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Ammonia Removal From Fly Ash in a Bubbling Fluidized Bed

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ECE 14

AMMONIA REMOVAL FROM FLY ASH IN A BUBBLING FLUIDIZED BED

Final Project Report to Emissions Control By-Products Consortium

submitted to

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ABSTRACT

This report deals with the development of a process to remove ammonia from dry fly ash. Laboratory experiments on three different fly ashes show ammonia can be removed from the ash by heating the ash in a bubbling fluidized bed, with the assistance of acoustics to promote active bubbling. Data are presented on the ash temperatures required to accomplish this. The bed in the experiments is a laboratory scale batch bed. Design calculations were also performed on a continuously operating system for commercial-scale applications.

BACKGROUND

As the utility industry gears up for the next major round of NO_X reductions, it is widely anticipated a significant number of units will be equipped with either selective non-catalytic reduction (SNCR) or selective catalytic reduction (SCR) technologies. For coal-fired applications, both techniques use either an ammonia or urea-based reagent. In all cases, some ammonia reaches the stack as part of the flue gas and some is adsorbed onto the fly ash. There is widespread concern the presence of ammonia on the ash will adversely affect ash utilization.

Much of the ammonia present on ash is in the form of ammonium sulfate or ammonium bisulfate. Tests of fly ash contaminated by ammonium salts show, in normal situations, the ammonia is not a problem unless the ash is moistened. Van der Brugghen et al. (1) performed laboratory tests in which concrete was prepared using fly ash containing from 100 to 300 mg/kg of ammonium. Ammonia concentrations were continuously measured in the ambient air during the preparation of the concrete and the pouring of the concrete floors. The results show, for some situations, unsafe concentrations of ammonia were measured in the vicinity of the wet concrete. The problem of the ammonia odor increased in severity with higher concentrations of ammonium in the ash and in applications in which concrete was being mixed or poured in enclosed areas.

It seems likely, based on the experiments reported in Reference 1, the presence of ammonium salts on fly ash will be a deterrent to the utilization of fly ash for some high volume applications, a problem which will become much more serious with more widespread installation of SCR and SNCR technologies.

This report describes results from a project, funded by DOE through the Combustion Byproducts Recycling Consortium and a group of electric utilities, to demonstrate that ammonia can be driven from dry fly ash by heating the ash in a fluidized bed to cause thermal decomposition of the ammonium compounds. Data are presented on the ash temperatures required to accomplish this.

FLUIDIZATION OF FLY ASH

Fluidized beds are widely used in industry, because, when operated with the right range of conditions, they exhibit excellent heat transfer, solids mixing, and gas contacting characteristics. In one type of fluidized bed, the particles are contained in a vessel and are supported by a gas distributor (see, for example, Figure 1). At low flow rates of fluidizing gas, the particle bed is in a packed state. As the gas velocity increases to a critical value, bubbles are formed at the distributor. These rise vertically through the bed,

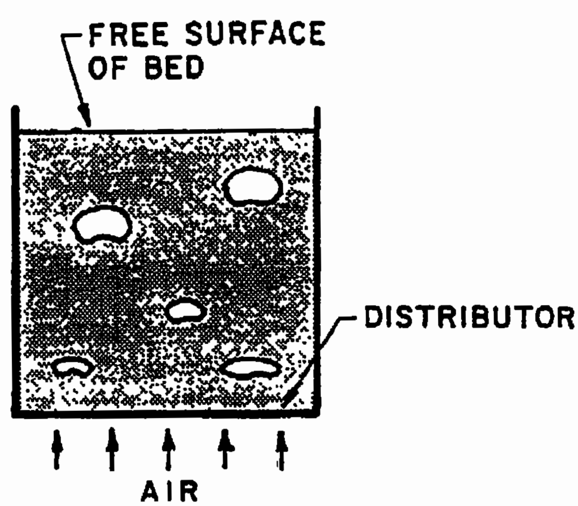

Figure 1 – Sketch of Bubbling Fluidized Bed

creating a turbulent-like motion and very good solids mixing. The gas velocity at which bubbles first appear is referred to as the minimum bubbling velocity, U_{mb}. At conditions above minimum bubbling, as gas velocity, U_o, is increased, bubble frequency and bubble size increase, with more vigorous mixing occurring in the bed.

Previous tests with fly ash in a fluidized bed in our laboratory have shown that because of the very fine size distribution of fly ash particles, the particles tend to be attracted to one another. This leads to a clustering of the particles in the bed which, in turn, makes it difficult to achieve stable fluidization with active bubbling. To get around this problem, we use an acoustic field to agitate the bed material. Figure 2 shows a laboratory-scale batch fluidized bed with a loud speaker positioned at the top of the bed.

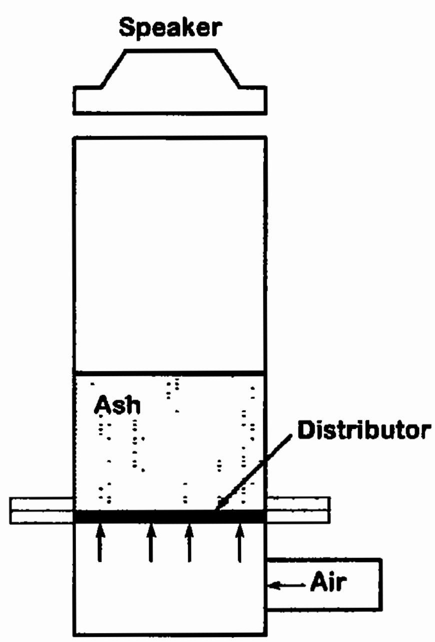

Figure 2 – Laboratory Batch Fluidized Bed

Bubble measurements performed inside the bed with a reflective type fiber optic probe show the effects of bed process conditions and the acoustic field on bubbling. Figure 3 shows a typical signal from the probe caused by the passage of a succession of bubbles past the probe tip. In this case, the signal indicates good quality fluidization with vigorous bubbling.

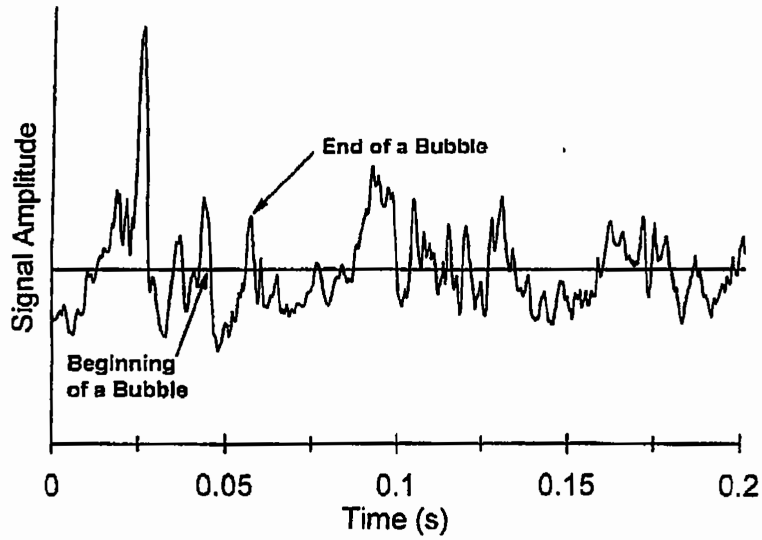

Figure 3 – Signal From Fiber Optic Probe Showing Wave Form Caused by Bubble

Figure 4 compares the fiber optic probe signals from a series of experiments with fly ash. The sound pressure level caused by the loud speakers was varied up to 140 dB and the excess air velocity (U_o - U_{mb}) was held at a fixed value. The data show intermittent bubbling activity at low dB levels, with the bubble frequency increasing and becoming much more regular as the dB level increased.

The ammonia removal process requires vigorous and consistent bubbling, and to achieve this, the ammonia removal process described in this report makes use of acoustics to promote active bubbling.

EXPERIMENTS ON AMMONIA REMOVAL

The experiments on ammonia removal were performed in a 6" diameter bed, fluidized with air. Electric resistance heaters, submerged in the bed, were used to heat the ash and a loud speaker was positioned at the top of the bed. Thermocouples in the bed measured ash temperature at several locations. As the ash temperature increased, samples of ash were periodically removed and these were subsequently analyzed for ammonium content. The ammonia measurements were performed using an ammonia ion

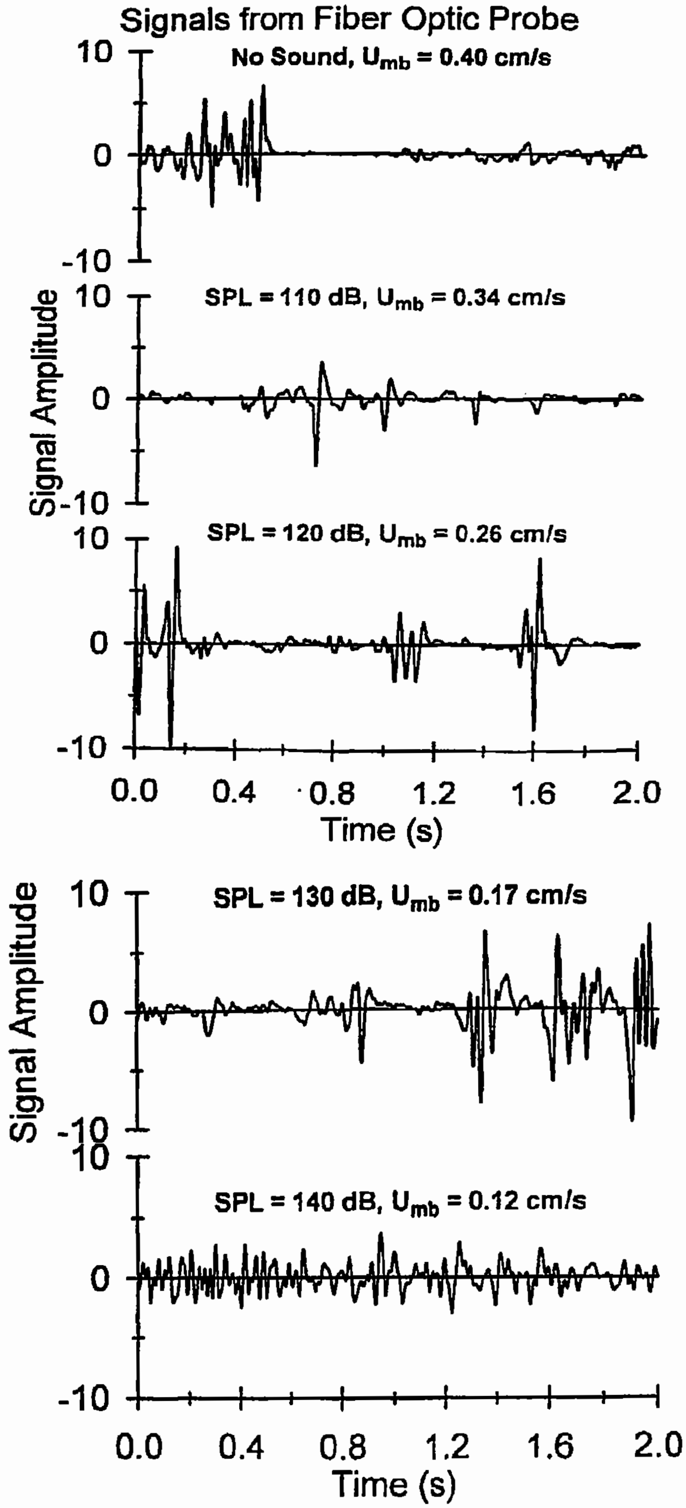

Figure 4 – Signals From Fiber Optic Probe Showing effect of SPL on Consistency of Bubbling

selective electrode. The measurement procedure requires a sample of ash be placed in a sulfuric acid solution. The ammonium compounds in the ash dissolve, making it possible for the electrode to detect the ammonia level.

Three different ashes were tested. For one ash, the initial ammonia concentrations were in the 700 to 850 ppm range. The results show reductions in ammonia began to occur in the 300 to 450°F range, depending on process conditions. The ash ammonia content was reduced to 30 percent of the initial at 600°F (Figure 5). A similar set of tests was performed on ash from a second power plant. In this case, the initial ammonia content ranged from 600 to 1100 ppm. Ammonia release began at lower temperatures with a residual ammonia content of the ash at 20 percent of the initial at around 650°F and at less than 5 percent of the initial at around 700°F (Figure 6). Finally, tests were performed on ash from Plant C with an initial ammonia concentration of approximately 500 ppm. The concentration was reduced to about 20 percent of the initial at 700°F (Figure 7). Figure 8 compares the ammonia separation characteristics for the three ashes, where each curve in this figure is an average drawn from the data shown in the corresponding figure for that ash (Figures 5 to 7). This comparison shows very similar ammonia separation characteristics for the three ashes.

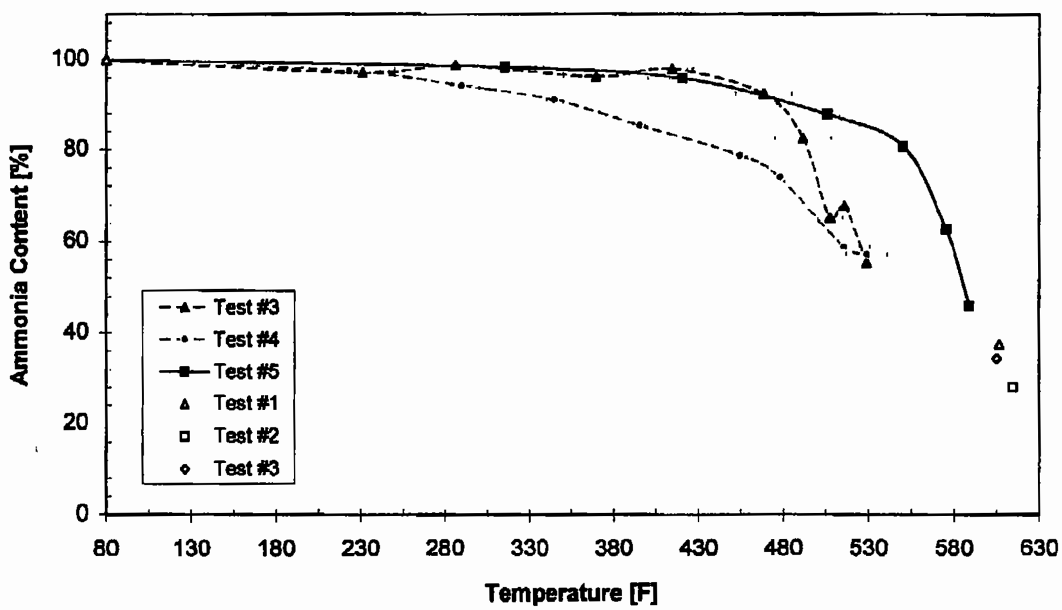

Figure 5 – Fly Ash – Ammonia Separation, Ash A

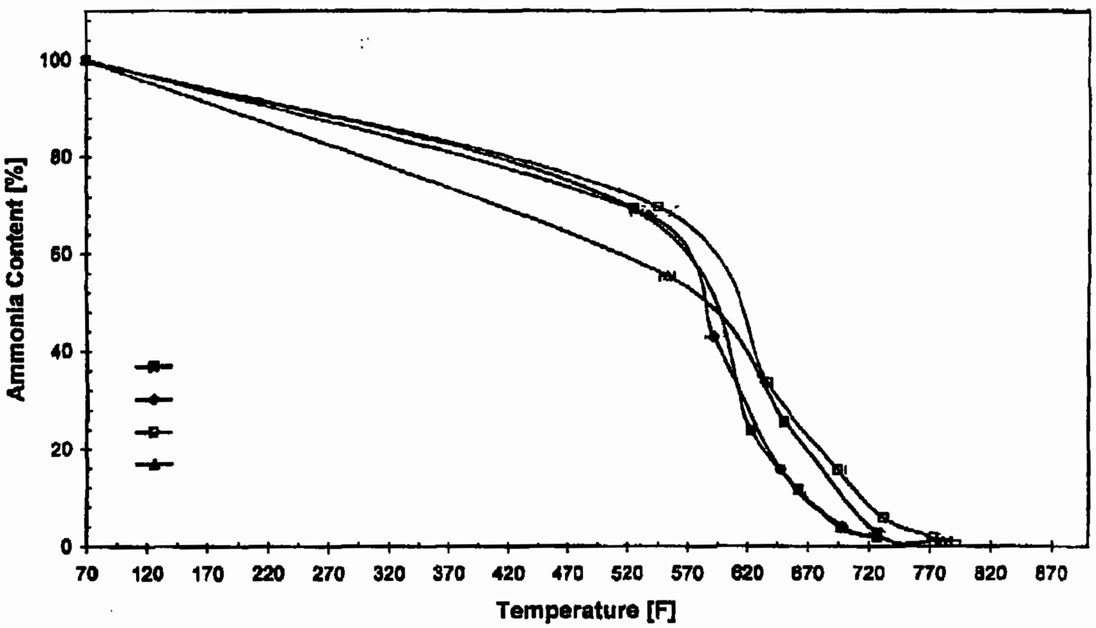

Figure 6 – Fly Ash – Ammonia Separation, Ash B

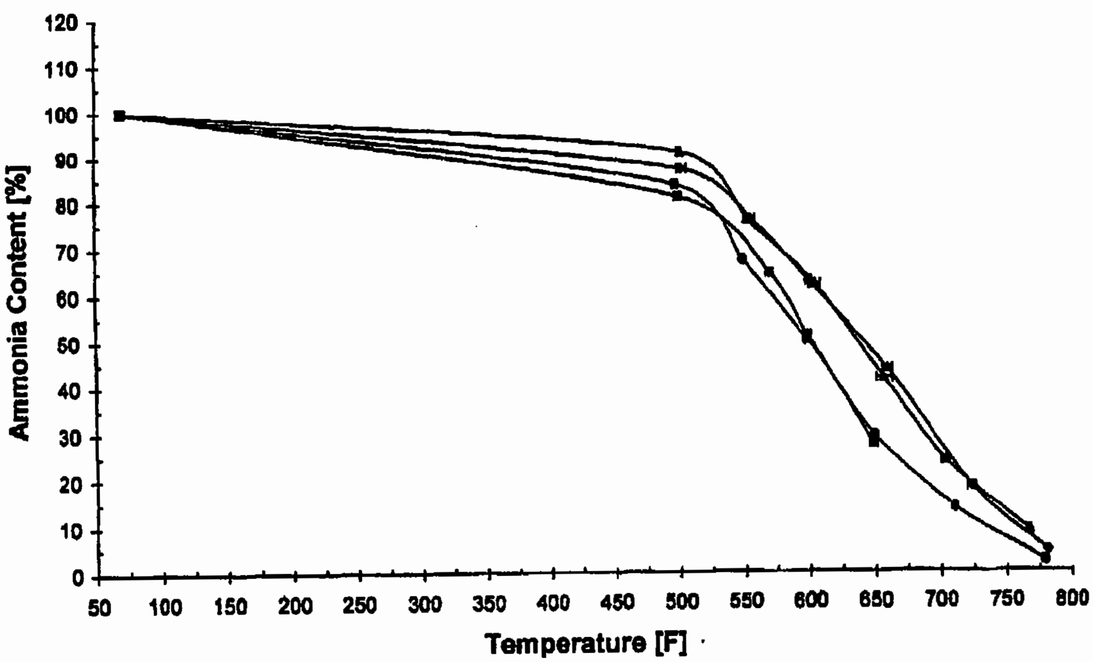

Figure 7 – Fly Ash – Ammonia Separation, Ash C

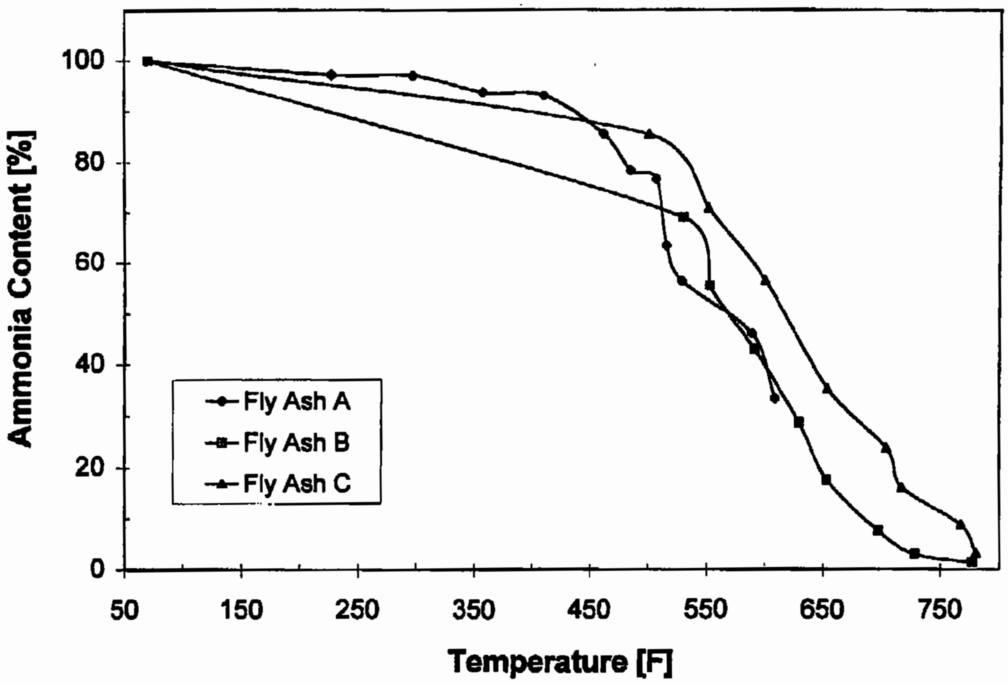

Figure 8

Ammonia removed from the ash is carried from the bed with the fluidizing gas. Figure 9 shows a plot of ammonia concentration in the air leaving the fluidized bed as a function of time during one experiment. The data were obtained by a UV spectroscopy instrument being used for on-line measurements of ammonia content of the off-gas.

CONTINUOUS OPERATION

The data in Figures 5 to 8 show ammonia can be removed from dry ash by heating the ash in a bubbling fluidized bed, with the assistance of acoustics to promote bubbling fluidization. The bed used in those experiments was a small, laboratory-scale batch bed. However, a full-scale commercial process will need to operate continuously, and we propose to accomplish steady operation using an inclined fluidized bed (Figure 10).

In the case of the inclined bed, dry ash is fed to the bed at one end and is heated as the ash flows along the surface of the distributor. Ammonia-free ash is removed at the far end of the bed. We believe the inclined bubbling fluidized bed is the ideal type of

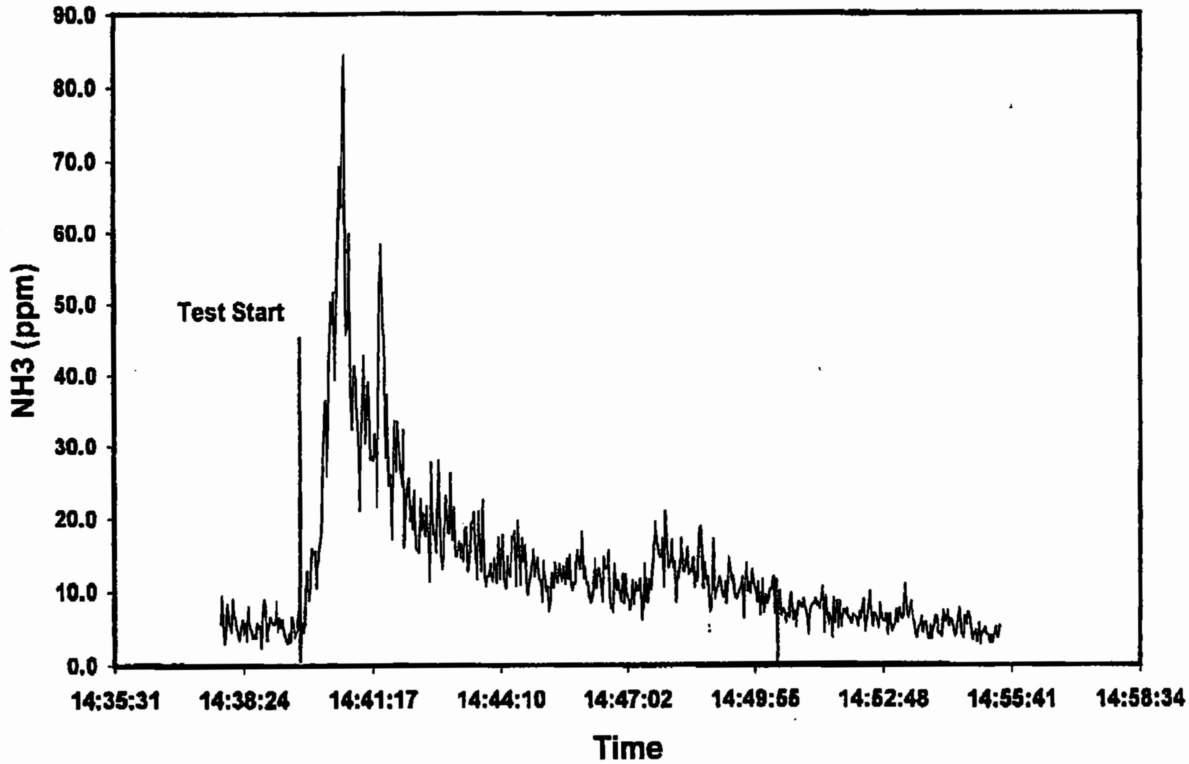

Figure 9 – Ammonia Signal From UV Spectrometer During Ammonium Decomposition Test

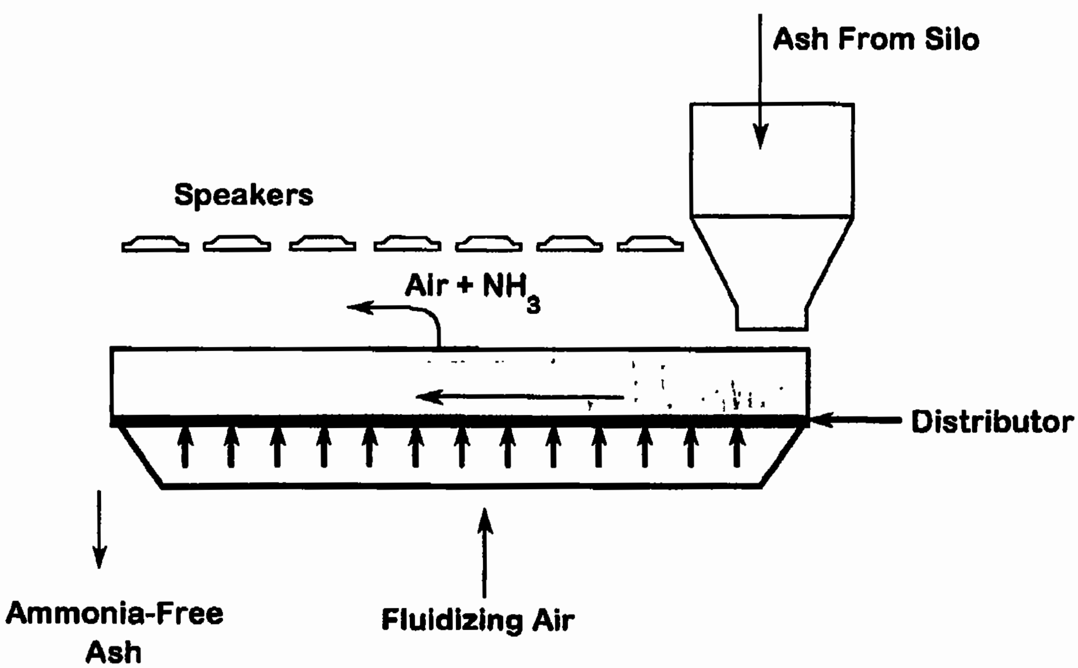

Figure 10 – Sketch of Inclined Fluidized Bed

reactor for this application. It is of simple construction, with no moving parts. It permits continuous operation. Finally, because of extremely low fluidizing air velocities, energy requirements for heating and the cost of solids-air separation can be kept to a minimum.

Design calculations were performed for a system processing 25 tons/hr of ash. It was assumed the ash is heated using electrical resistance heaters immersed in the bed. It was further assumed that ash enters the heating section directly from ESP ash hoppers at 250°F or is preheated to that temperature using flue gas from the ESP exit duct.

Figure 11 shows the ash heating costs as a function of the cost electric generation for ash feed temperatures of 70°, 150° and 275°F. At 4¢/kWh, the energy costs for ash heating range from $2.14/ton to $3.05/ton, depending on ash inlet temperature. If desired, energy types other than electricity can be used for ash heating. For example, a hot gas produced by natural gas combustion can be circulated through tubes immersed in the bed to heat the ash to the required temperature.

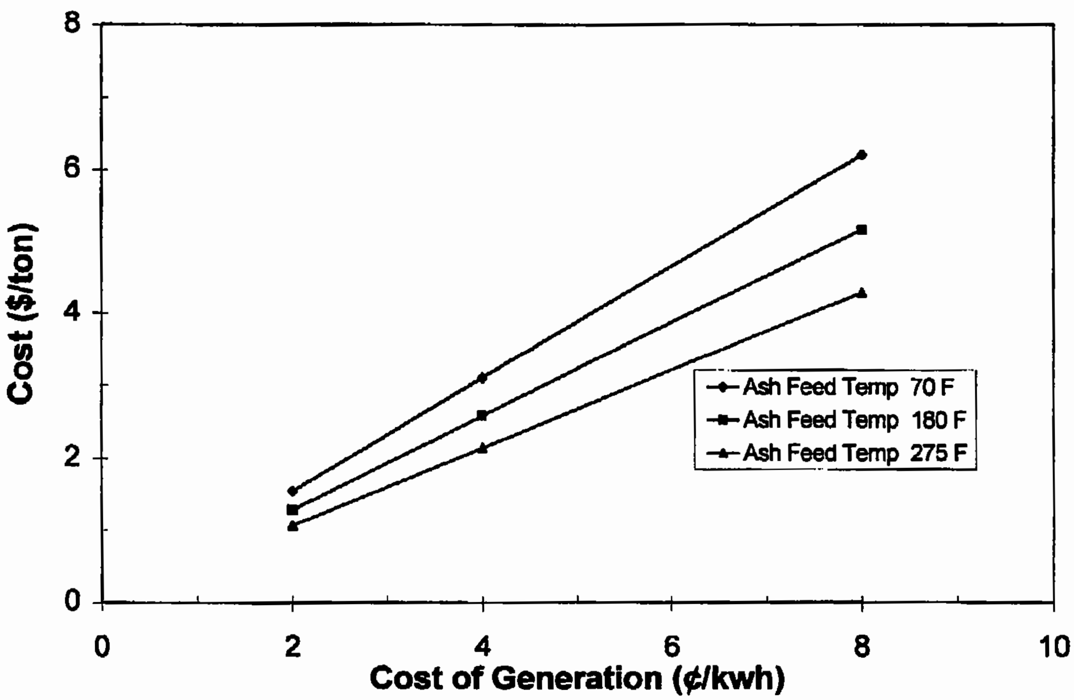

Figure 11

The off gas from the fluidized bed will consist of hot air, with small concentrations of ammonia, SO_2 and entrained ash particles. In some applications it will be possible to inject the off gas into the furnace, where the NH_3 will provide NO_x reduction through SNCR reactions. In other applications, an ammonia scrubber or a fabric filter and ammonia scrubber may be needed for cleaning the off gas prior to discharge to the atmosphere. In this case, however, the flow rate of gas to be treated will be quite small. The fluidizing velocities are less than 0.05 ft/s for this design and the flow rate of fluidizing air will be of the order of 200 to 300 scfm.

CONCLUSIONS

Experiments were performed in a heated batch fluidized bed to determine the potential for removing ammonia from fly ash in a dry process. The bed was equipped with a loud speaker to permit acoustic agitation of the bed and to promote active bubbling. The results of the experiments showed that typically 90 to 95 percent ammonium removal was achieved with ash temperatures in the range of 700 to 750°F. The ammonium compounds in the ash decomposed to release gas-phase ammonia which was carried from bed with the fluidizing air.

Design calculations were performed on an inclined fluidized bed for steady continuous operation. In this design, dry ash is fed to the bed at one end and is heated as the ash flows along the surface of the distributor. Ammonia-free ash is removed at the far end of the bed. Design calculations were performed for a system processing 25 tons per hour of ash. It was assumed the ash is heated using electrical resistance heaters immersed in the bed. At $0.04/kWh for electricity, the energy costs for ash heating ranged from $2.14 to $3.05/ton, depending on ash inlet temperature.

These results demonstrate the potential for using a heated fluidized bed to remove ammonia from fly ash. The Principal Investigator is in the process of building a small laboratory scale facility for demonstrating continuous processing of the ash in an inclined fluidized bed.

REFERENCES

1. F. W. van der Brugghen et al. "Problems Encountered During the Use of Ammonium Contaminated Fly Ash," Proceedings EPRI/EPA 1995 Joint Symposium on Stationary Combustion NO_x Control.

ACKNOWLEDGMENTS

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Department of Energy
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"Ammonia Removal from Fly Ash in a Bubbling Fluidized Bed"

WVU Subcontract no. 98-166-LU

Fund Source	Expenditures	1st	2nd	3rd	4th	5th	6th	Total Planned / Cumulative Actual
ECBC	Planned	$7,000	$30,000	$21,188	$25,000	$13,000	$9,582	$83,188
	Actual	$6,890	$25,560	$3,156	$31,826	$12,859	$2,897	$83,188
Applicant	Planned	$4,500	$9,000	$9,000	$8,000	$4,000	$3,052	$31,263
	Actual	$4,810	$6,600	$4,801	$8,305	$6,961	-$214	$31,263
Other	Planned	$3,500	$7,000	$7,000	$4,000	$8,000	$2,235	$25,000
	Actual	$530	$5,970	$4,265	$4,438	$8,419	$1,378	$25,000
Total Planned		$15,000	$46,000	$37,188	$37,000	$25,000	$14,869	$139,451
Total Actual		**$12,230**	**$38,130**	**$12,222**	**$44,569**	**$28,239**	**$4,061**	**$139,451**
Variance		-$2,770	-$7,870	-$24,966	$7,569	$3,239	-$10,808