Behavior of Contaminated Food Products in a Pilot-Scale Incinerator: Experiments and Modeling

Paper Number: 08-A-29-AWMA-IT3

Paul Lemieux and Joe Wood, US EPA, National Homeland Security Research Center, 109 TW Alexander Drive (E343-06), Research Triangle Park, NC 27711

Martin Denison and Michael Bockelie, Reaction Engineering International, 77 West 200 S. Suite 210, Salt Lake City, UT 84101

ABSTRACT

In response to a recall of botulism-tainted canned food, thermal incineration has been selected as the disposal method of choice for the highly contaminated materials. To understand the behavior of single cans and tightly packed groups of cans in an incinerator, testing is being performed in the EPA's pilot-scale Rotary Kiln Incinerator Simulator (RKIS). Results from these tests have been used to calibrate a computer simulation that predicts the behavior of the same materials in a stoker-fired waste-to-energy facility, to assess the effectiveness of operating parameters in full-scale units on destruction of the *Clostridium botulinum* spores and the biotoxin that the spores produce.

INTRODUCTION

In July 2007, approximately 90 types of canned chili, beef stew, corned beef hash, dog food, and other canned products manufactured by Castleberry Food Company in Augusta, Georgia were recalled because of an outbreak of foodborne botulism, caused by the presence of *Clostridium botulinum*, a spore forming bacteria which produces botulinum toxin, a potent poison. This recall encompassed tens of millions of cans that were distributed in all 50 states[1]. Thermal incineration in waste-to-energy combustors was used to destroy the contaminated stock that was returned to the manufacturer.

The behavior of canned food in an incinerator environment is not well understood. There are likely to be effects of materials handling, feed rate of the solid fuel and the contaminated materials, and the combustor operation that may have a significant impact on the ability of the incinerator to effectively destroy the pathogens and any associated biotoxin. In addition, future events may include food that has been deliberately contaminated with biological agents of concern, which may result in the disposal process being a highly visible, politically sensitive activity, where great care is used to assure agent destruction in the incineration process.

Past work on thermal destruction of biological agents in combustion devices has focused on performance criteria for medical waste incinerators and on incineration of building materials contaminated with simulants for *Bacillus anthracis*, the biological agent that causes anthrax. Wood et al.[2] reported on an EPA study where full-scale medical waste incinerators were doped with large quantities of *Geobacillus stearothermophilus*, a spore-forming bacterium that is commonly used to assess pathogen destruction in autoclaves. Results from this study indicated that most of the incinerators that were tested achieved a minimum 6-Log reduction in the number of viable spores present in the ash and stack gases, compared to the quantities initially fed to the system. However, a handful of facilities achieved only a 3-Log or less reduction of spores, in spite of operating within normal combustion temperature conditions. These results showed that just because the system is nominally operating in the 800-1000 °C temperature range, other important parameters, such as mixing, flame contact, and charging rates can govern pathogen destruction in an incinerator.

Other EPA studies[3,4] reported on the destruction of *Geobacillus stearothermophilus* spores in a pilot-scale rotary kiln incinerator, where measurements were taken to assess solid-phase residence time and combustor temperature requirements to assure spore destruction on a variety of building materials, including carpet, ceiling tile, and wallboard. These studies suggest that if the contaminated matrix in question can be heated up so that the entire mass of material reaches a minimum temperature of 300 °C, complete spore destruction can be achieved. It is believed that destruction of the toxin can be achieved at lower temperatures, with literature suggesting that 85 °C for 5 minutes can destroy the toxin in a food matrix[5].

Due to the difficulty of performing field testing of incinerators processing chemically/biologically contaminated materials (including building materials and food), EPA's National Homeland Security Research Center has been developing a methodology for using bench- and pilot-scale experiments, coupled with computer simulations of practical incineration systems, to evaluate the behavior in incinerators of chemical and biological agents bound on various materials. This approach uses a combination of chemical kinetics and computational fluid dynamics to estimate combustor temperature and pollutant profiles and agent destruction in both the gas-phase and the bed[6,7].

To increase understanding of the behavior of canned food in an incineration environment, a series of pilot-scale experiments and computer simulations were performed, as described in this paper. It is hoped that the results from this research can be used by facilities and regulatory decision makers in case of future food contamination events to maximize destruction of the contaminating agent and minimize potential risks to combustion facilities, human health, and the environment.

EXPERIMENTAL

Testing was performed at the EPA's Rotary Kiln Incinerator Simulator (RKIS) facility located in Research Triangle Park, NC. The RKIS (shown in Figure 1) consists of a 73 kW (250,000 Btu/hr) natural gas-fired rotary kiln section and a 73 kW (250,000 Btu/hr) natural gas-fired secondary combustion chamber (SCC). Following the SCC is a long duct that leads into a dedicated flue gas cleaning system (FGCS) consisting of an afterburner, baghouse, and wet scrubber. The RKIS is equipped with continuous emission monitors (CEMs) for oxygen (O_2), carbon dioxide (CO_2), carbon monoxide (CO), and nitrogen oxides (NO_x). A series of Type-K thermocouples (TCs) monitor the temperature throughout the system.

For the experiments described in this paper, cans of "hot dog chili" (Texas Pete, 9.6 cm tall x 6.7 cm OD; 283 g net weight) were used as the test material. Table 1 lists the proximate/ultimate analysis of the material and its heating value. The cans were placed in a metal rack on the edge of the rotating section inside the kiln, and the thermocouples were secured so that they would remain embedded in the chili inside the can after the cans initially ruptured following being fed into the combustor. Figure 2 shows a photograph of the apparatus used to secure the thermocouple within the can.

Table 1. Proximate and Ultimate Analysis of Chili

	As Received	**Dry Basis**
ULTIMATE ANALYSIS:		
Loss on Drying (%)	81.93	
Carbon (%)	8.09	44.78
Hydrogen (%)	10.27	6.08
Nitrogen (%)	1.03	5.71
Sulfur (%)	0.078	0.43
Chlorine (%)	0.66	3.68
Chlorine Matrix Spike Recovery (%)	116.5	
Ash (%)	1.85	10.24
Oxygen (% by difference)	78.02	29.08
Heat of Combustion (kJ/kg)	3484	19283
PROXIMATE ANALYSIS:		
Loss on Drying (%)	81.93	
Volatile Matter (%)	12.85	71.14
Ash (%)	1.85	10.24
Fixed Carbon (% by difference)	3.36	18.62

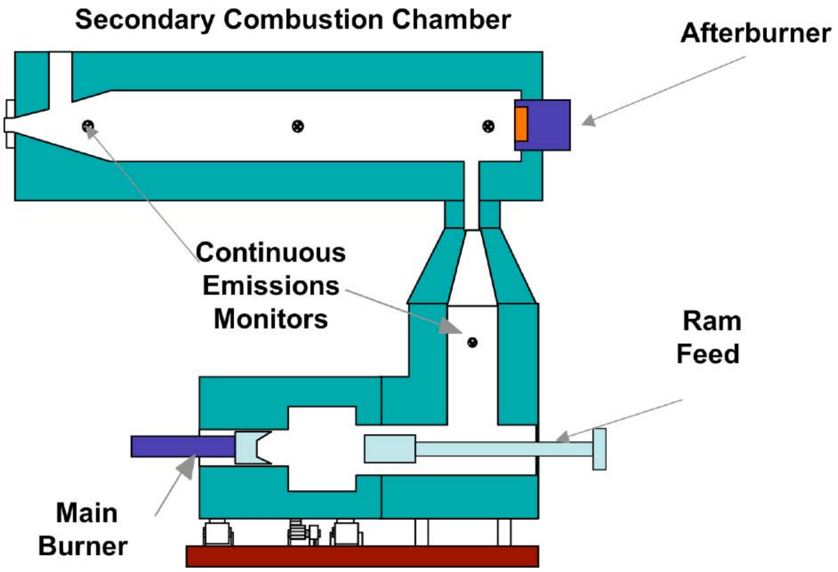

Figure 1. Rotary Kiln Incinerator Simulator

Figure 2. Thermocouple Restraining Apparatus

The RKIS is equipped with two TC probes that can be inserted through the kiln ram feed mechanism into the waste charges to measure their temperature as they burn. The effect of feeding was assessed by performing experiments with single cans, bundles of 9 cans (with one TC in the center can of the bundle and one TC in one of the outer cans of the bundle) and 18 cans (with one TC in the center-top can of the bundle and one TC in the center bottom can of the bundle).

Temperatures of the materials in the cans were monitored and the time required for both TCs to reach 300 °C were defined as the stopping point.

RESULTS

Pilot-Scale Testing

Table 2 lists the results the various test conditions, including the kiln temperature, and the time/temperature exposure results for the TCs inserted into the cans. Some cans were displaced after rupturing, resulting in exposure of the TC prior to complete combustion of the chili.

Table 2. Time/Temperature Results from Chili Combustion Tests

Run ID	Number of Cans	Kiln Temperature (° C)	Max. Charge Probe 1 T (°C)	Max. Charge Probe 2 T (°C)	Probe 1 Exposure Time to 300 °C (min)	Probe 2 Exposure Time to 300 °C (min)	Notes on Probe Location
1a	1	791	300		18.1		Probe 2 not used
1b	1	793	300		16.6		Probe 2 not used
1c	1	787	300		19.2		Probe 2 not used
2a	9	771	409	300	33.5	39.3	Probe 1 outside, Probe 2 inside
2b	9	800	355	300	35.2	38.6	Probe 1 outside, Probe 2 inside
2c	9	809	397	301	32.6	37.6	Probe 1 outside, Probe 2 inside
3a	18	765	300	506	43.9	28.0	Probe 1 lower, Probe 2 upper
3b	18	782	301	520	32.7	22.3	Probe 1 lower, Probe 2 upper
3c	18	786	298	684	37.2	16.2	Probe 1 lower, Probe 2 upper
4a	1	980	300		12.7		Probe 2 not used
4b	1	984	300		9.8		Probe 2 not used
4c	1	994	301		12.0		Probe 2 not used
5a	9	998	397	300	16.5	19.5	Probe 1 outside, Probe 2 inside
5b	9	970	751	304	4.6	13.4	Probe 1 outside, Probe 2 inside
5c	9	984	302	343	11.8	10.4	Probe 1 outside, Probe 2 inside
6a	18	997	300	975	15.3	5.2	Probe 1 lower, Probe 2 upper
6b	18	992	299	980	17.0	5.2	Probe 1 lower, Probe 2 upper
6c	18	1000	226	498	NA	13.7	Probe 1 lower, Probe 2 upper

NA – not applicable – did not reach 300 °C

Figure 3 shows the distributions of the time for the TC to reach 300 °C vs. the kiln temperature. At a kiln temperature of 800 °C, some of the cans took up to approximately 45 minutes to reach 300 °C, which is approaching the solid phase residence time of some incinerators. At a kiln temperature of 1000 °C, all cans reached 300 °C within 20 minutes.

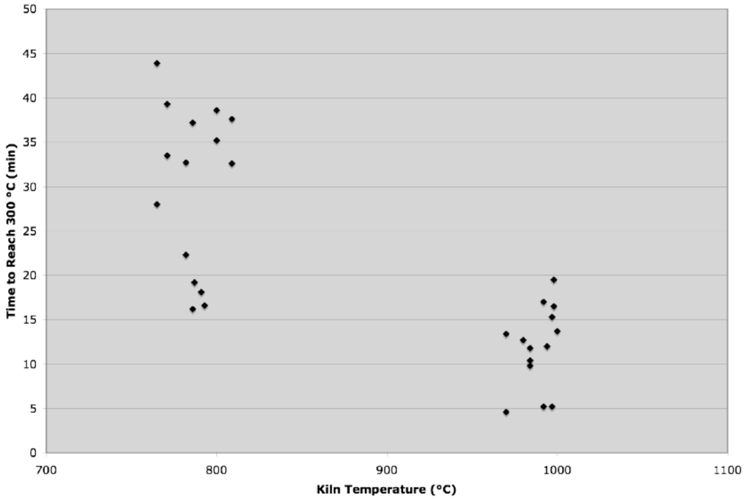

Figure 3. Time to Reach 300 °C vs. Kiln Temperature

If the data are examined with respect to the number of cans that were fed at a given time, it can be seen whether feed parameters might be expected to impact pathogen destruction of contaminated food within incinerators. Figure 4 shows the time vs. temperature for single cans, Figure 5 shows the time vs. temperature for 9 cans (with one TC in the center can and one TC in an outer can), and Figure 6 shows the time vs. temperature for 18 cans (with one TC in the top center can of the bundle and one TC in the lower center can of the bundle).

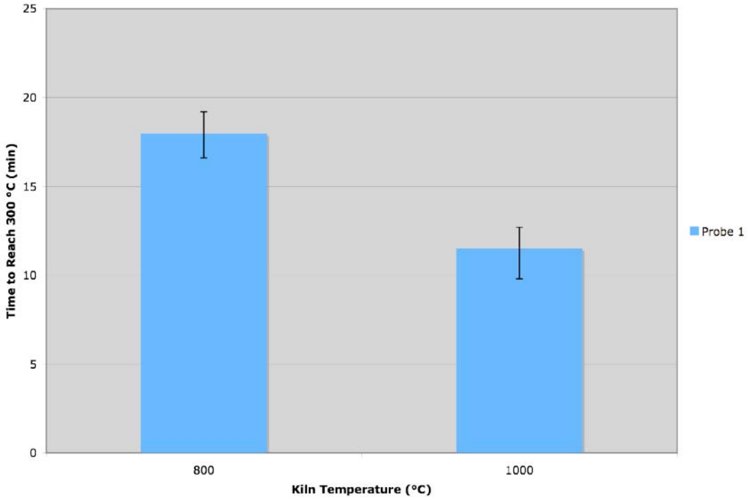

Figure 4. Time to Reach 300 °C vs. Kiln Temperature (single can)

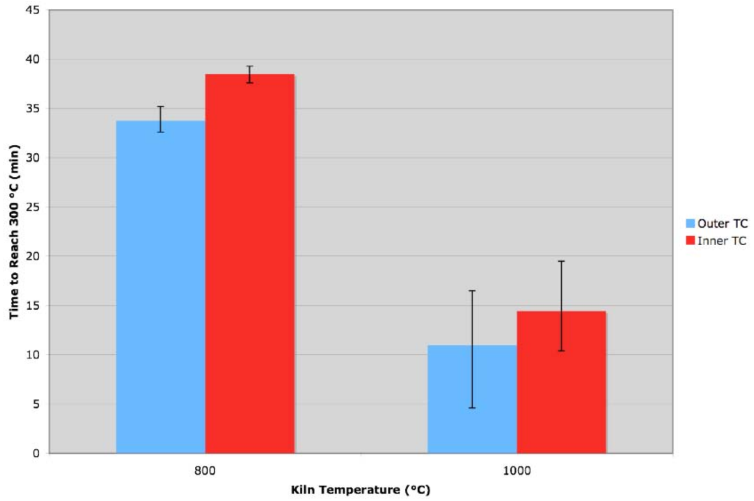

Figure 5. Time to Reach 300 °C vs. Kiln Temperature (9 cans)

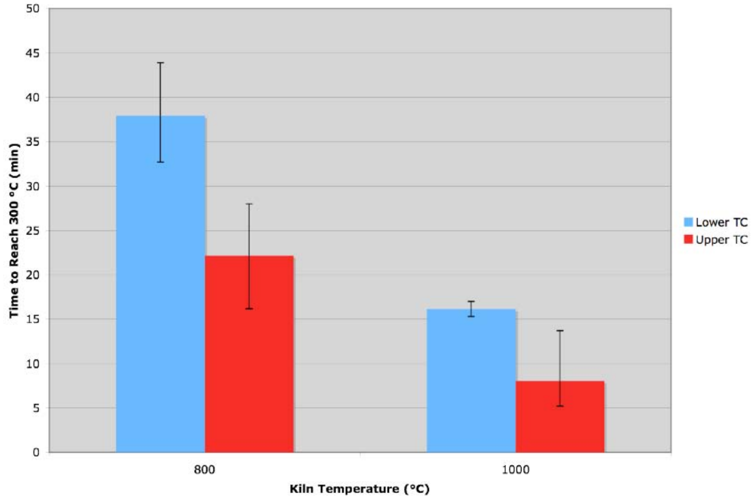

Figure 6. Time to Reach 300 °C vs. Kiln Temperature (18 cans)

In general, the single cans ruptured within 30 seconds of exposure to the kiln environment. Some of the cans within the larger groups of cans took several minutes to rupture. In addition, combustion was visually observed in some of the cans after times as long as 25-30 minutes. Cans were recovered from the incineration environment after 20-30 minutes and uncombusted chili was still found in some of the cans. This suggests that when incinerating large amounts of canned food, some effort should be expended to make sure that the cans separate from each other as they pass through the incinerator. Any banding around palleted cases should be cut, perhaps the cases should be cut open, and potentially only feed one case at a time.

Computer Simulations of Stoker Combustion

Based on the results obtained from the pilot-scale testing, a computer simulation of a stoker combustor[6] firing single cans of chili in municipal solid waste was run. First, based on the pilot-scale tests, the critical moisture parameter was estimated. This parameter defines when a slab of material, such as a ruptured can, will change from external rate heat transfer-controlled to internal heat and mass transfer-controlled. When the moisture content of the material is higher than the critical value, the temperature increase of the material is minimal. Thus, the water evaporation rate is calculated based on the external heat flux into the material, and the moisture mass fraction is assumed to be uniform. When the moisture mass fraction is lower than the critical value, the temperature of the can starts to increase and internal temperature and moisture gradients drive the drying process. To provide flexibility, this critical moisture mass fraction is an input to the model. Previous simulations had used a value of 0.08 for wetted ceiling tile. The water content of the chili cans is quite high. Therefore, a series of values for critical moisture of chili were used for several simulations, comparing the time that the mass of chili reached 150 °C, and the value of 0.8 was determined to generate the closest approximation of the heating time. Other parameters used in the simulation were the proximate and ultimate analysis of the chili on a dry basis, the heating value of the chili, and the size of the cans of chili (using an equivalent length and width of a rectangular solid that gave the same volume of chili in a cylindrical can, since the simulator uses rectangular solid bundles in the simulation). It is also an implicit assumption that the quantity of cans being fed to the unit is much smaller than the quantity of fuel being fed, so that the energy required to vaporize and initiate combustion in the material in the cans does not dramatically impact the temperature profile of the combustor.

Another shortcoming of the computer simulation was that the model did not allow for multiple phase change events (e.g., boiling of water and boiling of oils). The critical moisture parameter was fit based on an average time to achieve 150 °C, which was in between the boiling point of water and the apparent boiling point of the oils in the chili (based on observation of temperature vs. time measurements in the RKIS).

The simulation represents a type of worst-case scenario, where the can of chili remains upright without the contents spilling through its entire trip through the combustor. The simulation examines three scenarios: 1) with the chili can at the top of the bed; 2) with the chili can at the middle of the bed; and 3) with the chili can at the bottom of the bed.

Figure 7 shows the temperature profile of the stoker system generated by the simulation. In general the temperatures above the bed are in the 900-1000 °C range, although the temperatures near the waste charging zone are significantly lower. Figure 8 shows the predicted maximum can temperature as a function of time and position in the bed. It predicts that within approximately 15-20 minutes, the material in the cans is heated up to temperatures sufficient to destroy any residual agent.

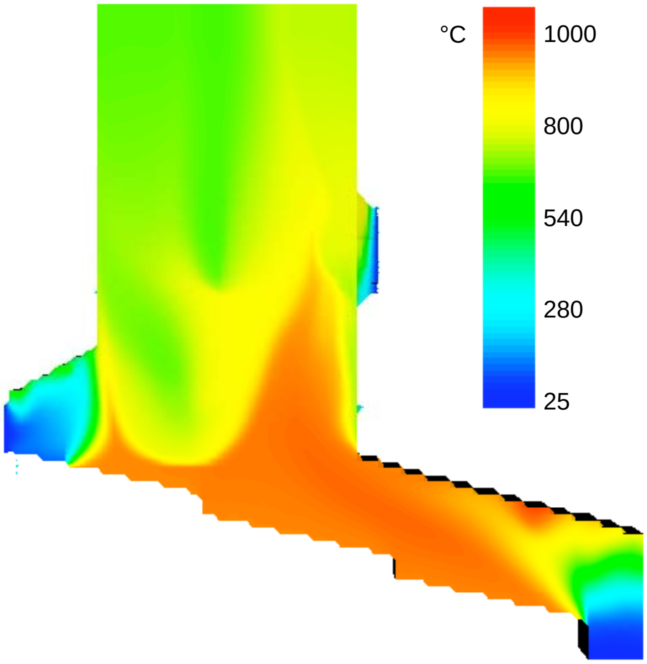

Figure 7. Stoker Temperature Profile Prediction

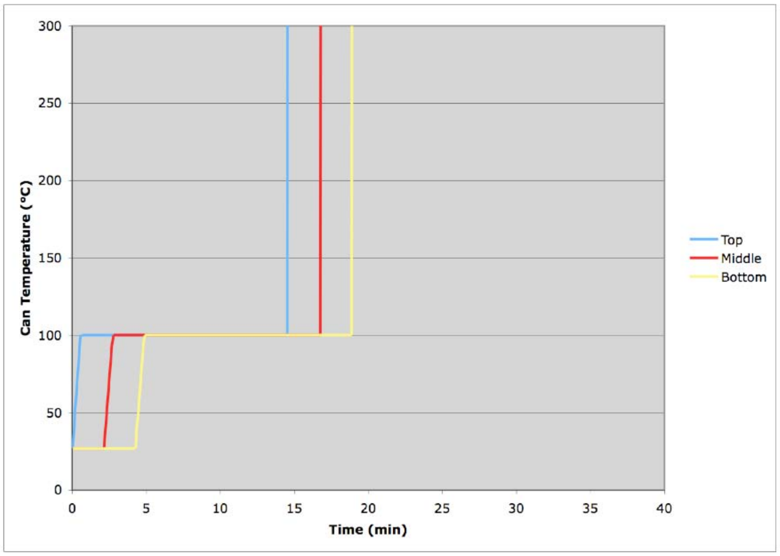

Figure 8. Predicted Can Temperature vs. Time and Bed Position

Figure 9 shows the predicted residual moisture in the can of chili as a function of time and bed position. The predicted moisture content tracks closely with the predicted can temperature.

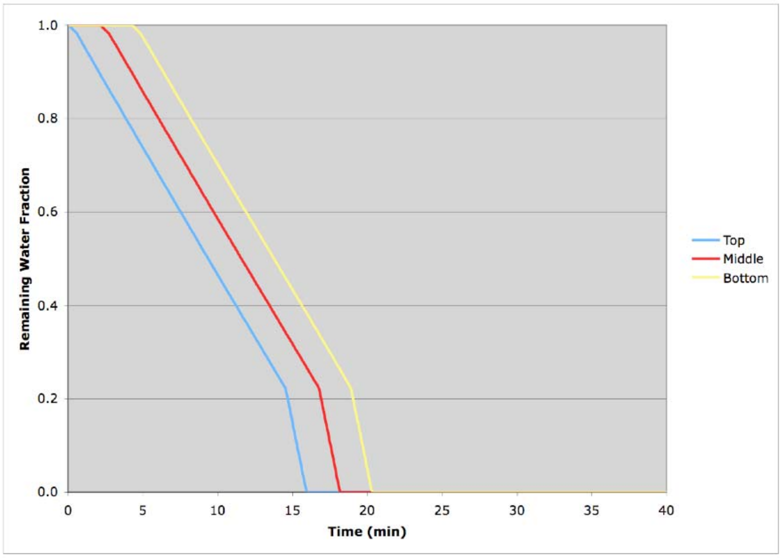

Figure 9. Predicted Residual Moisture vs. Time and Bed Position.

Figure 10 shows the predicted agent remaining, based on an agent destruction model for *Geobacillus stearothermophilus*, a spore forming bacterium that is a surrogate for other spore formers such as *Bacillus anthracis* or *Clostridium botulinum*[3]. Note that the agent does not begin decreasing until after the moisture is driven out of the chili, which suggests that spore destruction does not occur for at least 30 minutes of solid-phase residence time. The botulinum toxin should be destroyed prior to that point due to its lower thermal resistance than the spores[5].

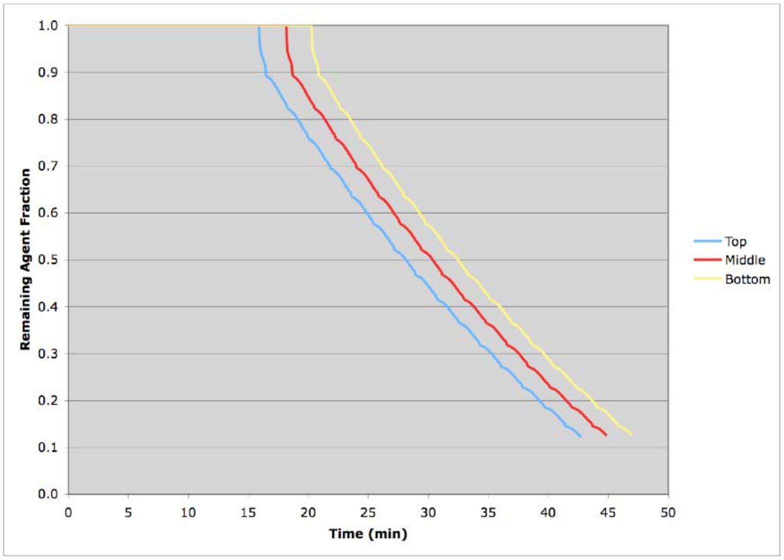

Figure 10. Agent Destruction vs. Time and Bed Location.

CONCLUSIONS

A series of tests were run on a pilot-scale incinerator where single cans and groups of cans of "hot dog chili" with embedded thermocouples were exposed to the incinerator environment for varying amounts of time and temperature. These tests were followed by a computer simulation to extrapolate the pilot-scale results to a full-scale stoker combustor processing municipal solid waste. The following observations were made:

- Although single cans ruptured within 30 seconds of insertion into the high temperature environment, when cans were tightly bundled together, some cans took several minutes to rupture, and uncombusted chili was recovered after times up to 25 minutes. This suggests that making efforts to assure that the cans separate from each other soon after feeding into the incinerator would promote destruction of residual agent. It also suggests that if feeding large quantities of packaged cans, any banding around pallets should be cut, and perhaps the cases of chili should be cut open to maximize distribution of cans within the incinerator environment.

- Computer simulations of stoker combustion of cans of chili suggest that single cans of chili (or cans spread out so as to not interact with each other) will be effectively combusted within nominal solid-phase residence times within a stoker, even if the cans are buried deep in the bed.

ACKNOWLEDGMENTS

The authors would like to acknowledge Peter Kariher, Richie Perry, and Jeff Quinto of ARCADIS and Marc Calvi of EPA/APPCD for their help in performing these tests.

DISCLAIMER

The U.S. Environmental Protection Agency through its Office of Research and Development funded and managed the research described herein under contract number EP-C-04-023 with ARCADIS G&M. It has been subject to an administrative review but does not necessarily reflect the views of the Agency. No official endorsement should be inferred. EPA does not endorse the purchase or sale of any commercial products or services.

REFERENCES

1. P. Allen, Ohio EPA memo, “Advisory: Recalled Canned Goods Contaminated with *Clostridium botulinum*,” September 11, 2007.

2. J. P. Wood, P. M. Lemieux and C. W. Lee, 2004, Destruction Efficiency of Microbiological Organisms in Medical Waste Incinerators: A Review of Available Data, International Conference on Incineration and Thermal Treatment Technologies, Phoenix, AZ, May 10-14.

3. J. Wood, P. Lemieux, N. Griffin, J. Ryan, P. Kariher and D. Natschke, 2006, Thermal Destruction of Bacillus Anthracis Surrogates in a Pilot-Scale Incinerator, AWMA Annual Conference and Exhibition, New Orleans, LA, June 20-23.

4. J. Wood, P. Lemieux, D. Betancourt, P. Kariher and N. Griffin, 2007, Pilot-scale experimental and theoretical investigations into the thermal destruction of a Bacillus anthracis surrogate embedded in building decontamination residue bundles, Environmental Science & Technology, in press.

5. Arnon, S., Schechter, R., Inglesby, T., Henderson, D., Bartlett, J., Ascher M., Eitzen, E., Fine, A., Hauer, J., Layton, M., Lillibridge, S., Osterholm, M., O'Toole, T., Parker, G., Perl, T., Russell, P., Swerdlow, D., and Tonat, K., 2001, Botulinum Toxin as a Biological Weapon, JAMA, Vol 285, No. 8, pp 1059-1070.

6. M. Denison, C. Montgomery, W. Zhao, M. Bockelie, A. Sarofim and P. Lemieux, 2005, Advanced Modeling of Incineration of Building Decontamination Residue, Air and Waste

Management Association's 98th Annual Conference & Exhibition, Minneapolis, MN, June 21-24.

7. P. Lemieux, J. P. Wood, C. W. Lee, S. D. Serre, M. Denison, M. Bockelie, A. Sarofim and J. Wendt, 2005, Thermal Destruction of CB Contaminants Bound on Building Materials: Experiments And Modeling, 2005 Scientific Conference on Chemical and Biological Defense Research, Timonium, MD, November 14-16.

KEY WORDS

Incineration, combustion, contaminated food, botulism, Clostridium botulinum, modeling, simulation