47°C, indicating that much longer times than would be expected could be required to inactivate viable Helminth ova at temperatures below 50°C (1) (8).

The processing requirements for Alternative #2 are described in Part 503.32(a)(4). The process conditions include a combination of a) elevating the pH above 12 for a period of 72 hours, b) maintaining the temperature of all of the biosoloids above 52-C for at least 12 hours and c) air drying the final product to over 50% dry solids. The combination of hostile conditions of high pH, high temperature for an extended period of time and high solids concentration allow for a less severe time - temperature regime then the EPA's thermal conditions listed above (1). It is, however, necessary that all particles of sewage solids comply with these processing requirements of time, temperature, pH and solids concentration in order to qualify as a Class "A" material under Alternative #2.

SUMMARY OF 503 REQUIREMENTS

The following excerpts were taken from the EPA's *Plain English Guide to the EPA 503 Biosolids Rule* and EPA's *Technical Support Document for Reduction of Pathogen and Vector Attraction in Sewage Sludge.*

There is a common theme of "time - temperature" that runs throughout all of the known pathogen reduction processes that are commonly used to comply with this portion of the 503 regulations. These process can be generally categorized as;

1. Pasteurization processes.
2. Composting processes
3. Heat drying processes.
4. Thermal processes including thermophilic aerobic digestion

Table 5-2 summarizes the requirements that must be met by all Class "A" processes.

TABLE 5-2

Pathogen Requirements for All Class A Alternatives

The following requirements must be met for all six Class A pathogen alternatives.

Either:

- The density of fecal coliform in the biosolids must be less than 1,000 most probable numbers (MPN) per gram total solids (dry-weight basis),

  or

- The density of *Salmonella* sp. bacteria in the biosolids must be less than 3 MPN per 4 grams of total solids (dry-weight basis).

Either of these requirements must be met at one of the following times:

- When the biosolids are used or disposed;

- When the biosolids are prepared for sale or give-away in a bag or other container for land application; or,

- When the biosolids or derived materials are prepared to meet the requirements for EQ biosolids (See Chapter 2).

Pathogen reduction must take place before or at the same time as vector attraction reduction, except when the pH adjustment, percent solids vector attraction, injection, or incorporation options are met.

Alternative 1 for Meeting Class A: Thermally Treated Biosolids

This alternative applies when specific thermal heating procedures are used to reduce pathogens. Equations are used to determine the length of heating time at a given temperature needed to obtain Class A pathogen reduction (i.e., reduce the pathogen content to below detectable levels). The equations take into consideration the solid-liquid nature of the biosolids being heated, along with the particle size and how particles are brought into contact with the heat. The equations also take into consideration that the internal structure of the mixture can inhibit mixing. For example, a safety factor is included in the equation for Regime C (See Table 5-3) that adds more time for heating because less information is available about operational parameters that could influence the degree of pathogen destruction per unit of heat input. The rule identifies and provides equations for four different acceptable heating regimes.

The minimum indicated boundary conditions (i.e., solids content, mixing with the heat source, time of heating, and operating temperature) are given below for each of the four thermal heating regimes. Any one of these four thermal heating regimes may be used. The equation specified for a particular heating regime is then used to calculate the actual time and temperature for operating the system within the boundaries of the applicable regime. In addition to the requirements, the requirements in Table 5-2 must be met.

The four regimes are listed in Table 5-3.

TABLE 5-3
The Four Time-Temperature Regimes for Class A Pathogen Reduction
Under Alternative 1

Regime	Applies to:	Requirement	Time-Temperature Relationship*
A	Biosolids with 7% solids or greater (except those covered by Regime B)	Temperature of biosolids must be 50°C or higher for 20 minutes or longer	$D = \frac{131{,}700{,}000}{10^{0.14t}}$ (Equation 2 of Section 503.32)
B	Biosolids with 7% solids or greater in the form of small particles and heated by contact with either warmed gases or an immiscible liquid	Temperature of biosolids must be 50°C or higher for 15 seconds or longer	$D = \frac{131{,}700{,}000}{10^{0.14t}}$
C	Biosolids with less than 7% solids	Heated for at least 15 seconds, but less than 30 minutes	$D = \frac{131{,}700{,}000}{10^{0.14t}}$
D	Biosolids with less than 7% solids	Temperature of sludge is 50°C or higher with at least 30 minutes or longer contact time	$D = \frac{50{,}070{,}000}{10^{0.14t}}$ (Equation 3 of Section 503.32)

*D = time in days; t = temperature in degrees Celsius.

The time-temperature requirements specified apply to every particle of sewage sludge processed. The restriction to temperatures of at least 50°C is imposed because information on the time-temperature relationship at lower temperatures is uncertain. For example, Brannen, et al. (1975) report that Ascaris ova are destroyed quickly at temperatures over 51°C but are unaffected by long exposure at 47°C, indicating that much longer times than expected could be required to inactivate viable Helminth ova at temperatures below 50 °C. The time-temperature relationship given by Equation 1 is conservative. Conservatism is required because sewage sludges with 7% or higher solids content may be pasty masses or clumps of particles several inches in diameter that are very difficult to bring to uniform temperatures. For sewage sludges with less than 7% solids, which are easier to bring to uniform temperatures, a less conservative time-temperature relationship, such as that given in Equation 2, is reasonable.

TESTING FOR HELMINTH OVA

The "White House Book" provides a brief introduction to the proper sampling and testing procedures for Enteric Viruses and viable Helminth ova. It is apparent that the results generated from these tests are only as good as the sampling technique used to gather them. The "White House Book" states: *"For example, Enteric viral and bacterial densities are noticeably reduced by even one hour at exposures to temperatures of 95°F or greater."*

One would imagine that the same results would occur if the samples were at a lower temperature, say 80°F, for a longer period of time, such as several days. Standard methods states that if samples are not tested within one hour of collection, then they need to be cooled to 50°F and the samples should be tested within six hours. Clearly, most plants are not going to be able to do this kind of testing; and therefore, the EPA recommends chilling the samples to 39°F and testing within 24 hours. Again, one would have to wonder what the impact on the end results would be if the samples were not completely or properly chilled before testing.

The testing for Helminth ova, for Lime Stabilization Processes, requires that the pH be neutralized immediately. The "White House Book" states: *"If the sludge is treated by a chemical such as lime, the lime may have to be removed (in this case by neutralization) immediately after sampling if the microbial tests are to be valid."*

If the sampling is not done in accordance with these procedures, then any test results would be questionable and not truly representative of the level of treatment. Considering that Enteric Viruses covered under the 503 Regulations consists of more than 100 types of viruses including Hepatitis A, this makes the testing and therefore, the sampling all the more important.

The key to developing accurate test data starts with the collection and handling of the samples; and therefore, this step is equally important and quite possibly more important than the testing itself.

DISCUSSION OF PREVIOUS WORKS

Considerable work has been done since the early '70s in the analysis of effective means of safely stabilizing pathogenic organisms that are commonly found in domestic sewage sludge. One such study was conducted in 1975 by Brannen, et al. This study entitled *Inactivation of Ascaris Lumbricoids Eggs by Heat, Radiation and Thermal Radiation* provides an insight to the basis of the Time-Temperature Requirements that are currently contained in the 503 Regulations. Brannen found that "the results obtained from the experiments conducted in this study indicate a narrow temperature band in which temperature effects vary from no inhibition of embryonation at 47°C to a very sharp drop and nearly inhibition of 55°C for a four-minute exposure. Experiments conducted at 51°C suggest this temperature to be the threshold at which heat effects become more readily discernible since no inhabitation was observed after 50 to 75 minutes at a temperature below 51° C. " In Brannen's study, fertilized Ascaris ova were subjected to temperature environments ranging from 47°C to 70°C for various period of time. There was no effect on the Ascaris ova even after two hours at 47°C. A similar experiment was conducted at 51°C and it was found that only 90% of the ova were inactivated after 13 minutes.

R.S. Reimers, et al. conducted a study in cooperation with the U.S Environmental Protection Agency in 1981. The study was entitled *Parasites in Southern Sludges and Disinfection by Standard Sludge Treatment.* Reimers reports that generally, the influence of sludge handling, treatment and disposal along with the effective wastewater treatment processes on parasite survival is very complex and influenced by many parameters. Such factors include the type of parasites, temperature, moisture content, etc. Field studies in Reimers investigation revealed the following:

1. Most raw samples contain viable parasite eggs and cysts.
2. Eighteen species of parasites (eggs or cysts) were observed in both stabilized and raw sludges.
3. Eggs of the most prevalent parasites were present in relatively high numbers (an average of 1,000 to 10,000 eggs per kilogram of dry sludge, depending upon the parasite).
4. From the parasite mass balance study, it was observed that secondary clarifiers tend to concentrate parasites in the return sludges.

FIELD STUDIES

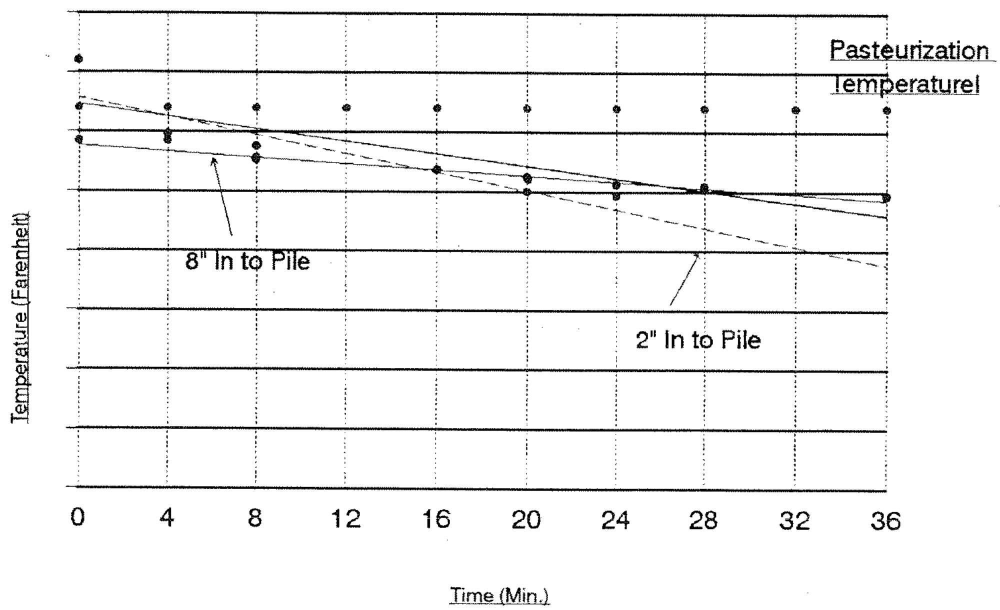
In the Fall of 1991, Muhs studied the characteristics of open pile lime stabilization. The results show:

1. Open piles cool rapidly when exposed to ambient conditions.
2. Balls or lumps are formed by the pugmill mixer.
3. The lumps may not be thoroughly and effectively stabilized.

Muhs' work corroborated EPA work which indicated a need for conservatism in setting operating requirements for sewage sludges with greater than 7% concentration. Secondly, Muhs showed that the temperature of the sewage solids in the open pile dropped dramatically at ambient conditions. He

showed that the temperature measured 2" into the pile dropped rapidly after treatment while the temperature measured 4" and 8" into the pile dropped more gradually and at nearly identical rates. This indicated that the outer several inches of a stockpile cooled more rapidly than the interior. Although the product started out a temperature of 70°C, the outer 2" of the pile cooled to below 50°C within 30 minutes. The temperature of the Biosolids for each run was measured immediately after discharge from the mixer. Discharge for runs 11 through 14 was placed in an insulated container immediately after the discharge from the mixer. The discharge temperature of the insulated material was easily maintained for at least 75 minutes without additional heat input.

Ambient Cooling of Heated Sludge



Similar results were found during studies associated with the development of this paper. The work is continuing but the preliminary data shows the following cooling in a open windrow composting operation in North Carolina. The temperature was measured at a distance of 2" into the pile, an area where there is the also the greatest potential for post processing inoculation;

Time =	0 minutes with a temperature of	68°C
=	5 minutes	64°C
=	10 minutes	61°C
=	15 minutes	58°C
=	20 minutes	55°C
=	25 minutes	52°C
=	30 minutes	50°C
=	35 minutes	48°C

In order to qualify as a RSRP, composting can be conducted by the aerated static pile, windrow, or within-vessel method and the solid waste must be "maintained at a minimum operating condition of 40°C for 5 days. For 4 hours during this period the temperature exceeds 55°C. Composting at temperatures of 55°C or greater for 3 days (within-vessel or aerated-pile methods) qualifies as a PFRP. The degree of pathogen inactivation attained in the sludge during composting is mainly dependent on temperature (2). Studies conducted in Los Angles County with windrow composting have revealed that Ascaris ova can survive this process if sufficient temperatures are not attained (3). This result is expected because laboratory experiments carried out at the Sandia National Laboratories have shown that Ascaris ova are quite stable at temperatures of 47°C or below, whether in water or compost (4).

Clearly this North Carolina facility is operating outside of the prescribed time - temperature regime. The product is, however, being distributed and marketed as a Class "A" product that is being given to homeowners. The plant's data and records may look acceptable because the temperature probes are buried 3 - 4 feet in to the pile but what about the perimeter? This is the area of the compost pile that is most susceptible to inoculation and there is nothing, in terms of an elevated temperature, to prevent the growth of pathogens.

REGROWTH & POST TREATMENT HANDLING OF BIOSOLIDS

Disinfection processes (PSRP and PFRP's) greatly reduce or eliminate the pathogen populations in domestic sewage, however, repopulation can result in levels of microorganisms that again represent a public health threat(2). The 503 Regulations require testing prior to land application but the regulations do not address any guidelines for post treatment handling of biosolids products to insure that the products remain free of pathogenic organism.

Pathogen regrowth will depend upon recontamination. Frequently this occurs by way of vector transport. For example, the role of mosquitoes in transmitting malaria. Vectors are defined as any agent that is capable of transmitting pathogens either physically or biologically. The hazards from vector transport are difficult to quantify and thus tend to be underestimated (1). In 1986 Gemmell documented a case where the parasite eggs from a dog pen were transported by flies and contaminated 30 hectares of grazing land.

Sagik et al. (6) listed moisture, pH, temperature, sunlight, organic matter, and microbial antagonism as factors that are likely to influence regrowth. It is possible to predict regrowth when inoculation occurs and there are the following conditions:

a) the moisture level is greater then 20%,
b) the pH is between 5.5 to 9.0;
c) the temperature is in the range of 10°C to 45°C

Yanko studied windrow and static pile composting operations in Los Angeles County for a period of two years (7). The results indicated that current composting practices may not insure complete elimination of pathogenic bacteria. Relatively few salmonellae were detected in the final compost product but significant increases occurred during the subsequent production of commercial soil amendment products. Yanko reported that these increases were consistent with a regrowth phenomenon. Bacteria can grow to higher densities if conditions favorable to regrowth are created such as a poorly composted sewage sludge that has been cooled in the process from the thermophilic temperature range to the mesophilic range (1).

The 503 Regulations require Class A Biosolids to be tested at the time of use or disposal. The phrase "at the time of use or disposal" is used to indicate that the appropriate pathogen requirements have to be met just prior to when the sewage sludge is used or disposed. Enough time must be allowed to test the sewage sludge and obtain the test results before the sewage sludge is used or disposed. The main reason this phrase is used in the Regulation is to ensure that the pathogen regrowth requirement (i.e., fecal coliform or Salmonella sp. bacteria density value must be below the specified value) is met at the time the sewage sludge is used or disposed (1).

EMERGING ISSUES

Properly stabilized biosolids are a safe and effective soil conditioner but there continues to be a need for public education. There is considerable continuing interest in all aspect of human health issues.

The Sunday, June 30, 1996 edition of the New York Times featured a headline story entitled: *"Illness Outbreak Puzzles Officials - Microbe Elusive as it Navigates the Nation's Food Supply"*. The article goes on to explain that the microbe known as Cyclospora, is a parasite that infects the intestine and can cause intense diarrhea, weight loss and fatigue. The *Times* also states that "the epidemic is yet another in a long line of new and emerging infections like Legionnaire's Disease and AIDS that have struck this year." The Times continues on and relates this incident to an outbreak of Cryptosporidiosis that sickened 400,000 people in Milwaukee in 1993.

In a related story, the June 25, 1996 issue of the *Wall Street Journal* included a featured article entitled: *"Drug Makers Go All Out to Squash 'Superbugs"*. The *Journal* told of an elderly woman who was

isolated in a Boston hospital, not because of her heart trouble but rather "...she was kept segregated because of a more frightening problem. Of all the antibiotics available in the hospital, not a single once can kill a dangerous strain of bacteria she harbors."

The *Journal* article basically focused on the commercial aspect of this new problem of drug resistant bacteria. These new "Superbugs" are a result of the prevalent use of antibiotics over the past 30 years. Stuart Levy, a professor at Tufts University Medical Schools is of the opinion: "By introducing large quantities of these drugs, we have drastically altered the ecology of microbes and unwittingly given a selective advantage to resistant bacteria."

These articles could turn out to be the tip of the iceberg as the media may latch onto this new and emerging topic. With all the new and shocking topics, there is a tendency for some to sensationalize events and blow the truth out of proportion to the facts. Professionals in our industry are keenly aware of the importance of the public's perception because perception is reality. We all need to make sure that we are doing things right so that land application does not get caught up in a media attack, whether that be on a local level or a national level, on the prudent and proper beneficial reuse of biosolids.

CONCLUSIONS AND RECOMMENDATIONS

1. Time-Temperature is important.
2. Fecal Coliform indicator organism testing is accurate only if the Time-Temperature Regimes are met.
3. The Time-Temperature Regulations apply to every particle of sewage solids.
4. Regulators should consider specific language when they permit Class A facilities that require the processor to demonstrate every particle of sewage solids meets the Time-Temperature Requirements.
5. Regulators may want to consider testing requirements that call for the biosolids to be spiked with Helminth ova to demonstrate process and process equipment performance, prior to placing a Class "A" facility in to full scale operation.
6. Current media attention under scores the importance for professionals in the industry to focus their efforts on "doing it right" and effectively documenting of the processing parameters for every particle of sewage solids.

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