Cofiring Animal-Tissue Biomass in Coal-Fired Boilers to Dispose of Specified Risk Materials and Carcasses: An Overview of an University/Industry Collaboration

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Introduction

Background

Livestock deaths pose daunting carcass-disposal challenges regardless of the cause – accidental disease entry, typical animal-production mortality, natural disaster, or an act of terrorism. Effective means of carcass disposal are essential regardless of the cause of mortality but are perhaps most crucial for disease eradication efforts.

There are several disposal technologies being considered by industry and regulatory agencies including burial, incineration, composting, rendering, lactic acid fermentation, alkaline hydrolysis, anaerobic digestions, and novel technologies. Penn State, in conjunction with industry collaborators, has been exploring the possibility of cofiring animal-tissue biomass (ATB) in coal-fired fluidized-bed boilers as an additional disposal option. In July 2004, Penn State, Cargill Taylor Beef, and McDonalds Corporation hosted a stakeholder meeting/workshop at Penn State to discuss and develop strategies to utilize ATB as fuel in industrial and utility boilers, brainstorm on the development of a national infrastructure that could utilize ATB as fuel on both a routine and large-scale emergency basis, and stimulate public-private collaboration. Representatives from federal and state government, beef and dairy producer groups, meatpacking and rendering industries, food service industry, banking, equipment supply, co-generation companies, fluidized-bed boiler manufacturing, and academia attended the workshop.

As a first step in addressing the action items identified in the workshop, a pilot-scale demonstration program was developed [1, 2]. Funding for this testing was provided from America's Beef Producers through the Cattlemen's Beef Board (and administered by the National Cattlemen's Beef Association) and Cargill Taylor Beef. The project was performed during the first quarter of 2005 with the objective to demonstrate the technical viability of cofiring ATB in a coal-fired fluidized-bed combustor (FBC) as an option for disposing of carcasses and SRM. This is a potential option for beneficially utilizing carcasses and SRM that must be removed from the food chain, allowing them to be used as an energy feedstock rather than disposing them. The pilot-scale testing was necessary to demonstration to regulatory agencies, USDA, and industry the technical viability of this option [2-5]. Subsequent testing was performed with support from Cargill Taylor Beef and the Pennsylvania Energy Development Authority (PEDA) in which modifications were made to the ATB feed location in order to improve combustion/emissions performance [6]. This paper presents the overall ATB cofiring concept, summarizes the results from the pilot-scale FBC testing where carcasses and SRMs were cofired with coal, discusses testing currently underway at Penn State for the U.S. Department of Energy, and discusses the next steps necessary to perform a full-scale demonstration of this concept.

Cofiring ATB in Coal-Fired Boilers for Carcass Disposal

Fluidized-bed combustion is a proven technology for low-grade fuels and is a candidate technology for utilizing carcasses and SRMs. In the United States, the estimated annual 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 [7, 8]. 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 [7, 8]. The heating value of carcasses and SRMs is illustrated in Figure 1 and compared to that of various boiler feedstocks, both fossil fuels and biofuels, which have been tested and/or characterized at Penn State. ATB energy densities, while at the lower end of the spectrum, compare similarly to feedstocks that are successfully utilized in boilers. Feedstocks with energy densities as low as 4000 Btu/lb (*e.g.*, poultry litter and wood wastes) are fired in boilers as sole fuels, while fuels with even lower energy densities, such as grasses, have been successfully cofired with coal [9]. In addition, wood wastes and sawdust have been successfully cofired in coal-fired utility boilers, further supporting the concept of cofiring ATB in coal-fired boilers. The following discussion summarizes the results from the pilot-scale FBC testing where carcasses and SRMs were cofired with coal, and discusses the next steps leading to a full-scale demonstration of this concept.

Experimental Procedures

ATB Preparation

Cargill Taylor Beef provided the ATB for the pilot-scale testing projects. Cargill Taylor Beef prepared 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 – Cull Cow Carcasses. 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 – Cull-Cattle SRMs. High-bone mixture 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.

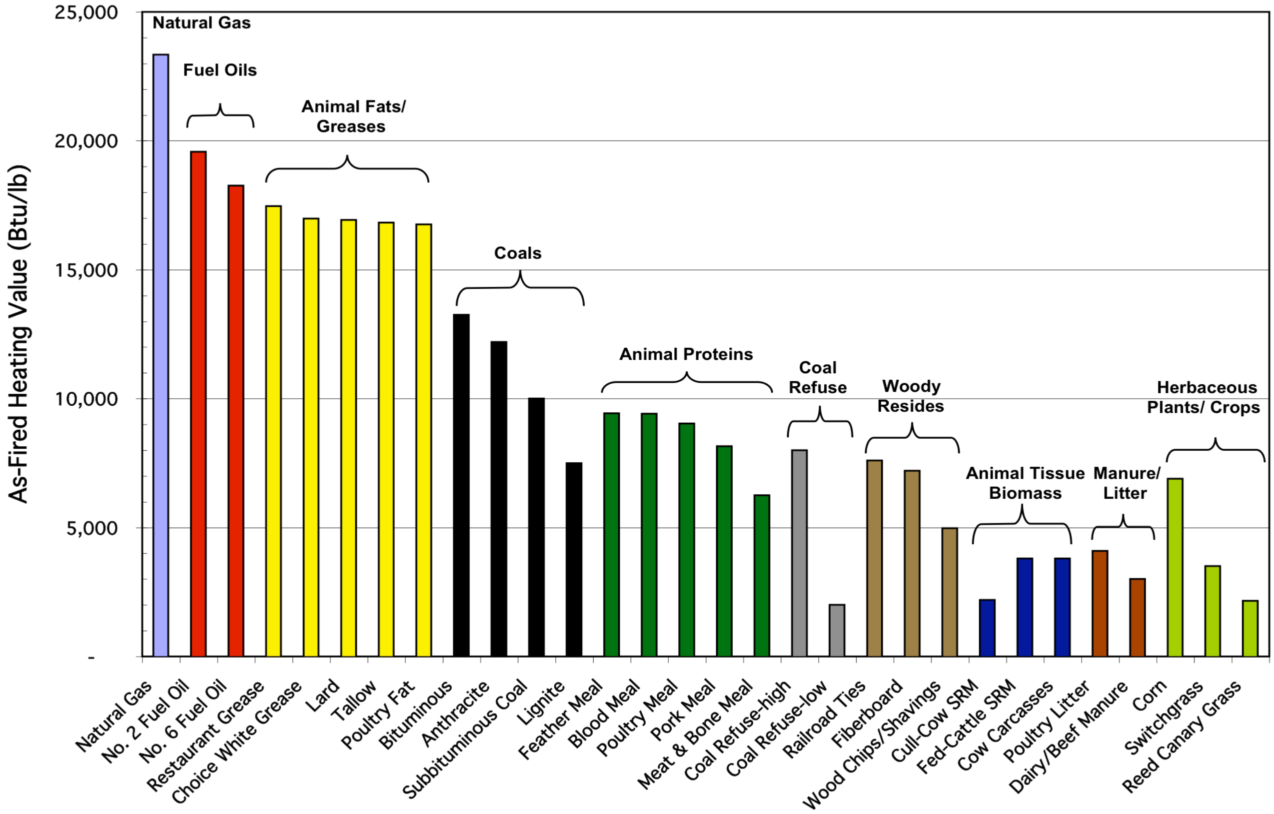

Figure 1. Comparison of As-Fired Energy Densities of Fuels Evaluated at Penn State

Fluidized-Bed Combustor System and Test Procedures

The FBC used during the test programs, shown schematically in Figure 2, is designed to operate as a circulating fluidized-bed combustor. It was modified to operate in a bubbling-bed mode for this testing. Details of the unit and testing procedures can be found elsewhere [2, 3, 6]. In both the NCBA/Cargill and PEDA projects, baseline coal tests were performed followed by tests cofiring coal and ATB.

Results and Discussion

Table 1 is a summary of selected tests representing coal baseline and ATB/coal cofiring tests performed at various levels of flue gas recirculation (FGR), coal/ATB ratios, and feed locations for the NCBA/Cargill project. In all, 35 tests were performed and used in the statistical analysis although only eight are listed in Table 1 for brevity. Similarly, Table 2 contains a summary of the ATB testing during the PEDA project.

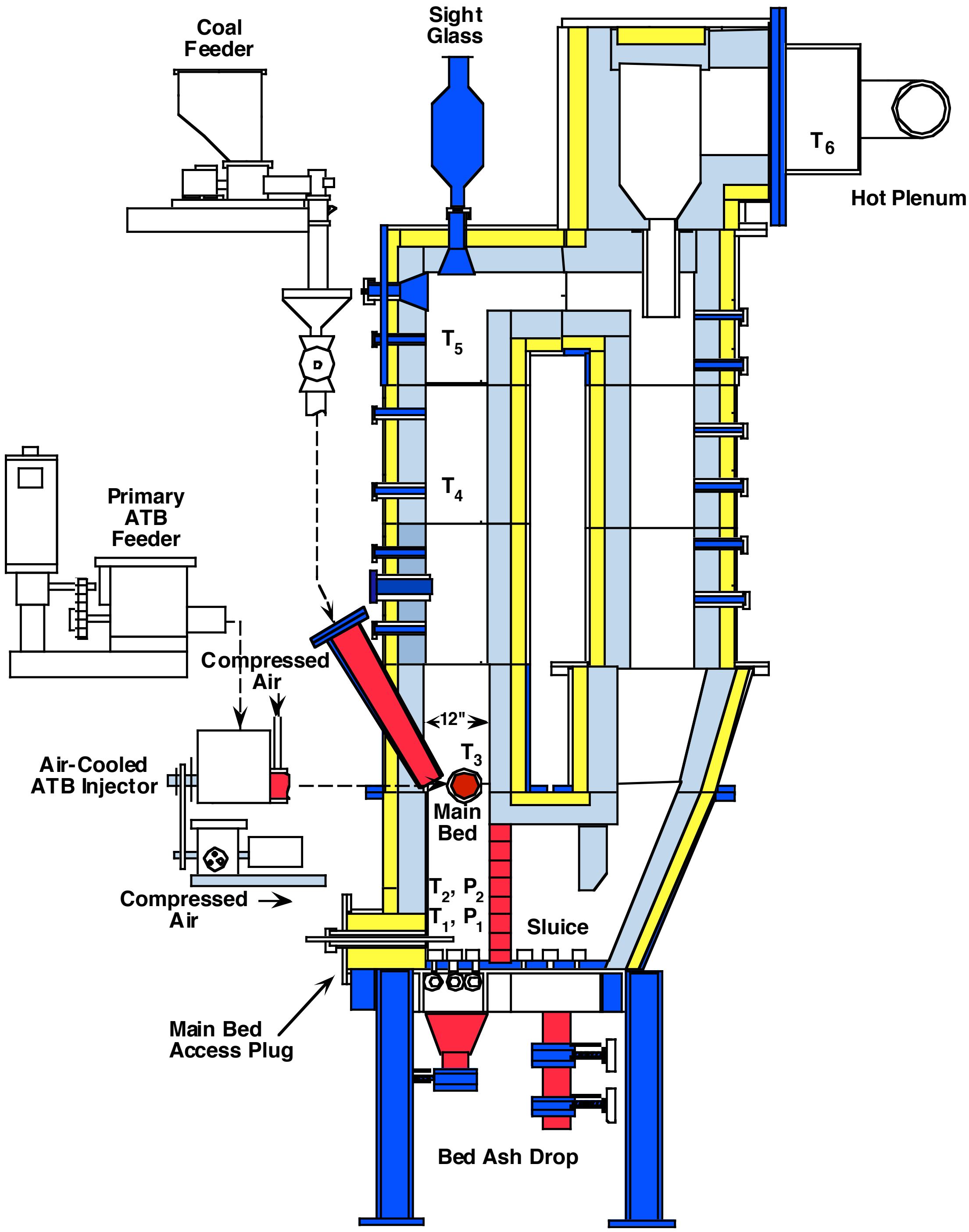

Figure 2. Schematic Diagram of the FBC

Table 1. Summary of Average Operating Conditions and Emissions for Selected NCBA/Cargill Tests

Fuel:	100% Coal	87% Coal 13% ATB1	100% Coal 25% FGR [a]	83% Coal 17% ATB1 23% FGR	100% Coal 27% FGR	90% Coal 10% ATB2 25% FGR	100% Coal 26% FGR	82% Coal 18% ATB3 24% FGR
Test Number	11	12	26	27	30	31	34	35
Firing Rate:								
Btu/h coal	393,080	229,396	342,194	246,779	419,566	230,154	406,206	242,789
Btu/h ATB	N/A[b]	31,147	N/A	51,882	N/A	24,710	N/A	54,899
ATB Feed Location	N/A	In-bed	N/A	Above-bed	N/A	Above-bed	N/A	Above-bed
Main Bed Velocity (ft/s):	6.4	6.5	6.5	6.6	6.5	6.5	6.7	6.6
Temperatures (˚F):								
T2: Upper Bed	1,665	1,690	1,655	1,716	1,639	1,702	1,667	1,696
T4: Middle Freeboard	1,178	1,314	1,268	1,598	1,302	1,551	1,314	1,627
T5: Upper Freeboard	1,087	1,233	1,158	1,503	1,216	1,472	1,207	1,532
Emissions:								
O_2 (%)	8.7	10.1	7.4	4.0	7.2	4.6	5.8	2.8
CO (ppm) @ 3% O_2	1,093	1,364	755	2,570	798	2,098	830	2,607
CO_2 (%) @ 3% O_2	15.4	15.8	15.7	14.9	15.5	15.3	15.9	14.9
SO_2 (ppm) @ 3% O_2	524	471	520	420	490	327	507	465
NO_x (ppm) @ 3% O_2	441	493	331	342	320	353	293	307
HC[c] (ppm) @ 3% O_2	90	74	56	207	28	221	41	338

[a] Flue gas recirculation

[b] N/A - not applicable

[c] HC - Total Hydrocarbons

Table 2. Summary of Average Operating Conditions and Emissions for PEDA Tests

Fuel:	100% Coal 22% FGR[a]	80% Coal 20% ATB1 18% FGR	100% Coal 22% FGR	89% Coal 11% ATB2 17% FGR	100% Coal 19% FGR	81% Coal 19% ATB3 21% FGR
Firing Rate:						
Btu/h coal	430,560	273,240	339,480	264,960	284,400	215,280
Btu/h ATB	N/A[b]	66,388	N/A	34,216	N/A	50,154
ATB Feed Location	N/A	Above-bed	N/A	Above-bed	N/A	Above-bed
Main Bed Velocity (ft/s)	6.2	6.1	6.1	6.1	6.2	6.1
Temperatures (°F)						
T2: Upper Bed	1,647	1,639	1,635	1,634	1,645	1,644
T4: Middle Bed	1,318	1,386	1,345	1,308	1,334	1,405
T5: Upper Freeboard	1,216	1,314	1,246	1,242	1,240	1,332
Emissions:						
O_2 (%)	9.2	11.2	8.3	11.9	8.4	11.2
CO (ppm) @ 3% O_2	632	1,167	547	1,618	580	933
CO_2 (%)@ 3% O_2	16.5	16.3	16.1	16.2	16.3	16.0
SO_2 (ppm) @ 3% O_2	529	491	521	532	492	512
NO_x (ppm) @ 3% O_2	451	647	417	507	399	499
HC[c] (ppm) @ 3% O_2	5	2	< 2	532	< 2	< 2

[a] Flue gas recirculation
[b] N/A - not applicable
[c] HC - Total Hydrocarbons

A summary of the average operating conditions for the selected tests is provided in Tables 1 and 2. Selected temperatures listed in Tables 1 and 2 correspond to the location of the thermocouples shown in the FBC schematic in Figure 2. The emissions listed in Tables 1 and 2 have been normalized to 3% oxygen in the flue gas in order to compare emissions results from tests with varying O_2 concentrations. The CO emissions during the NCBA/Cargill coal-fired tests were higher than normally observed in the FBC. The coal contained a significant quantity of fines which did not get mixed into the bed but rather were entrained and not completely consumed. In addition, the ATB was introduced midway in the freeboard (just below thermocouple 4 (T4)) and, hence, overfire air (commonly used to reduce CO emissions and enhance combustion performance) was not used. In the PEDA project, the ATB feed location was moved so the ATB was fed directly above the bed (as shown in Figure 2), which also allowed for the use of overfire air.

A general linear model was used to conduct an analysis of variance (ANOVA) and analysis of covariance using MINITAB Release 14 software [10]. The general linear model ANOVA tested the hypothesis that the means and variances of several sample sets were equal, therefore, the samples were from the same general population. The variance is a measure of how far the data are spread about the mean. In the case of the tests conducted, the ANOVA tested the hypothesis that the factors (Fuel Feed Location and FGR) did not affect the combustion efficiency in a statistically significant manner. CO levels were used as an indicator (response) of combustion efficiency because incomplete combustion produces some unreacted carbon in the form of CO; therefore, the ANOVA tested the hypothesis that Fuel and FGR did not affect the levels of CO emissions. 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 during the NCBA/Cargill testing, due to the equipment limitations and atypical coal particle size distribution (see references 2, 3, and 6 for a detailed discussion of the results), 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.

As observed in Table 2, the combustion/emissions performance was improved substantially when firing the ATB directly above the bed. While some difficulties were still encountered, primarily during feeding the ATB due to its heterogeneous nature, these would likely be reduced or possibly eliminated in a full-scale system with the proper equipment and more appropriate fuel line size to FBC diameter (see references 2, 3, and 6 for a detailed discussion of unit size and feed variability).

Next Steps in Implementing the Concept

The ultimate goal of the ATB testing is to provide information for the establishment of the infrastructure necessary to address carcass/SRMs disposal and massive depopulation needs from either diseased animals or transmissible spongiform encephalopathies (TSEs) such as BSE, which would include installation of handling systems on several fluidized-bed boilers in the United States. Prior to this though, a full-scale demonstration needs to be conducted. In addition, fundamental studies need to be performed investigating prion deactivation under FBC conditions. In investigations where TSEs have been exposed to temperatures of 1000°C (1830°F) for 15 minutes, sterile output products have been observed as it is reported that the minimum temperature required to achieve sterility is probably only marginally above 600°C (1110°F) [11]. Testing however, needs to be performed under residence time conditions that are more typical of that found in an FBC boiler, which is on the order of seconds. Currently, Penn State is performing additional pilot-scale testing with funding from the U.S. Department of Energy where oxygen-enhanced combustion of ATB in an FBC will be performed where it is anticipated that the higher oxygen content will further improve combustion performance.

Conclusions

The objective of the pilot-scale testing was to demonstrate the technical viability of cofiring ATB in a coal-fired FBC as an option for disposing of SRMs and carcasses. This testing is necessary to demonstrate to the regulatory agencies, USDA, FDA, and industry the technical viability of this disposal option prior to securing funding for a full-scale demonstration. The purpose of this testing was to assess technical issues of feeding/combusting the ATB and not to investigate prion deactivation/pathogen destruction. Overall, the project successfully demonstrated that carcasses and SRMs can be cofired with coal in a bubbling FBC.

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