A literature Review on Disinfecting Chemicals for Improved Bio-Security of Emergency Animal Mortality Composting and Anaerobic Digestion

By: Lam Nguyen, ABE – Iowa State University

This work reviews literature on disinfecting chemicals that could be used to inactivate pathogens in carcass composting and anaerobic digestate. Our review suggests the pathogens sometimes survive in compost and anaerobic digestate. The objective of this review is to look for a possibility of a two-phase treatment, composting and anaerobic digestion followed by a chemical treatment, to improve the bio-security of livestock mortality management. First, we review the available information on liquid and gaseous disinfecting chemicals that have been used historically for inactivating pathogens in solid and liquid matrixes such as soil, grains, and certain food products. Based on the scientific, practical appeal of those chemicals, we evaluate and discuss their potentials and suggest some chemicals that could be used in emergency disposals of animal mortalities. Finally, we highlight future emerging research needs.

IOWA STATE UNIVERSITY

Department of Agricultural and Biosystems Engineering

4th International Symposium:
Managing Animal Mortalities, Products, By-Products & Associated Health Risk
Dearborn, Michigan
May 21-24, 2012

L. Nguyen[1], T. Glanville[1], J. Koziel[1], T. Frana[2]
[1]Department of Agricultural Biosystems Engineering, Iowa State University, [2]Veterinary Diagnostic and Production Animal Medicine, Iowa State University
Corresponding author: koziel@iastate.edu

A review of chemicals to improve bio-security of emergency animal mortality composting and anaerobic digestion

Abstract:

This is a review of literature on disinfecting chemicals that could be used to inactivate pathogens in composting and anaerobic digestate of animal catastrophic disposals. Our review suggests that pathogens sometimes survive in compost and digested residues. The objectives of this study are to look for: (1) The available information on liquid and gaseous disinfecting chemicals that have been used for inactivating pathogens in solid and liquid matrices such as soil, grains, and certain food products; (2) An alternative method for chemical treatment of composting and/or anaerobic digestate, to improve the bio-security of emergency animal disposals. Based on the scientific data, practical appeal and the applications of the reviewed chemicals, ammonia (NH_3) appears to have the best potential for disinfection of composting and/or anaerobic digestate for emergency disposals of animal mortalities.

Background:

Massive loss of poultry and livestock caused by diseases and natural disasters are of health and environmental concerns. These animal mortalities need to be readily disposed of, but lack of bio-safety measures in buried-out method leads to groundwater hazardous and odors. In South Korea, 9.7 million cattle, swine, and poultry carcasses were buried in mass graves after outbreaks of foot-and-mouth disease and bird-flu in the winter of 2010. This raised concerns that contaminants may enter groundwater when the soil has thawed. Composting and anaerobic digestion are disposal methods of interest. Therefore, health officials want to be very sure that these processes are safe. The effectiveness in reduction of pathogens in both processes is affected by temperature, a factor that generally cannot be controlled when used under emergency conditions. Composting is not always completely heat-treated. Research has documented cases of pathogen survival and re-growth in composted materials.[1, 2] *Escherichia coli* and *Salmonella* spp are not damaged by mesophilic temperatures.[3] This justifies the need for post-process disinfection with appropriate chemicals.

Suitable chemicals for pathogen disinfection:

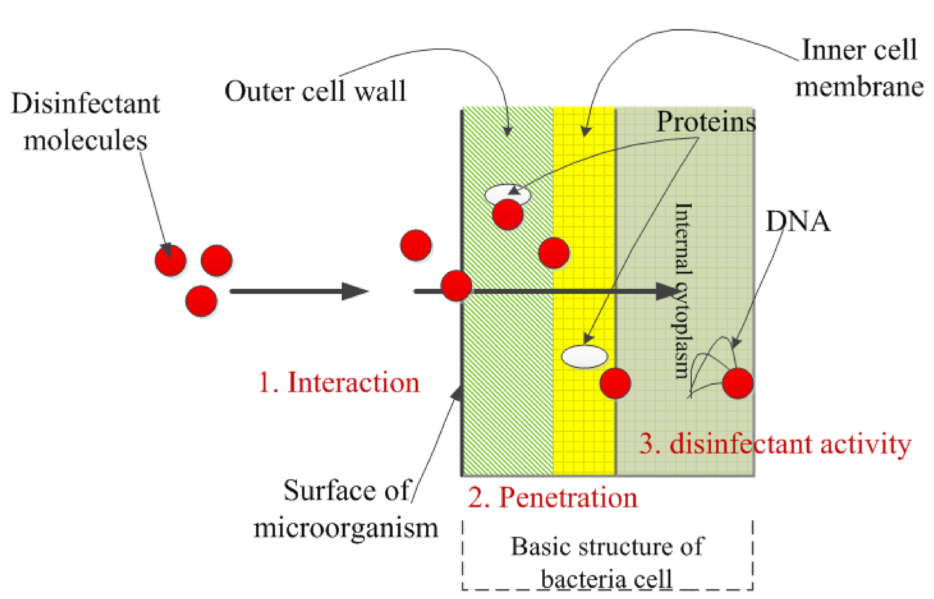

Figure 1. Mechanism of actions of disinfectants

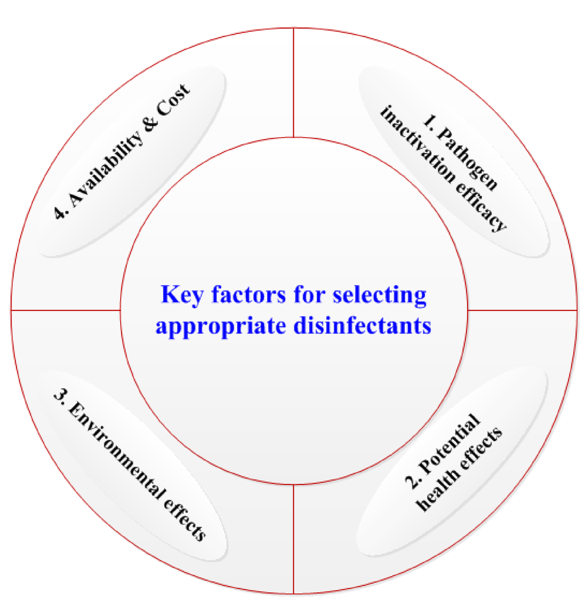

Figure 2. Key factors for selecting appropriate disinfectants

The disinfectants should be at a sufficient level in order to inactivate the pathogens by: (1) Interaction with microbial surface; (2) Penetration into microorganism; (3) Action at the target sites.[4]

Figure 2 summarizes in order of importance the factors to be considered when using them as disinfectants for composting and digested residues.

	Suitable physical forms of disinfectants		
	Gas	**Liquid**	**Solid**
Composting	Yes	No	No
Anaerobic digestion	Yes	Yes	Yes

Table 1. Selecting physical forms of chemicals for composting and anaerobic residues

List of chemicals that have been used for disinfection of grains, soils, & certain food products:

Chemical/agent	Pathogen carriers	Inactivation of Specific Pathogens	Net reduction (CFU/g)
Anhydrous ammonia gas (NH_3)	Corn silage[5]	Salmonella newport	Least effective in silage because silage alone showed strong antibacterial activity
	Cotton seed[5]	Salmonella newport	4.9 – 7.2 log
	Wheat straw[5]	Salmonella newport	4.9 – 8.7 log
	Corn grain[5]	Salmonella newport	5.6 - 6.8 log
		Escherichia coli O157:H7	7.4 – 8.8 log
		Listeria monocytogenes	5.1 – 6.3 log
		Campylobacter jejuni	5.0 – 6.2 log
		Yersinia enterocolitica	5.5 – 6.6 log
Chlorine dioxide solution (ClO_2)	Lettuce[6]	Escherichia coli O157:H7	1 log
	Apples[7]	Escherichia coli O157:H7	2 to 4 log /apple
	Tomatoes[8]	Salmonella enterica	7.1 log (cfu/mL)
		Escherichia carotovora	6.8 log (cfu/mL)
Chlorinated water (Cl_2 and HOCl)	Lettuce[9]	Escherichia coli ATCC 25922	2 log
Peroxy-acetic acid solution (CH_3CO_3H)	Apples[7]	Escherichia coli O157:H7	2 to 5.5 log/apple
Ozonated water (3 ppm & organic acid (1%) such as acetic, citric, or lactic acids)	Mushroom[10]	Listeria monocytogens	0.92 - 2.26 log
		Escherichia coli O157:H7	
Ozonated water (1, 3 and 5 ppm)		Listeria monocytogens	< 1 log
		Escherichia coli O157:H7	
Lemon juice mixed with vinegar (1:1)	Carrots[11]	Salmonella typhimurium	1.59 to 6 log
Fresh lemon juice (4.46% v/v citric acid)		Salmonella typhimurium	0.79 to 3.95 log
Vinegar - Acetic acid (4.03%)		Salmonella typhimurium	1.57 to 3.58 log
25% hydrogen peroxide plus 5% peracetic acid (Ox-Virin)	Goat kids[12]	Cryptosporidium parvum oocysts	% pathogen inactivation 26.5 to 100 %
48% hydrogen peroxide plus 0.05% silver nitrate (Ox-Agua)			35.1 to 100 %
Cyanogen (C_2N_2)	Soil fumigation[13]	Schlerotium rolfsi, Pythium sulcatum, Rhizoctonia solani, Fusarium acuminatum, Phytophthora cactorum, Phytophthora cryptogea, Bipolaris soroikiniana	120 mg/kg C_2N_2 can control all soil borne pathogens and soil fungi
Sulfuryl fluoride (SO_2F_2)	Soil fumigation[14]	Bacillus anthracis (Ames strain) spores.	0.43 to 1.22 log
Ozone (O_3)		Bacillus anthracis (Ames strain) spores	1.76 to 7.68 log
Methyl bromide gas (MeBr) (> 99% pure)	Soil fumigation[15]	Escherichia coli O157:H7	Fumigation alone may not eliminate the pathogens, but may decrease microbial diversity which may enhance the survival of the pathogens.
Methyl iodide liquid (MeI) (> 99% pure)		Escherichia coli O157:H7	

Table 2. List of disinfectants for grains, soils and certain food products

Availability and use consideration for some of disinfecting agents

Agent	Availability, cost, and use considerations (equipment, chemical, labor, training)	Mechanism of actions*	Cancer classification[16]	Health hazard Ranking[17]	Environmental hazard Ranking[17]
Ammonia (NH_3)	- Can purchase anhydrous ammonia or liquid urea solution from agricultural fertilizer suppliers. - Can obtain ammonia gas from urea.[18]	(2), (3)	Not classifiable	1.0	1.5
Ozone (O_3)	- Ozonation is more complex than other disinfection technologies. - Must be generated on-site. - The cost of treatment is relatively high, being both capital- and power-intensive.[19]	(1), (2), (3)	Not classifiable	1.5	3.0
Chlorine dioxide (ClO_2)	- Almost always used as a dissolved gas in water (concentration < 10 mg/L).[20] - Must be generated on-site.[16] - Chlorine dioxide is less expensive than other disinfection methods, such as ozone.	(2), (3)	Not classifiable	1.8	1.5
Cyanogen (C_2N_2)	- Cyanogen diffused and penetrated through the soils faster and farther than MeBr and was more rapidly and strongly sorbed by all soils compared to MeBr.[21]	(3)	Not classifiable	N/A	N/A
Methyl bromide (MeBr)	- Treatment cost less than Sulfuryl fluoride method.[22]	(2)	Potential occupational carcinogen	N/A	N/A
Sulfuryl fluoride (FO_2S_2)	- Sulfuryl fluoride uses about two thirds more than Methyl bromide in order to have the same effectiveness.[22]	(2), (3)	Not classifiable	N/A	N/A

Table 3. List of disinfectants for grains, soils and certain food products

*** Mechanism of actions:**
(1) Interaction with microbial surface.
(2) Penetration into microorganism.
(3) Action at the target sites.

Several of the disinfecting agents pose significant potential safety hazards for workers. Based on the documentation for Immediately Dangerous to Life or Health (IDLHs)[23] and the Rankings of National Pollution Inventory[17], Ammonia appears to be much less serious than those listed for the other disinfecting chemicals.

Conclusions:

1. Ammonia (NH_3) will be the most useful disinfectant for a chemical treatment of composting and anaerobic digestion products. This chemical is not too very toxic and not expensive.
2. For composting: Anhydrous ammonia gas would be is the best suite for treatment application. It will be very difficult to pour liquid ammonia on compost and have it distribute to the whole compost pile.
3. For anaerobic digestion: The potential for mechanical mixing of the digestate means that solid, liquid or gas form of ammonia could be introduce into digested residues.

References:

1. Hussong, D; W.D Burger, N.K. Enkiri. 1985. Occurrence, growth, and suppression of Salmonellae in composted sewage sludge. Appl Environ Microbiol. 50:887–893.
2. Zaleski, K. J; K.L. Josephson, C.P. Gerba, and I.L. Pepper. 2005. Survival, Growth, and Regrowth of Enteric Indicator and Pathogenic Bacteria in Biosolids, Compost, Soil, and Land Applied Biosolids. Journal of Residuals Science & Technology. Vol.2, No.1.
3. Smith, S. R., Lang, N. L., Cheung, K. H. M. & Spanoudaki, K. Factors. 2005. Controlling pathogen destruction during anaerobic digestion of biowastes. Waste Management 25, 417-425.
4. McDonnell, G.E. 2007. *Antiseptis, disinfection, and sterilization: types, actions, and resistance*. Washington D.C.: ASM Press.
5. Tajkarimi, M; H. P. Riemann, M. N. Hajmeer, E. L Gomez, V. Razavilar, and D. O Cliver. 2008. Ammonia disinfection of animal feeds --laboratory study. International journal of food microbiology.122: 23-8.
6. Keskinen, L; A. Burke, and B. Annous. 2009. Efficacy of chlorine, acidic electrolyzed water and aqueous chlorine dioxide solutions to decontaminate Escherichia coli O157:H7 from lettuce leaves. International journal of food microbiology. Elsevier B.V., 132: 134-40.
7. Wisniewsky, M; B. Glatz, M. L. Gleason, and C. Reitmeier. 2000. Reduction of Escherichia coli O157:H7 counts on whole fresh apples by treatment with sanitizers. Journal of food protection. 63:703-8.
8. Pao, S; D. F. Kelsey, M. F. Khalid, and M. R. Ettinger. 2007. Using aqueous chlorine dioxide to prevent contamination of tomatoes with Salmonella enterica and erwinia carotovora during fruit washing. Journal of food protection. 70: 629-34.
9. Akbas M. Y. 2007. Effectiveness of organic acid, ozonated water, and chlorine dippings on microbial reduction and storage quality of fresh-cut. Society. pp. 2609-2616.
10. Yuk, H; M. Yoo, J. Yoon, D. Marshall, and D. Oh. 2007. Effect of combined ozone and organic acid treatment for control of Escherichia coli O157:H7 and Listeria monocytogenes on enoki mushroom. Food Control. 18: 548-553.
11. Sengun, I. Y; Mehmet Karapinar. 2004. Effectiveness of lemon juice, vinegar and their mixture in the elimination of Salmonella typhimurium on carrots (Daucus carota L.). International journal of food microbiology. 96: 301-5.
12. Quilez, J; C. Sanchez-acedo, C. Avendan, E. Cacho, and F. Lopez-bernad. 2005. Efficacy of Two Peroxygen-Based Disinfectants for Inactivation of Cryptosporidium parvum Oocysts. Society. 71: 2479-2483.
13. Ren, Y.L; M. Sarwar, and E.J. Wright. 2002. Development of cyanogen for soil fumigation. Available at: http://mbao.org/2002proc/063reny%202%20cyanogen%20for%20soil%20.pdf. Accessed 28 June 2011.
14. USEPA. 2010. Evaluation of Sulfuryl Fluoride and Ozone fumigation technologies to inactivate *Bacillus anthracis* spores. Washington, DC.: US EPA.
15. Ibekwe, A. M; S. K. Papiernik, C. M. Grieve, and C. Yang. 2010. Quantification of persistence of Escherichia coli O157:H7 in contrasting soils. International Journal of Microbiology. 2011: Article ID 421379.
16. USEPA. 1999a. EPA Guidance Manual: Alternative Disinfectants and Oxidants. Available at: http://www.epa.gov/ogwdw/mdbp/alternative_disinfectants_guidance.pdf . Accessed 28 June 2011.
17. National Pollutant Inventory. 1999. Technical Advisory Panel: Final report. Canbera, Austrialia.: Department of Sustainability, Environment, Water, Population and Communities.
18. Whitehead, D. C., D. R. Lockyer. (1989). "Volatilization of ammonia from urea applied to soil: Influence of hippuric acid and other constituents of livestock urine." Soil Biology and Biochemistry 21(6): 803-808.
19. USEPA. 1999b. Wastewater Technology Fact Sheet: Ozone Disinfection. Available at: http://www.epa.gov/owm/mtb/ozon.pdf. Accessed 28 June 2011.
20. Gates, Don. 1998. *The chlorine dioxide handbook-Water disinfection series*. Denver, CO.: American Water Works Association.
21. Waterford, C.J; Y.L. Ren, S. Mattner, and W. Sarwar. (Undated). Ethanedinitrile (C_2N_2) – a novel soil fumigant for insect, nematode, pathogen & weed control. Available at: http://mbao.org/2004/Proceedings04/019%20WaterfordC%20Ren%20Orland%20MBAO%20C2N2%20soil%20trial%202004.pdf . Accessed 28 June 2011.
22. Adam, B.D; E.L. Bonjour, and J.T. Criswell. 2010. Cost comparison of Methyl Bromide and Sulfuryl Fluoride (ProFume®) for fumigating food processing facilities, warehouses, and cocoa beans. 10th International Working Conference on Stored Product Protection.
23. CDC (Center for Disease Control and Prevention).1994. Documentation for Immediately Dangerous To Life or Health Concentrations (IDLHs). Available at: http://www.cdc.gov/niosh/idlh/intridl4.html. Accessed 28 June 1011.
24. AWWA (American Water Works Association). 1999. *Water Quality and Treatment*. F.W. Pontius (editor). McGraw-Hill, New York, NY.
25. Berge, A. C .B; T. D Glanville, P.D. Millner, and D. J. Klingborg. 2009. Methods and microbial risks associated with composting of animal carcasses in the United States. Journal of American Veterinary Medical Association. 234(1):47-56.
26. Cekmecelioglu, D; A. Demirci, and R. E. Graves. 2005. Feedstock optimization of in-vessel food waste composting systems for inactivation of pathogenic microorganisms. Journal of food protection. 68: 589-96.
27. Glanville, T. D; H. K. Ahn, T. L. Richard, L. E. Shiers, and J. D. Harmon. 2008. Soil Contamination Caused by Emergency Bio-Reduction of Catastrophic Livestock Mortalities. Water, Air, and Soil Pollution, 198: 285-295.
28. Herzstein, J. and M.R. Cullen. 1990. Methyl bromide intoxication in four field-workers during removal of soil fumigation sheets. American Journal of Industrial Medicine, 17: 321–326. doi: 10.1002/ajim.4700170304
29. HSDB (Hazardous Substances Data Bank). 2007. Cyanogen. HSDB, Natl. Library of Medicine, TOXNET system. July 10, 2007.
30. NPIC (National Pesticide Information Center). 2000. Technical Fact Sheet for Methyl bromide. Available at: http://npic.orst.edu/factsheets/MBtech.pdf. Accessed 28 June 2011.
31. NPIC. 2000. Technical Fact Sheet for Sulfuryl fluoride. Available at: http://npic.orst.edu/factsheets/sftech.pdf . Accessed 28 June 2011.
32. OSHA (Occupational Safety and Health Administration). 1978. Occupational health guideline for Ozone. Available at http://www.cdc.gov/niosh/docs/81-123/pdfs/0476.pdf . Accessed 28 June 2011.

Acknowledgements: The authors wish to thank to the National Institute of Animal Science – South Korea Rural Development Administration for funding this research and granting a partial graduate fellowship to Mr. Lam Nguyen.