Demonstrate the technical feasibility of cofiring animal-tissue biomass (SRMs and carcasses) with coal in a pilot-scale bubbling fluidized-bed combustor

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Background

The estimated annual U.S. supply of fed-cattle SRMs, cow carcasses from packinghouses, on-farm mortalities, and cull cow SRMs is 850, 75, 2500, and 650 million pounds, respectively [1, 2]. With heating values ranging from 2300 to 6200 Btu/lb as fired, approximately 15 trillion Btu of energy is available for use as a fluidized-bed boiler fuel [1, 2]. Figure 1 illustrates the energy value of various boiler feedstocks, both fossil fuels and biofuels, which have been tested and/or characterized at Penn State [3]. Feedstocks with energy densities as low as 4000 Btu/lb (e.g., poultry litter) are fired in boilers as sole fuels while fuels with even lower energy densities are successfully cofired with coal [3].

With the implementation of USDA’s recently launched enhanced BSE (bovine spongiform encephalopathy) surveillance program (effective June 1, 2004), the need for additional cost-effective options for carcass disposal is necessary [1]. Additionally, the need for large-scale carcass disposal should a catastrophic event occur needs to be developed [4]. The National Agricultural Biosecurity Center Consortium USDA-APHIS (Animal Plant and Health Inspection Service) Cooperative Agreement Project, Carcass Disposal Working Group [5] reviewed 8 disposal options for carcasses/SRMs. These included burial, incineration, composting, rendering, lactic acid fermentation, alkaline hydrolysis, anaerobic digestions, and novel technologies. This study did not review combustion in boilers, which was definitely an oversight. EPA (Fran Kremer and Paul Lemiux, July 2004) have subsequently noted that: there are several design options for industrial and utility boilers available offering significant capacity for utilizing carcasses and SRMs; boilers have good control over combustion processes; and they provide particulate matter and acid gas control [6]. Although Kremer and Lemiux identified disadvantages of this technique in that fluidized-bed boilers are not permitted to burn wastes, they lack suitable feeding equipment, and there will be permit issues dealing with biocontaminants, they also stated that no technical issues appear to be insurmountable. Handling the carcasses/SRMs is not considered problematic. Fluidized-bed combustors have historically utilized low-grade fuels such as paper mill sludge, coal-water mixtures/pastes, waste coal, and others [3, 7]. A variety of handling equipment is available for these fuels. Similarly, the rendering industry processes and handles carcasses and other animal-tissue biomass (ATB); consequently, the handling, grinding, and delivery of the ATB into a boiler is not an issue. Also, fluidized-bed boilers have been used to combust hazardous wastes, plastics, and waste oils with complete combustion achieved. Fluidized-bed combustion is a proven technology for low-grade fuels and is ideal for utilizing carcasses and SRMs.

Although the disposal technologies listed above are being considered by industry and regulatory agencies, Cargill Taylor Beef, with the assistance from Penn State, has been exploring the possibility of cofiring ATB in coal-fired boilers as an additional disposal option. In July 2004, Penn State, Cargill Taylor Beef, and McDonalds Corporation hosted a workshop at Penn State to discuss and develop strategies to utilize ATB as a fuel in industrial and utility boilers, brainstorm on the development of a national infrastructure that could utilize ATB as a fuel on both a routine and large-scale emergency basis, and stimulate public-private collaboration [8]. Representatives from federal and state government, meatpacking and rendering industries, food industry and service, banking, equipment supply, cogeneration companies, fluidized-bed boiler manufacturing, and academia attended the workshop. The workshop consisted of presentation that outlined the issues of carcass and tissue disposal and provided overviews of the technology of energy generation from fluidized-bed boilers, followed by breakout sessions that addressed the issues of concept-to-
commercialization, logistics, and economics and incentives. A major highlight of the presentations was that the boiler vendors informed the audience that the concept of cofiring ATB with coal was technically sound. One of the key points and future action items developed during the workshop included performing pilot-scale testing to demonstrate to regulatory agencies, USDA, FDA, and industry the technical viability of this option [8]. It was determined that this is necessary prior to securing funding for a full-scale demonstration cofiring carcasses/SRMs with coal.

The stated objectives for this work were:
To demonstrate the technical viability of cofiring animal tissue biomass in a coal-fired fluidized-bed combustor as an option for disposing of Specified Risk Materials (SRMs) and carcasses.

Methodology

a) Fuel Preparation and Analysis – ATB and Coal

i) ATB
Cargill Taylor Beef provided the ATB for the project. Cargill Taylor Beef attempted to prepare mixtures that approximated cull cow carcasses and both cull-cattle SRMs and SRMs from fed cattle. The samples, referred to as ATB1, ATB2, and ATB3, respectively, were prepared as follows:
ATB1 – Dead-cow mix was approximately 47% skeletal muscle (inedible beef), 30% cow slaughter plant offal (heads, legs, intestinal tract, etc.), 20% bones and fat trim from cow carcass deboning operation and 3% hide trimming. This material was coarse ground and mixed using commercial rendering equipment; ATB2 – High-bone mixture (intending to represent composition of SRMs from cattle aged 30 months or over) was approximately 55% bones and fat trim from cow carcass deboning operation and 45% cow slaughter plant offal. Material was coarse ground using an inedible meat grinder with a final 1/8th inch plate; and ATB3 – Fed-cattle SRMs or low ash, high moisture mixture consisting of 100% small intestine with contents harvested during slaughter, predominately from fed cattle. This material was ground using an inedible meat grinder with a final 1/8th plate.
All materials were immediately blast frozen in the form of 50-pound blocks (≈ 22” x 18” x 5”) and stored in such form until delivery to Penn State. Figure 2 is a photograph of a 50-pound block of ATB3.

The ATB received from Cargill Taylor Packing was extremely heterogeneous and could not be used as received. It was anticipated that the material would arrive with a hamburger-like consistency, which could be utilized in the pilot-scale FBC. However, the material arrived in much larger sizes than could be handled by the feeding system as well as be properly fluidized and combusted in the FBC. Examples of hide, teeth, bone fragments, and inedible meat that were too large for use in the combustor are illustrated in Figures 3, 4, 5, and 6, respectively.
Prior to each test, 200 pounds of medium grade industrial sand was added to the FBC via the top sight port. The sand served as initial bed material. The induced draft fan was then turned on and the controller set to maintain a draft pressure of -0.10 inches water column within the boiler.
The FBC typically operates with a slightly positive internal pressure during testing. Next, the combustion air blower was started and the butterfly valve controlling the main bed air flow rate was adjusted to achieve a bed velocity of approximately 6 to 7 ft/s at operating temperatures. This velocity was maintained throughout the test. The FBC natural gas burner was then ignited and the combustor allowed to preheat until temperature T2 (upper bed temperature) was approximately 1,300 to 1,400°F. Coal was then fed into the main bed and the flow rate of natural gas decreased until a transition to burning 100% coal was completed. After the gas burner was shut off and airflow through the burner eliminated, the total air flow through the bed was adjusted to maintain the bed velocity. Additional sand was added to the combustor to achieve a bed depth of approximately 15 to 20 inches. Each test began with at least a one-hour baseline period burning only coal. During this period, the feed rate of coal was adjusted to maintain a bed temperature of approximately 1,600 to 1,700°F. If flue gas recirculation was to be applied, the throttling valves were adjusted to achieve the desired percent recirculation. Following the baseline period, tests performed cofiring ATB with the coal were initiated by feeding ATB while reducing the feed rate of the coal. The thermal input contributed by the coal and ATB were adjusted to achieve the desired percent cofire and to maintain the bed temperature. Additional ductwork was added to outlet of the baghouse to permit recirculation of flue gas into the main bed of the FBC. This ductwork connected the outlet of the baghouse to the inlet of the blower providing fluidizing air to the FBC. Using a pair of throttling valves, flue gas recirculation percentages ranging from 0 to 70 percent can be achieved when the FBC is operated as a bubbling fluidized-bed combustor. Orifice plates installed in the ductwork and the main bed airline, combined with other FBC air inputs, provide constant monitoring of the percentage of flue gas recirculated.

After establishing each baseline or cofiring condition, the various temperature, pressure, flow rate and emissions data were collected during each test at 30-second intervals by the data acquisition system. The operators recorded the ATB feed rate, along with other manual readings and observations, at 15-minute intervals. Copies of the operators’ log and data sheets are provided in Appendix A.

d) Experimental Procedures for Measuring Flue Gas Composition

i) Continuous Emissions Monitoring

EPA stack testing was performed to measure the following emissions: NOx, SO2, CO, CO2, O2, and total hydrocarbons. Procedures outlined in EPA Methods 3A, 6C, 7E, 10, and 25A were used:

Method 3A Determination of Oxygen (O2) and Carbon Dioxide (CO2) Concentration in Emissions from Stationary Sources (Instrumental Analyzer Procedure); Method 6C Determination of Sulfur Dioxide (SO2) Emissions from Stationary Sources (Instrumental Analyzer Procedure); Method 7E Determination of Nitrogen Oxide (NOx) Emissions from Stationary Sources (Instrumental Analyzer Procedure); Method 10 Determination of Carbon Monoxide (CO) Emissions from Stationary Sources; and Method 25A Flame Ionization Detection for Total Hydrocarbons with GC Analysis of Bag Samples for Methane and Ethane, i.e., a CEMs will be used to measure total hydrocarbons with a gas chromatograph used to measure C1-C4 compounds.

ii) Particulate Emissions Testing

To augment data obtained from the on-line gas analyzers, particulate samples were collected isokinetically from the flue gas stream just prior to the waste heat recovery boiler. The particulate was collected by what is commonly referred to as a Modified Method 5 (MM5) sampling train (EPA Method 0010) [9]. The train is used to isokinetically collect samples at desired locations in flue gas streams. The collected sample can be separated into solid, condensed liquid, and, if desired, gaseous phases. Only the particulate samples were analyzed during this testing.
A modular sampling train meeting all of the requirements of EPA Methods 5 and 0010 was utilized for sampling the flue gas stream. EPA Methods 1 through 4 were utilized to determine various parameters needed for isokinetic sampling. A portion of the gas stream was withdrawn from the stack through a heated probe where the particulate matter was filtered out of the flue gas. The remaining portion of the gas stream was passed through a condenser, a module containing a polymeric resin, and a series of glass impingers.

Specifically, the sampling train contained the following components. They are listed from the most upstream component to the most downstream component. A buttonhook borosilicate glass nozzle is located at the end of a sampling probe. The nozzle opening is placed into the flue gas stream facing upstream with pitch and yaw angles of 0°. The inside diameter of the nozzle is precisely known, as its size affects the sampling rate. Connected to the nozzle by a Teflon® ferrule is a probe of borosilicate glass surrounded by a stainless steel jacket. The stainless steel jacket contains heating elements. While sampling, the probe was maintained at 250°F by a temperature controller. The seal between the reactor and the probe was made airtight.

The probe was connected to a borosilicate glass filter assembly located within a heated oven. The filter assembly was also maintained at 250°F. A filtering media was selected to retain particles larger than 0.2 μm. The gases then pass through a series of condensers, traps, impingers, and silica gel to remove and collect gases, condensed liquids, and moisture. The components that are collected can be analyzed for composition when desired. This was not done in this project due to time constraints.

The gases were passed through an air tight pump, dry gas meter, across a manometer, (gas samples may be collected at this point if desired) and vented. These devices, along with thermocouple readouts, temperature controllers, manometers, valves, timer and other equipment were contained in a metering console. Prior to sampling, data sheets were prepared and leak checks were performed on the sampling system. Proper temperatures and flow rates were maintained. Leak checks were also performed at the conclusion of the sampling runs. Sampling locations (traverse points) across the flue gas stream were determined. All other appropriate EPA sampling procedures were adhered to, and all samples were collected within the acceptable sampling range of 90% to 110% of isokineticity.

The collected sample can be separated into as many as six (or more) fractions. The collected flue gas stream samples for these tests were separated into two subsamples. The first subsample contained recovered materials from the nozzle to the filter assembly combined with the filtered solids, and other solids removed from the filter assembly. This subsample represents the particulate matter fraction of the flue gas stream. The second subsample contained recovered materials from the back half of the filter paper assembly, condenser, resin module, trap and impingers. This subsample represents the condensed liquid fraction of the flue gas stream. The samples were placed in Teflon containers and are being stored at 4°C but were not analyzed.

### iii) Gas Chromatograph Analysis

Gas-bag samples were analyzed for composition using a Shimadzu GC17A gas chromatograph (GC) equipped with flame ionization (FID) and thermal conductivity (TCD) detectors. Analytical columns employed were a Chimpack C18 (6’ X 1/8”) for separation of hydrocarbons and a Carboxen 1000 (15’ X 1/8”) for separation of fixed gases. Volumes injected on each column were 1,000 mL and 50 mL, respectively. The GC oven temperature was held constant at 35°C for 7.5 minutes then ramped to 200°C at a rate of 20°C/min then held at 200°C for 5 minutes. Standard hydrocarbons (Supelco, Scotty-14, C1-C6, ~15 ppm) and standard fixed gases (Supelco Scotty-14, H2, O2, N2, CO CH4 and CO2, ~5%) were analyzed to quantify compositions of gas-bag components. Laboratory air was also used as a standard for quantifying CO2 abundances.
Findings

Overall, the project successfully demonstrated that carcasses and SRMs can be cofired with coal in a bubbling FBC. Feeding ATB into the FBC presented several new challenges not encountered with other types of feedstocks previously tested at Penn State. Specifically, handling/feeding issues were encountered during the testing; however, they were primarily artifacts of the small scale of the equipment and the specific feeders available for use with such a heterogeneous material. These issues would not be expected at the full scale since full-scale units routinely handle low-quality fuels. After several feeder modifications and trials at different injection locations in the pilot-scale FBC, an overbed feed system was selected for the testing. In addition, a 4-inch diameter screw feeder was used and this large feed size, relative to the combustor diameter of 1 foot, resulted in fuel slugging into the combustor. This slugging, in turn, resulted in fluctuating carbon monoxide and total hydrocarbon emissions, which are indicators of incomplete combustion. However, the average emissions from ATB cofiring tests in many cases were similar to the average emissions from coal baseline testing, indicating that under the conditions tested in the small-scale unit, the ATB performed similarly to coal. In a full-scale unit, the disproportionate ratio of feed line size to unit diameter would be eliminated thereby eliminating feed slugging. Also, the ATB would either be injected into the bed, thereby ensuring uniform mixing and complete combustion or the ATB would be injected directly above the bed with overfire air ports used to ensure complete combustion.

Implications

In summary, the objectives of the project were met in that cofiring carcasses and SRMs with coal was successfully demonstrated. While the test conditions were not optimum, due to the equipment limitations, performance of the ATB cofire tests was comparable to coal baseline testing. Statistically it was shown that the ATB feed location had a greater effect on CO emissions, which were used as an indication of combustion performance, than the fuel type due to feeding difficulties. Baseline coal (fed about 2 feet above the bed) tests and tests cofiring ATB1 into the bed were statistically indistinguishable. This indicates that a demonstration at the full scale, which is the next activity in demonstrating this concept, should be successful since equipment limitations would not be a factor. Hence, emissions cofiring ATB with coal would be expected to be similar to that when firing coal only.

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