



---

## A FLUIDIZED-BED COMBUSTOR FOR TREATMENT OF WASTE FROM LIVESTOCK OPERATIONS

<sup>1</sup>Virgil Flanigan, <sup>1</sup>Honglan Shi, <sup>1</sup>Naga Nateri, <sup>1</sup>Paul Nam, <sup>1</sup>Kanisa Kittiratanapiboon, <sup>2</sup>Keesoo Lee, and <sup>1</sup>Shubhen Kapila

<sup>1</sup>*Center for Environmental Science and Technology, University of Missouri – Rolla, Rolla, MO 65409-0530; Phone: (573) 341-6603; Fax: (573) 341-6605.*

<sup>2</sup>*Division of Science, Truman State University, Kirksville, MO 63501; Phone: 660-785-7498; Fax: 660-785-4045.*

---

### ABSTRACT

There is a growing concern for adverse effects of untreated discharge from concentrated animal feedlot operations (CAFOs) in the Midwestern states. Ample data exist to show that waste discharge from livestock operations is a major contributor to the contamination of surface water systems. A fluidized-bed combustion system was designed and fabricated in our laboratory for treatment of the waste from livestock operations. Fuel for the burner is derived from the livestock wet-waste slurry (15-20% solids). The slurry is fed into the fluidized-bed dryer maintained at approximately 650°C (1200°F). Hot combustion gases are used to remove excess moisture from the waste stream in a fluidized-bed dryer. Dry solids are fed into the solid-fuel burner. High temperatures and long residence times ensure complete destruction of residual pesticides, herbicides, pharmaceuticals, and microorganisms such as *Salmonella* and *E. coli*. The process holds promise as an economical means of treatment for the wet farm waste.

**Key words:** fluidized bed, combustion, pesticide, antibiotics, animal waste

### INTRODUCTION

U.S. Environmental Protection Agency (EPA) reports state that rural and urban runoff accounts for more than one-half of all water pollution. Runoff from animal feeding operations in particular has been associated with threat to human health and the environment. EPA estimated that 41 percent of the total non-point source (NPS) pollution results from agricultural sources, and a third of that is attributable to large CAFOs. Water quality concerns such as the spread of pathogens, residual antibiotics, and pesticides have become serious. In addition, noxious odors emitted from the waste are a major nuisance in vicinity of such operations. Clearly effective and economical treatment technologies are required to reduce the discharge volume, destroy pathogens and other harmful components such as residual pesticides, and eliminate or reduce odor. In a draft plan issued March 5, 1996, by the U.S. EPA, plans were made to regulate runoff from factory farms with large numbers of cattle, pigs, and chickens. The draft plan calls for aggressive enforcement of the Clean Water Act permit requirements. It is estimated that these requirements will affect approximately 450,000 animal feeding operations in the United States. In Missouri alone, approximately 3.3 million head of swine are raised every year. Annual waste resulting from these operations is estimated to be 19,500 tons.

It is anticipated that reduction in animal waste runoff would lower or eliminate the excess nutrients which are contaminating lakes and streams in states with large livestock feed operations. This pollution has been blamed for drinking water contamination, fish kills, noxious odors, and a host of other deleterious environmental effects. In Missouri, the runoff situation is particularly acute with the swine feedlots. These operations are centered in northwestern Missouri, and similar situations exist in other states. The estimated volume of wet solid waste resulting from these operations is approximately 1 million tons. These wastes are rich in carbonaceous materials, urea, and related ammoniacal compounds and noxious sulfurous volatiles. Combustion processes hold potential for rendering wastes from CAFOs harmless; however, energy costs associated with combustion treatment of high moisture content wastes can be prohibitive. To minimize operational costs, a simple self-fueled, fluidized-bed combustor was designed and evaluated at the University of Missouri – Rolla. The design, operation, and efficiency of the combustor, in terms of pathogen and pollutant destruction, are presented in this article.

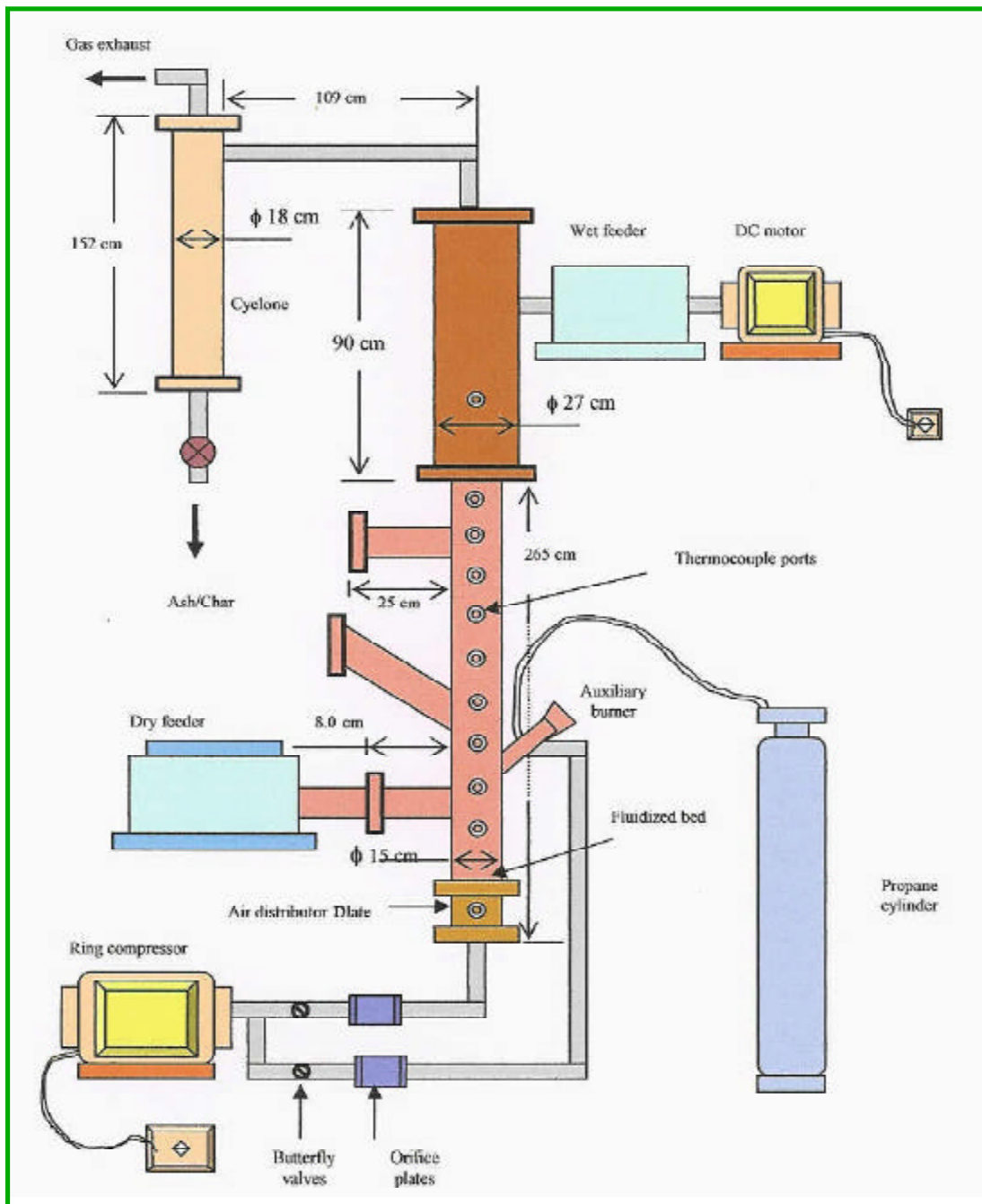
## **EXPERIMENTAL**

### ***Chemicals***

Pesticide standards, including aldicarb, atrazine, carbaryl, carbofuran, chlopyrifos, diazinon, methyl parathion, pendimethalin, permethrin and trifluralin, with purity higher than 99% were obtained from Chem Service, Inc. (West Chester, Pa.). Antibiotics tetracycline (TC), oxytetracycline (OTC), and chlortetracycline (CTC) were obtained from Durvet, Inc. (Blue Springs, Mo.), Animal Health (Exton, Pa.), and Fort Dodge Animal Health (Fort Dodge, Iowa), respectively. The HPLC-grade solvents, such as methanol, acetonitrile, hexane, methylene chloride, and iso-octane, and other chemicals including certified A.C.S. grade anhydrous sodium sulfate, acetic acid, oxalic acid, nutrient broth, etc., were purchased from Fisher Scientific (Fairlawn, N.J.).

### ***Design of the Fluidized-Bed Combustor***

The fluidized-bed combustor was fabricated in the laboratory. A schematic of the combustor is given in Figure 1. The combustor consisted of a 265 cm x 15 cm steel combustion tube. As an auxiliary burner, a 150,000 BTU, gas-fired burner is attached to the combustion tube. An air-distribution plate housed in a 20 cm x 20 cm steel tube is attached to the bottom of the combustion tube. An auger-type dry feeder is also attached to the lower part of the tube. An auger-type feeder for wet waste (Model 18221, Dry Solids



**Figure 1.** Schematic of the fluidized-bed combustor.

Processing Equipment, Metaflab, Inc., Vernon, N.Y.) is attached to the top of the combustion tube through a 90 cm x 27 cm steel tube. The feed rate of the wet waste and dry matter is controlled with variable-speed DC motors (Model 253G-200E, Dart Controls, Inc., Zionsville, Ind.). The combustion output from the combustor is made to pass through a cyclone. Char from the cyclone is collected and introduced into the combustor through the dry matter feeder.

### ***Combustor Operation***

The combustor operation was initiated by passing sufficient air through the sand bed above the air distribution plate to fluidize the sand bed. Volume of the fluidized sand bed was approximately 2.5 times the volume of the sand bed at rest. Air for the fluidized bed and auxiliary gas-fired burner was provided by a ring compressor (Model VFC500A-7W, Fuji Electric Corp. Ltd., Tokyo, Japan). The flow rates were regulated with butterfly valves and monitored through pressure drop across a calibrated orifice plate. The auxiliary propane burner was then ignited, and the fuel flow rate was maintained at 2.84 liter/min until the temperature of the sand rises to ~550°C. The temperatures inside the combustion tube were monitored with thermocouples placed 30 cm apart along the length of the combustion tube. Once the temperatures of the fluidized bed stabilized at ~ 550°C, the wet waste feed was introduced into the combustor, and the feed rate was varied by changing speed of the auger feeder with a variable-speed motor. Feed rate of the wet waste was adjusted to maintain the fluidized bed temperature at or above ~550°C. Once the combustion of the wet waste had stabilized, the propane burner was turned off. Wet feed was then continuously introduced and combusted in the self-fueled mode of operation without auxiliary fuel.

The combustion by-products were made to flow into the cyclone, which separated particulate matter including char (partially burnt organics and carbon) and sand from the combustion gases. The particulate matter was transferred to the dry matter feeder and used as combustor fuel.

### ***Combustor Evaluation***

Operation of the combustor was evaluated with wet, crushed soybean hulls. Moisture content of hulls was determined gravimetrically by placing pre-weighed samples of hulls in an oven at 110°C. The hulls were dried to a constant weight, and the difference between the initial weight and the dry weight was used for assessing the percent moisture content. The moisture content was adjusted by adding water.

Destruction efficiencies of the combustor were assessed by fortifying wet waste with known concentrations of microorganisms, antibiotics, herbicides, and insecticides. To minimize the effect from antibiotics fortified prior to the combustion, microorganism fortification was carried out on separate samples of soybean hull feed. Microorganism destruction was assessed with *E. coli* and *salmonella*. A 500ml of *E. coli* and a 500ml of *salmonella* cultures grown overnight were added to 20 kg of wet soybean hulls with varied moisture content. Separate batches of wet soybean hulls were fortified with aldicarb, atrazine,

carbaryl, carbofuran, chlopyrifos, diazinon, methyl parathion, pendimethalin, permethrin, trifluralin, antibiotics tetracycline, oxytetracycline, and chlortetracycline. Concentrations of antibiotics, insecticides, and herbicides in the wet soybean hulls ranged from 14 to 138 parts-per-million (ppm).

Combustion by-products, i.e. char residue and exhaust gases from the cyclone, were collected and analyzed for residual microorganisms, antibiotics, insecticides, and herbicides. In addition, exhaust gases were analyzed with a combustion gas analyzer for O<sub>2</sub>, CO, CO<sub>2</sub>, and NO<sub>x</sub>. Exhaust gas samples from the combustor were dried by passing them through a flow-through chiller (Model KR-60A, Poly Science, Niles, Ill.) prior to introducing into gas analyzers. The CO and CO<sub>2</sub> concentrations were determined with an infrared analyzer (Model 300, California Analytical Instruments, Orange, Calif.). A paramagnetic analyzer was used for O<sub>2</sub> determination, and a chemiluminescence-based analyzer (Model 951A, Rosemount Analytical, Orrville, Ohio) was used for NO<sub>x</sub> determination.

### ***Pesticide and Herbicide Residue Analysis***

Residual pesticides, herbicides, and antibiotics in the combustion char and exhaust gas were analyzed with gas chromatography – mass spectrometry (GC-MS) and high-performance liquid chromatography (HPLC). Steps involved in these analyses were adapted from officially recommended methods (EPA, 1994, 1996, and 2000) and previously published procedures (Fodor-Csorba, 1992; Tekel and Kovacicova, 1993) and are summarized below.

### ***Sample Extraction and Cleanup***

To ascertain the fortification uniformity and average concentrations, 10g aliquots of fortified soy hull were extracted and analyzed prior to combustion. To establish destruction efficiency, 10g aliquots of the residual char were collected from the bottom of the cyclone. These samples were mixed with 40g to 80g of anhydrous sodium sulfate to completely dry the samples and obtain a free-flowing powder. The dried sample was extracted overnight in a Soxhlet extractor with 300 ml of methylene chloride. Immediately after extraction, 0.5 ml of isooctane was added to each extract. The extracts were concentrated down to ~ 2 ml with a rotary evaporator. The solvent was exchanged to hexane and again concentrated down to ~2 mL. To remove co-extracted lipids from the extracts, each was partitioned three times with 20 mL of acetonitrile. The acetonitrile extracts were combined and divided into two equal portions. One portion was concentrated down to 1 ml with a rotary evaporator, followed by nitrogen blow-down for HPLC analysis. The second

portion of the acetonitrile extract was evaporated to about 2 ml and then combined with 10ml iso-octane for solvent exchange, and evaporated to 2 ml for GC-MS analysis.

Samples from the gas exhaust were collected by splitting the stream of exhaust gases exiting the cyclone, passing it through an impinger containing 60ml of deionized water (for HPLC) or iso-octane (for GC-MS), and bubbling it for 20 min at the flow rate of 0.5L/min. These samples were analyzed with HPLC and GC-MS without any further process.

### ***High-Performance Liquid Chromatographic Analysis***

The HPLC analysis was performed with a Hitachi Model L-7300 HPLC system (San Jose, Calif.), with dual-piston pumps, an auto-sampler, and a diode array detector (DAD). Separations were carried out with a 4.6 x 250 mm C<sub>18</sub> column (Purospher RP-18) with an end-capped stationary phase. The mobile-phase flow rate was 1 ml/min. A gradient elution program was used to achieve desired separation of aldicarb, carbaryl, and permethrin. Composition of the mobile phase was from 65 % A: 35 % B for 2 min. and change to 50% A : 50% B in two minutes, and then to 100% B in the next 17 minutes. Both solvent A (water) and solvent B (acetonitrile) contained 0.1% acetic acid. The separated analytes were monitored at a wavelength in the 210 to 300 nm range. Quantitative determinations were carried out at 210, 254, and 280 nm.

### ***Gas Chromatography – Mass Spectrometric Analysis***

GC-MS analyses were carried out with a capillary gas chromatograph interfaced to a quadruple ion-trap mass spectrometer (Model Saturn 2000, Varian Instruments, Walnut Creek, Calif.). Chromatographic separations were achieved with a 30m x 0.25mm fused-silica capillary column coated with a 95% methyl + 5% phenyl polysiloxane stationary phase (DB-5, J&W Scientific, Folsom, Calif.). The GC operating condition was as follows: carrier gas helium flow rate at 1 mL min<sup>-1</sup>, injector temperature at 280°C, column oven temperature program from 60 to 280°C at 20°C min<sup>-1</sup> rate.

### ***Antibiotics Determination***

Antibiotics in the fortified soybean hull and residual char, as well as exhaust gas from the combustion, were analyzed with the HPLC method with a few modifications (Cunnif, 1997). Briefly, 1g aliquot of fortified soybean hulls or 0.35g to 0.5g aliquot of char was weighed into a 30 ml vial with cap. The antibiotics were extracted with 10ml methanol. The extract was centrifuged and the supernatant was filtered through a 0.2m filter, and analyzed by a 1090 Series II HPLC system (Hewlett Packard Instruments, Wilmington,

Del.) with a UV detector. Separations of antibiotics were achieved with a 3.9 mm (i.d.) x 150mm C18 column (Nova Pack, Waters, Milford, Mass.). The mobile phase was 35% acetonitrile / 65% of 0.01M oxalic acid solution at a flow rate of 0.5ml/min. The absorption wavelength was set at 350 nm.

### ***Microorganism Detection***

Aliquots of soybean hulls fortified with *E. coli* and *salmonella*, and char residue obtained from the cyclone of the fluidized-bed combustor, were collected in separate sterilized petri dishes. The contents were transferred to culture test tubes containing nutrient broth. In addition, a split stream of the exhaust gases exiting the cyclone was made to pass through an impinger containing 60ml of nutrient broth. A small portion of this sample was transferred to a culture test tube. The culture test tubes with the samples were incubated at 37°C for 24 hours and examined for the presence of microbial growth through turbidity measurement.

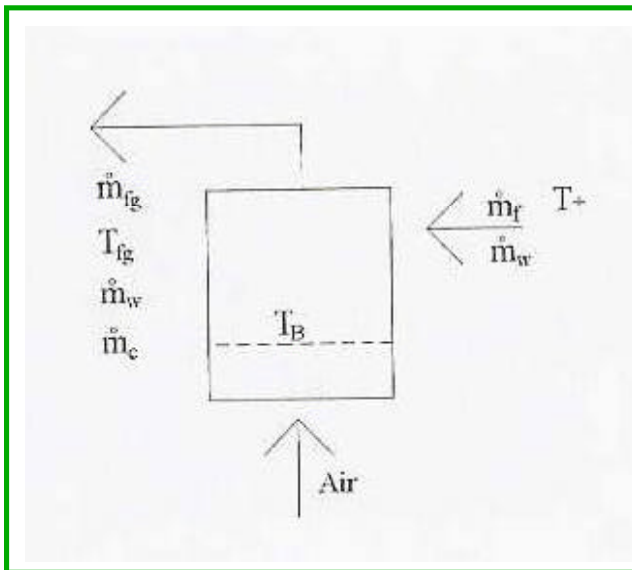
### ***Proximate Analysis***

The moisture, volatile matter, ash content, fixed carbon of the soybean hulls, and char were determined through proximate analysis (Potter, 1959). Moisture content was determined by heating 1g of sample at 110°C in an oven for 1 hour. The weight loss of the sample during this period yielded the moisture content. Volatile matter was determined by heating 1g of sample in a covered platinum crucible for 7 min at 950°C. The weight loss during the period was used to determine volatile matter. Ash content was determined by heating 1g of sample in an uncovered platinum crucible at 750°C until the sample was completely burned. A constant weight of the sample after repeated heating indicated the complete combustion. Fixed carbon was determined as the difference between total mass and the sum of the moisture, ash, and volatile matter. These determinations were carried out with a muffle furnace (Type 30400, Thermolyne, Dubuque, Iowa).

## **RESULTS AND DISCUSSION**

### ***Combustion***

The wet feed material introduced from the hopper into the top section of the reactor falls towards the bed at the bottom, and during the fall the material is dried and partially combusted. Exhaust gases from combustion are cooled during the drying period of the incoming wet feed. The fluidized bed insures well-mixed oxidation of the feed material and provides thermal stability. The top feed setup permits a more stable operation because the feed is dried before complete combustion in the bed. The air supplied by a small blower below the distribution plate results in a constantly stirred, bubbling bed, fluid combustor.



**Figure 2.** Schematic of inputs and outputs of the fluidized-bed combustor.

The bed also includes a gas burner for heating required to reach the initial operating conditions of the system. Once stability has been obtained, the gas is turned off and the operating conditions recorded to insure independent operation. Figure 2 shows the inputs and outputs of the system. The bed temperature ( $T_B$ ) is greater than the flue gas temperature  $T_{fg}$ . The equation is approximately:

$$\dot{m}_f HHV + \dot{m}_w c_{p\text{air}} (T_f - T_a) + \dot{m}_{\text{air}} c_{p\text{air}} (T_{\text{air}} - T_a) = \dot{m}_{fg} c_{pfg} (T_{fg} - T_a) + \dot{m}_c C_{p\text{char}} (T_{\text{char}} - T_a) + \dot{m}_w (970.3 + 0.5(T_{fg} - 212)) + (212 - T_a)$$

where

$$\dot{m}_{fg} = (\dot{m}_{\text{air}} + \dot{m}_f) \quad \text{mass flow rate of the flue gas lb/min}$$

$$T_{\text{char}} = T_{fg} \quad \text{temperature above } ^\circ\text{F}$$

$$\dot{m}_{\text{air}} \quad \text{mass flow rate of the air lb/min}$$

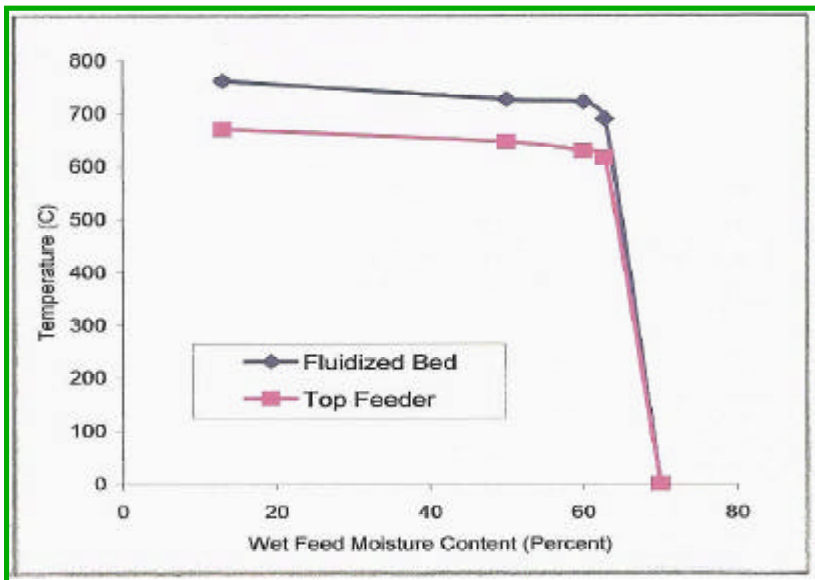
$$\dot{m}_f \quad \text{mass flow rate of the dry feed lb/min}$$

$$\dot{m}_w \quad \text{mass flow rate of the water in feed}$$



$\dot{m}_c$	mass flow rate of the char lb/min
$T_a$	ambient temperature °F
$T_{air}$	temperature of air °F
$T_f$	temperature of feed °F
$T_{fg}$	temperature of the flue gas °F
$C_{pair}$	specific heat air (BTU/lb °F)
$C_{pfg}$	specific heat flue gas
$C_{pfeed}$	specific heat feed materials
$C_{pw}$	specific heat water
$C_{pchar}$	specific heat char
$HHV$	higher heating value of the dry feed

The source of energy in the system is the organic matter in the feed materials. Energy outputs are the hot flue (the mass flow of the flue gas times its specific heat, plus the energy content of the water vapors exiting the combustor and the residual energy in the char. For the system to be stable, the energy in must equal the energy out. If the input is greater than the output, the temperature will increase. If the input is less, the temperature will decrease. The bed temperature must remain ~ 540 oC or higher to provide a temperature-controllable reactor system. The system operated very well and stability was easy to obtain.



**Figure 3.** Temperatures in the fluidized-bed combustor for wet feeds of various moisture contents.

### *Operation of Combustor with Wet Waste*

The combustor operation was assessed over a range of wet-waste feed rates. With proper adjustments of the fluidized-bed air flow, the combustor could be operated satisfactorily over feed rates ranging from 0.022 – 0.33 kg min<sup>-1</sup> in the self-fueled mode without the need for external fuel. The fluidized bed could be maintained at sufficiently high temperatures to initiate combustion of the organic waste with moisture contents up to 65 percent as shown in Figure 3. Under these conditions, the thermal energy output was sufficient to remove moisture and sustain combustion. At moisture content greater than 68 percent, the temperature of the fluidized bed and the combustion tube plummeted dramatically. Self-fueled combustion could not be sustained beyond 68 percent.

Exhaust gas from the fluidized bed combustor was analyzed for O<sub>2</sub>, CO<sub>2</sub>, CO, and NO<sub>x</sub> during the combustion of wet feeds. Content of the combustion gas for the soybean hull feeding with two different

**Table 1.** Dry gas-based composition of the exhaust gas from the fluidized-bed combustor for sample input with different moisture contents.

	50% Wet Soy Hull	65% Wet Soy Hull
O <sub>2</sub>	0.69%	0.20%
CO <sub>2</sub>	18.56%	14.52%
CO	2.09%	7.03%
NO <sub>x</sub>	138.5ppm	61.0ppm

moisture levels are reported in Table 1. It is apparent the combustion requires additional air to reduce the high CO content in the flue gas.

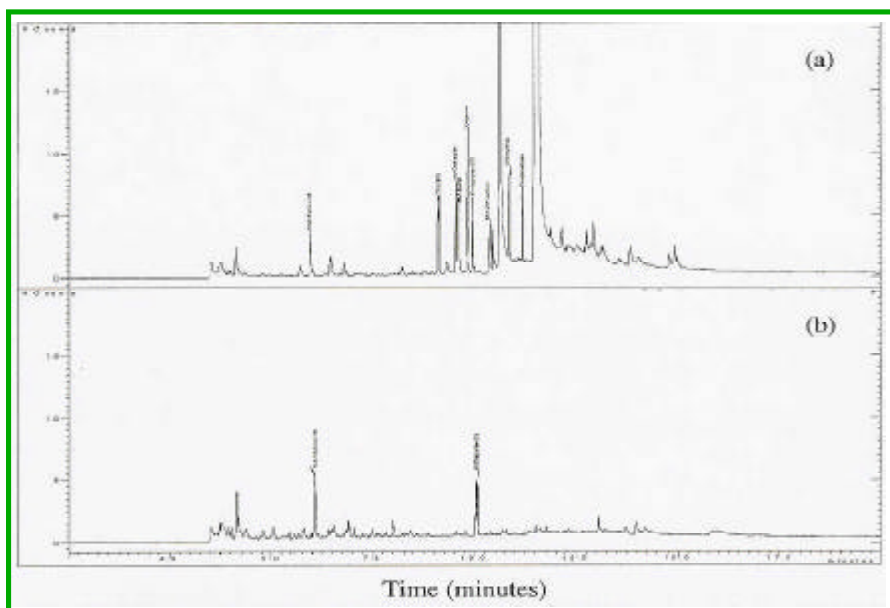
After combustion of the soybean hulls with a variety of moisture contents, proximate analysis results show that the char residue contains the same percentage range of moisture, volatile matter, ash, and fixed carbon regardless of the moisture content of the feeding soybean hull. Results from the proximate analyses of both the wet soybean hull sample and char residue collected are shown in Table 2. The char residue collected from the combustion of the wet soybean hull sample was approximately 8-10 % of the dry weight of soybean hull used.

### ***Pesticide and Herbicide Destruction***

To check the effectiveness of destruction of the hazardous pesticides and herbicides by this fluidized-bed combustor, ten different pesticides and herbicides were fortified in the feeding soybean hull, and the residues were analyzed by GC-MS and HPLC techniques. Among the ten hazardous chemicals, seven were detected by GC-MS and the other three, including aldicarb, carbaryl, and permethrin, were detected by HPLC. To verify the method recovery, deuterated isotopes of anthracene and naphthalene were used as a surrogate and an internal standard, respectively. A typical GC-MS chromatographic profile of the seven pesticides and herbicides in fortified soybean hull feeding and char collected after combustion are shown in Figure 4, a and b. The figure shows that all seven pesticides and herbicides, as well as surrogate and internal standards, were well separated under the experimental conditions. After combustion, all of the fortified hazardous chemicals were completely destroyed, and none were detected in the char residue. Detailed results for all of the chemicals and samples are shown in Table 3. HPLC analysis results of the three polar pesticides and herbicides in the fortified soybean hull feed and char residue samples are also shown in the same table. None of the target chemicals were detected in the char by-product after combustion.

**Table 2.** Results from the proximate analyses of soy hull samples and char residues produced.

	Soybean Hull	Char Residue
<b>Moisture (%)</b>	10.8—12.9	4.0—6.7
<b>Volatile Matter (%)</b>	73.4—74.6	20.1—25.6
<b>Ash (%)</b>	4.0—4.1	33.9—40.3
<b>Fixed Carbon (%)</b>	10.5—11.7	31.6—39.3



**Figure 4.** GC/MS chromatograms of pesticides and herbicides extracted from (a) fortified soybean hull feed and (b) char residue collected after combustion.

To confirm that removal of the hazardous chemicals was through the thermal destruction and not through the volatiles in gas exhaust, the impinger samples collected from exhaust gas were also analyzed by GC-MS and HPLC methods. None of the fortified pesticides and herbicides was detected in the gas samples above the detection limits of the analysis.

**Table 3.** Results of pesticide/herbicide destruction efficiencies by the fluidized-bed combustor.

Pesticides/Herbicides	Concentration ( $\mu\text{g/g}$ dry sample)			
	Soy Hull 50% Mean $\pm$ RSD	Char 50% Mean $\pm$ RSD	Soy Hull 65% Mean $\pm$ RSD	Char 65% Mean $\pm$ RSD
Trifluralin	13.84 $\pm$ 33.5%	<4x10 <sup>-4</sup>	20.52 $\pm$ 28.8%	<3x10 <sup>-4</sup>
Carbofuran	28.08 $\pm$ 3.2%	<8x10 <sup>-4</sup>	45.03 $\pm$ 5.7%	<6x10 <sup>-4</sup>
Atrazine	19.04 $\pm$ 1.8%	<4x10 <sup>-4</sup>	36.28 $\pm$ 6.9%	<3x10 <sup>-4</sup>
Diazinon	24.68 $\pm$ 6.2%	<4x10 <sup>-4</sup>	38.52 $\pm$ 3.4%	<3x10 <sup>-4</sup>
Methyl Parathion	28.04 $\pm$ 3.4%	<8x10 <sup>-4</sup>	N/A*	N/A
Chlopyrifos	15.96 $\pm$ 1.8%	<8x10 <sup>-4</sup>	22.86 $\pm$ 16.3%	<6x10 <sup>-4</sup>
Pendimethalin	18.2 $\pm$ 0.9%	<8x10 <sup>-4</sup>	30.11 $\pm$ 13.2%	<6x10 <sup>-4</sup>
Aldicarb	15.74 $\pm$ 6.3%	<2x10 <sup>-4</sup>	32.63 $\pm$ 13.4%	<2x10 <sup>-4</sup>
Carbaryl	20.3 $\pm$ 8.8%	<4x10 <sup>-4</sup>	35.86 $\pm$ 8.5%	<3x10 <sup>-4</sup>
Permethrin	15.02 $\pm$ 5.5%	<4x10 <sup>-4</sup>	33.75 $\pm$ 12.1%	<3x10 <sup>-4</sup>

\*N/A - Not analyzed since methyl parathion is not fortified in soybean hull with 65% moisture.

### ***Antibiotics Decomposition***

Tetracycline, oxytetracycline, and chlortetracycline are three of the most widely used antibiotics for the animals. These pharmaceuticals are generally present in animal waste and are one of the main sources for environmental pollution. In this study, these antibiotics were added to the soybean hull feed for combustion in the fluidized-bed combustor. The collected combustion residues and fortified feedings were analyzed by HPLC to determine the decomposition of the antibiotics. Results of the analysis are shown in Table 4. All three antibiotics tested were completely destroyed by the combustion process, and no residues were detected in the char or exhaust gas.

### ***Microorganism Destruction***

Harmful microorganisms present in animal wastes are a major concern for animal diseases and water pollution. To test the potential of the fluidized-bed combustor for killing microorganisms, cell cultures of *E. coli* and *salmonella* were added to the soybean hull feeding. Contaminated soybean feeding prior to combustion and char residue and exhaust gas from the combustor were cultured for determination of combustion sterilization efficiency. Test results of the cell cultures of the fortified-soybean hulls and the combustion residues are shown in Table 5. All of the char residue samples and gas exhausts collected from the combustion of microorganism fortified soybean hulls containing 50 - 65% moisture were free of any microorganisms. No cell growth in the combustion by-product samples indicated that fortified *E-coli* and *salmonella*, as well as other microorganisms in the soybean hull feed, are killed by combustion.

**Table 4.** Results of animal antibiotics decomposition by the fluidized-bed combustor.

<b>Antibiotics</b>	<b>Concentration (<math>\mu\text{g/g}</math> dry sample)</b>				
	<b>Hull 50%</b> Mean $\pm$ RSD	<b>Char 50%</b> Mean $\pm$ RSD	<b>Hull 65%</b> Mean $\pm$ RSD	<b>Char 65%</b> Mean $\pm$ RSD	<b>Exhaust Gas</b> Mean $\pm$ RSD
<b>Oxytetracycline</b>	49.11 $\pm$ 3.0%	<0.5	137.9 $\pm$ 9.9%	<0.5	ND*
<b>Tetracycline</b>	22.59 $\pm$ 20.2%	<0.5	35.28 $\pm$ 7.2%	<0.5	ND
<b>Chlortetracycline</b>	62.21 $\pm$ 32.9%	<2.0	106.4 $\pm$ 35.4%	<2.0	ND

\*ND-Not detectable

## CONCLUSIONS

An effective and economical fluidized-bed combustor system for treatment of the waste from livestock operations has been developed. This self-fueled combustor system can operate without the input of external energy by utilizing the organic matter in the waste. Combustion of the feeding material up to 65% moisture generated the operation temperature above 650°C with feeding rates ranging 0.022-0.33 kg per min. Due to the high operation temperature and long residence time, hazardous chemicals such as pesticides, herbicides, and antibiotics in the feeding material were completely destroyed during combustion. In addition, all of the microorganisms present in the feeding material were killed completely during the combustion process, thereby having the potential to destroy other pathogens.

**Table 5.** Microorganism test results for soybean hull feed and combustion by-products from the fluidized-bed combustor.

Sample #	Sample Description	Test Results
0	Control blank	-
1	Soybean hull feed sample with 50% moisture	+
2	Char residue from combustion of sample #1	-
3	Soybean hull feed sample with 50% moisture + <i>Salmonella</i> culture	+
4	Char residue from combustion of sample #3	-
5	Soybean hull with 50% moisture + <i>Salmonella</i> + <i>E. coli</i> culture	+
6	Char residue from combustion of sample #5	-
7	Soybean hull with 65% moisture + <i>Salmonella</i> + <i>E. coli</i> culture	+
8	Char residue from combustion of sample #7	-
9	Gaseous by-products from combustion of sample #7	-

(-) indicates the absence of microorganisms in the sample tested

(+) indicates the presence of microorganisms in the sample tested

## **ACKNOWLEDGMENT**

This study was supported in part through funds provided by the Missouri Water Resources Center of the U.S. Geological Survey, Columbia, Mo.

## **REFERENCES**

Barcelo, D., 1993. Environmental Protection Agency and Other Methods for the Determination of Priority Pesticides and Their Transformation Products in Water, *J. Chromatography*, 643, pp. 117-143.

Cunniff, Patricia, 1997. AOAC Official Method 995.09, Chlortetraxylene, Oxytetracycline, and Tetracycline in Edible Animal Tissues, *Official Methods of Analysis of AOAC International*, 16<sup>th</sup> ed, Ch. 23, pp. 19-23.

EPA Method 3500C, 2000. Organic Extraction and Sample Preparation, pp. 3500C-1-17.

EPA Method 8270C, 1996. Semivolatile Organic Compounds by Gas Chromatography-Mass Spectrometry, pp. 8270C-1-54.

EPA Method 8318, 1994, N-Methylcarbamates by High-Performance Liquid Chromatography, pp. 8318-1-18.

Fodor-Csorba, Katalin, 1992. Chromatographic Methods for the Determination of Pesticides in Foods, *J. Chromatography*, 624, pp. 353-367.

Potter, Philip J., 1959. Fuels and Combustion, Power Plant Theory and Design, 2<sup>nd</sup> ed., The Ronald Press Company, New York, Ch.5, pp.170-171.

Tekel, Jozef, and Kovacicova, J., 1993. Chromatographic Methods in the Determination of Herbicide Residues in Crops, Food, and Environmental Samples, *J. Chromatography*, 643, pp. 291-303. The Ronald Press Company, New York, Ch.5, pp.170-171.

Tekel, Jozef, and Kovacicova, J., 1993. Chromatographic Methods in the Determination of Herbicide Residues in Crops, Food, and Environmental Samples, *J. Chromatography*, 643, pp. 291-303.