ENERGY AND NUTRIENT RECOVERY FROM COMBUSTION OF SWINE SOLIDS AND TURKEY LITTER

T. R. Miles[1] and B. R. Bock[2]

[1]T. R. Miles Technical Consultants, Inc., 1470 SW Woodward Way, Portland, OR 97225
[2]B. R. Bock Consulting, Inc., 218 N. Sequoia Blvd., Florence, AL 35630

ABSTRACT

Land application of manure from concentrated animal feeding operations (CAFO) in the Southeastern United States causes accumulations of excess phosphorus in soils. There is increasing concern about phosphorus runoff from land application of manure causing water quality problems. Combusting manure and recovering the energy for use as process heat and nutrients for use in fertilizers and feed supplements is a promising alternative use of manure. This project demonstrated in a 15-day 24/7 pilot-scale test that staged combustion of mixtures of swine solids and turkey litter in a conventional fluidized bed boiler can be used to recover process heat for a variety of uses and ash fractions containing phosphorus and potassium that can be used in the feed and fertilizer industries. Swine solids were provided by BEST Solutions, LLC (reported in last symposium) using a two-stage solid-liquid separation system. The swine solids and turkey litter were stable, relatively odor free, and easy to handle. Even though the fuels compacted during transportation in super sacks, the fuel flowed and blended readily at the combustion facility. No special precautions were required for odor control. Combustion air was preheated for wet fuels. Over-fire air and flue gas recirculation were adjusted to optimize each fuel combination. Fluidized bed agglomeration, slagging, fouling, and SO_X and NO_X emissions were controlled without lime amendment of the fuel and without ammonia injection in the flue gas stream. Ash was carbon free and conducive for use in fertilizers and feed supplements (results reported in companion paper). The combustion tests demonstrated that it is practical to recover energy and ash nutrients from combinations of swine solids and turkey litter.

Key words: fluidized bed combustion, energy recovery, nutrient recovery, swine solids, turkey litter

INTRODUCTION

Land application of manure from concentrated animal feed operations (CAFO) in the Southeastern United States causes accumulations of excess phosphorous in soils. Alternatives include the recovery of heat and power from residues and the disposal of ash in the fertilizer industry or as soil amendments.

Commercial disposal of manures through combustion has had mixed success. Processing facilities built in the 1980s closed due to problems with ash agglomeration, fouling and corrosion in fluidized beds, slag in secondary combustors of fixed and fluidized bed gasifiers, fouling in the convection passes of spreaders stokers and excess carbon in ash.

Spreader stokers are used in the commercial recovery of ash from poultry litter in the U.K. One new installation is planned for the US. The success of these systems has encouraged the potential use of energy conversion to recover value from litter and manure. These systems are expensive. Most depend on public subsidy for capital investment. The animal industry seeks methods to recover value from the manure at the farm and industrial scale without subsidies. Previous pilot studies with poultry litter have demonstrated that fluidized bed combustors can be used to burn poultry litter and recover useable ash (Bock 1999).

Fuel moisture is a major limitation for the use of swine manure. BEST Solutions, LLC of Kenansville, North Carolina has developed methods of recovering solids from swine manure. In the BEST system solids are separated at the farm. The BEST process is composed of the following elements:

- On-farm, two-stage solid-liquid separation of the swine manure
- Transporting swine solids to a centralized fluidized bed combustor
- Mixing poultry litter with the swine solids to provide a sufficiently dry feedstock

- Combustion of the mixture of swine solids and poultry litter
- Use of the heat from the combustor for direct drying or to produce process steam and/or electricity
- Exporting the nutrient rich ash to existing fertilizer granulation plants and incorporation of the ash into existing fertilizer products

The objective of this study was to test the combustion of turkey litter and swine solids from the BEST process and prepare it for sale as ash (Bock 2004). Gasification of the solids had been considered but a suitable gasifier was not found. The project steps therefore were to locate a suitable fluidized bed combustion facility, prepare and transport the swine solids and turkey litter to the pilot facility, test the fuels for a long enough period to optimize process conditions and overcome potential problems, monitor the operation and emissions, and generate sufficient ash for testing as a fertilizer and possibly as a feed supplement.

FLUIDIZED BED PILOT FACILITY

Commercial fluidized bed manufacturers were interviewed to determine their interest in supplying a commercial fluidized bed for industry and to determine the capabilities of their pilot facilities. Companies were sought that had an operating fluidized bed with sufficient experience to scale up equipment from their pilot tests. The pilot facility must have the capacity to generate 40 tons of ash in a reasonable period and recover boiler or cyclone ash separately from baghouse ash. The facility must be equipped for continuous monitoring of principal emissions. And the company should be interested in supplying a commercial system.

Some suppliers of bubbling and circulating fluidized beds were not interested due to previous negative experiences, or they saw more risk than benefit in burning animal manure. Others did not have sufficient capacity at their pilot facilities to process 200 tons of litter and manure or extract 40 tons of ash. Others had no pilot facilities in North America. Energy Products of Idaho (EPI) met the selection criteria (Energy Products of Idaho). They have built more than 80 commercial fluidized beds, with cogeneration facilities up to 50 MWe. EPI had successfully burned poultry litter and was interested in supplying a commercial plant. Operators of the EPI pilot facility are experienced with a variety of fuels and were interested in the mixture of turkey litter and swine solids. Their pilot facility (Figure 1) has:

- 900 kW fuel input based on HHV
- Freeboard 7.9m
- Bed area 0.8m2
- Bed media silica sand 600-800 µm
- 7 sets of over-fire air (OFA) nozzles that can be used for flue gas recirculation(FGR) or NH3 injection
- Preheat to 427°C
- Auxiliary freeboard burner
- Periodic ash cleaning or removal
- Continuous analyzers for SO2, NO/NOx, O2, CO

Figure 1. Fluidized bed combustion pilot facility

FUELS

Fuel preparation and handling

Fuels were prepared using the Biomass Energy Sustainable Technology (BEST) system. Smithfield Foods and their partners selected the BEST system for demonstration in North Carolina because:

- It was the most practical and seemingly affordable solids separation technology for the swine producer while not requiring special investments for the poultry producer.
- It relies on already established high volume in-organic fertilizer markets as an outlet for surplus nutrients rather than the high-value, low volume organic fertilizer markets as an outlet for surplus nutrients. A worldwide assessment indicated that markets for organic fertilizers are too small to serve as a primary outlet for the surplus nutrients from southern North Carolina and other nutrient rich areas, especially considering transportation costs per unit of nutrient organic fertilizers.

BEST Solutions, LLC permitted and installed solids-liquid separation equipment on three existing swine farms in North Carolina and provided turkey litter from farms under the control of a single processor. BEST Solutions LLC provided 115 tons of turkey litter (TL) and 60 tons of swine solids (SS) in super bags for transportation to the pilot facility (Figure 2). Samples of each were sent for analysis (see Table 1).

Figure 2. Loading super sacks of turkey litter and dewatered swine solids for transportation

Table 1. Fuel analysis

	Poultry Litter	Turkey Litter	Swine Solids
Carbon, dry wt %	39.50	33.77	51.30
Hydrogen, dry wt %	4.30	3.55	6.08
Nitrogen, dry wt %	3.90	0.62	1.83
Sulfur, dry wt %	0.80	0.62	0.28
Ash, dry wt %	22.90	38.63	5.94
Chlorine, dry wt %	1.28	0.39	.07
Oxygen, dry wt %	27.30	20.01	34.57
Moisture, % (as delivered)	20-35	30 (32-46)	58.41 (66.5-71.6)
Dry HHV, MJ/kg	15.3	11.8	19.3
LHV, MJ/kg as fired	8.4-9.3	4.8-6.7	3.4-4.4

Fuel characteristics

The turkey litter and swine solids were stable, relatively odor free and easy to handle. Even though the fuels did compact during transportation in the super sacks the fuel flowed and blended readily at the pilot facility (Figure 3). No special precautions were needed for odor control.

Figure 3. Swine solids and blended manure and litter

Table 1 compares the turkey litter and swine solids in this test with poultry litter (PL) from previous tests (Bock 1999.). The moisture content of the turkey litter when it was removed from the turkey houses was in the same range as the poultry litter from previous trials. In recent years moisture levels in litter has been reduced due to improvements to watering systems. A commercial facility can expect to receive litter in the 20% MC to 30% MC range. Fuels were exposed to rain during storage and before bagging so that the moisture content of the delivered fuels was considerably higher than the moisture content when the fuels were prepared. As-received moisture for the turkey litter was 32% to 46% MC. The swine solids were dewatered to 58% MC at the farms but the moisture gained in storage brought as-received moisture up to 66.5% to 71.6% MC.

Ash content of the turkey litter at 38% is considerably higher than ash in poultry litter. The high ash content combined with the variation in moisture content led to a poor quality fuel with a lower heating value (LHV) of 4.8

MJ/kg to 6.7 MJ/kg. An LHV of 4.5 MJ/kg is considered to be a lower limit for combustion. The dewatered swine solids had a low ash content of 5.94 % but the high moisture content resulted in a fuel (3.4 MJ/kg to 4.4 MJ/kg) that would not support its own combustion.

Nitrogen content of both the turkey litter and swine solids was lower than in poultry liter. Sulfur content of turkey litter was similar to the poultry litter. Both turkey litter and swine solids had much lower chorine content than poultry litter. From the fuel analysis it could be expected that the combustion of turkey litter and TL/SS mixtures would be similar if not better than poultry litter.

Ash mineral composition of the three fuels is compared in Table 2. Silica content of the turkey litter is higher than in poultry litter and swine solids. This is thought to be because turkeys scratch the soil beneath the bedding and ingest sand. There are higher concentrations of calcium and phosphorous in the ash from swine solids. Sodium and potassium contents are lower in both turkey litter and swine solids than in poultry litter.

Table 2. Ash mineral analysis

	Poultry Litter	Turkey Litter	Swine Solids
SiO2,%	26.7	47.27	8.34
Al2O3,%	2.9	<0.01	1.91
TiO2,%	0.19	0.31	0.11
Fe2O3,%	1.0	1.01	2.73
CaO,%	17.1	13.90	29.80
MgO,%	3.9	3.57	6.61
Na2O,%	5.3	1.77	1.71
K2O,%	14.4	8.26	8.31
P2O5,%	19.2	17.65	27.37
SO2,%	5.1	3.68	3.21
Cl,%	N/A	1.28	0.48
CO2,%	4.2	1.52	3.27

Turkey litter and swine solids were burned in different combinations. The mixed fuel composition can be seen in Table 3.

Table 3. Fuel combinations and properties

	Turkey Litter	75% TL 25% SS	67%TL 33% SS	50%TL 50% SS	Swine Solids
Source MC % NC	30%				58%
Delivered MC % ID	32%-49%	36% to 45%	40% to 46%	48% to 55%	67 to 72%
Ash, dry % (as fired)	38.6 (22)	31.6 (18)	27.1 (15.4)	26.7 (14.1)	5.9 (2)
Ca:S	4.95:1	6.23:1	4.52:1	3.89:1	3.6:1
LHV, MJ/kg	4.8-6.7	5.7-7.0	6.1-6.9	5.2-6.2	4.4-4.7

Table 3 shows that the actual moisture content of the fuel blends was much higher than expected. Blends of 67% and 75% turkey litter resulted in the highest consistent fuel quality by lower heating value (LHV).

COMBUSTION TESTS

Turkey litter and swine solids were burned in combinations of 100%, 75%, 67%, and 50% TL and 100% SS as shown in Table3. The objectives of the combustion tests were:

- Obtain low CO emissions (max 25 ppm)
- Observe fuel handling
- Determine minimum temperatures for combustion in the bed and vapor space
- Optimize the process conditions for emissions
- Minimize fouling and slagging, and
- Generate ash for further testing.

The five fuel combinations were fired in continuous operation for 15 days, 24 hours per day during the Fall of 2003. Tests consumed all the turnkey litter and swine manure and generated approximately 40 tons (80 barrels) of ash. Air was preheated as required for the wet fuels. Over-fire air and flue gas recirculation were adjusted to optimize each fuel combination. Typical combustion conditions are shown in Table 4.

Table 4. Typical combustion conditions and emissions

Vapor temp	760 °C max 982 °C
Min Bed temp	704 °C to 760 °C
O2	6%-12%
CO	25 ppm dv
NOx w/FGR	10-50 ppm
SOx	0- 25 ppm

The fuel blends handled well in the combustor. Fuel moisture was the most significant challenge. Minimum bed temperatures of 720 °C resulted in the most stable operation. Oxygen levels of 6% and vapor temperatures of 760 °C were required for minimum CO emissions. Typical conditions were 9% to 12% O2. NOx and SOx emissions were very low and at times non-detectable.

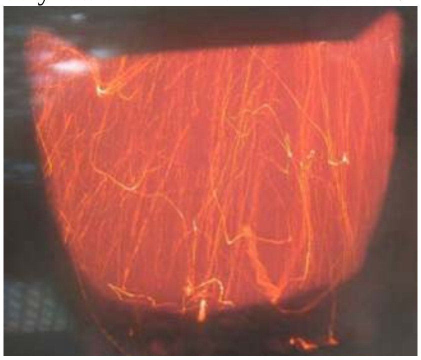

Figure 4. Combustion in vapor space of fluidized bed

Sulfur oxide emissions were apparently aided by a favorable calcium to sulfur ratio in the ash of all fuel combinations. Lime is usually added to a fluidized bed to obtain a Ca:S ratio of 3:1 in order to control sulfur and chlorine emissions. Table3 shows that the Ca:S ratio exceeds 3:1 for all fuel combinations. No lime was added during these tests.

Initial bed material was silica sand in the 600 to 800 micron size range. During operation the sand was quickly displaced by ash from the litter, especially silica. More bottom ash was continuously removed from the bed during these trials than when firing poultry litter. The media and bottom ash were free flowing. No bed agglomeration or sintering was experienced. No limestone or other additives we required to keep the bed from agglomerating. Ash deposition was observed on the refractory walls of the combustor. Buildup was not excessive and considered manageable in commercial operation.

Fouling occurred when vapor temperatures (furnace exit temperatures) exceeded 890 °C for prolonged periods. This happened initially when adjusting operating parameters for very wet fuels but did not reoccur during the tests. An advantage of the fluidized bed appears to be the ability to control vapor space temperatures and the generally lower furnace exit temperatures than is possible with other combustors.

Figure 5. Potassium enriched (top) and chlorine enriched (bottom) ash.

These combustion tests demonstrated that high moisture and ash fuels require controlled combustion conditions. These include:

- Air preheat
- Staged Combustion
- Properly placed nozzles for over-fire air (OFA) and flue gas recirculation (FGR)
- Extended residence time
- Controlled temperature in a refractory vessel
- 6% O2 and 871 °C to maintain low CO

CONCLUSIONS

These combustion tests in a commercial pilot facility demonstrate that it is practical to recover energy and ash from turkey litter and swine manure solids.

The BEST fuel preparation system produces a suitable fuel that is easily handled in combustion feed systems. High moisture in the fuels demonstrated that covered storage will be required in a commercial operation.

Combinations of turkey litter and dewatered swine manure solids can be readily combusted in a fluidized bed.

The good control of agglomeration, NOx and SOx emissions demonstrates that fuel properties can be used to facilitate furnace operation.

Ash was free of carbon and easily processed to access existing fertilizer markets. Results of fertilizer trials are reported separately.

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