A Pilot Demonstration of Spray Dryer Evaporation as a Method to Treat Power Plant FGD Wastewater

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ABSTRACT

The United States Environmental Protection Agency (USEPA) is expected to limit the concentrations of species including selenium and mercury allowed to be discharged in wastewater from wet flue gas desulfurization (FGD) units. One treatment idea is spray drying evaporation, a Zero Liquid Discharge (ZLD) technology. In this process, FGD wastewater droplets are sprayed concurrently with hot flue gases and the dried solids are collected using an electrostatic precipitator (ESP) or baghouse.

A pilot scale test was conducted at a coal fired power plant to demonstrate this technology. The droplet mass mean diameter was adjusted to 40μm during the test. A thermal model was established. The model showed that to evaporate 200 gpm FGD wastewater with 40,000ppm chloride, with an inlet and outlet gas temperatures of 620°F and 400°F, the required flue gas flow was estimated to be 0.95 million acfm. Data illustrated that the dissolved mercury in the FGD wastewater did not evaporate back to the flue gas. Instead, the mercury deposited in the solids. Around 99% of the chloride in the wastewater was crystallized, and the remaining 1% was evaporated into the flue gas. An increased baghouse pressure drop was observed during the test.

INTRODUCTION

The implementation of wet FGD allows utilities to reduce acid gas and mercury emissions; however, gas-scrubbing units can cause increased volumes of wastewater in effluent streams. Typical scrubbing units produce 50-2000 gallon/min of wastewater, which must be treated before being discharged to the environment.

ZLD systems for FGD wastewater treatment are developing technologies and encompass two major sub-processes: spray drying and brine concentrator-crystallizer units. Both ZLD options provide a way of treating FGD wastewater by using steam, power or hot gas to evaporate water while leaving behind a solid product for handling. Using process steam, generating steam, or power for use specifically in the wastewater treatment evaporator is costly, so alternative sources of heat need to be investigated. This paper focuses on the use of flue gas as the heat source to spray dry FGD wastewater.

The use of hot flue gas to spray dry liquid feed solutions is a proven technology and is in use in many manufacturing processes. Coal fired furnaces generate an excess amount of heat which is not used for electric generation. A portion of that heat could be utilized to operate a spray drying system. Converting commercial spray drying systems to operate with ash laden flue gas is possible, but operational issues need to be fully understood before implementation of spray drying in a full-scale setting.

A pilot-scale testing program was performed at a coal-fired power plant to determine if spray drying FGD wastewater is a viable and economical process.

To determine what happens to the components of FGD wastewaters, when using spray drying, parametric testing was performed. The questions posed fall under the following major topic areas:

1. How much heat is needed to evaporate the required FGD wastewater?
2. Does the composition of the wastewater affect the ability of the system to fully dry the liquid to a salt?
3. What happens to volatile contaminants in FGD wastewater, in particular mercury?
4. What are the characteristics of the solids produced during spray drying?
5. How do the solids produced during spray drying impact the baghouse performance?

SYSTEM DESCRIPTION

The Spray Dryer pilot plant is located at a coal-fired power plant in Alabama. The plant burns eastern Alabama low sulfur coal in two Combustion Engineering corner-fired boilers. Each boiler is fitted with an economizer, an air heater and two electrostatic precipitators arranged in series.

The FGD water evaporation tests were conducted at the spray dryer test facility. The test facility's process and instrumentation diagram is shown in Figure 1. The facility consists of the ductwork, valves and fans needed to withdraw exhaust gas from the plant, pass it though the facility's test equipment and return it to the plant upstream of the second electrostatic precipitator. The facility can take exhaust gas either from the Unit 1 air heater inlet, from outlet of the Unit 1

American Standard ESP (the first of the two in-series electrostatic precipitators) or from the outlet of the Buell ESP (the second of the two in-series ESPs).

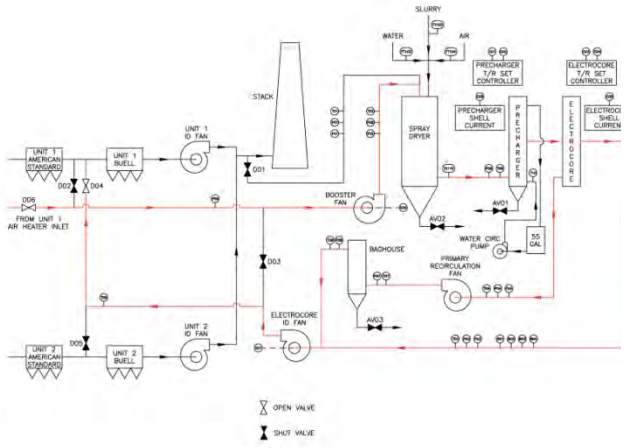

Figure 1. Pilot spray dryer schematic (Air Heater Inlet Alignment)

The spray dryer is a cylindrical vessel with an outside diameter of 12 feet (3.66 meters), shown in Figure 2. The cylindrical section has an internal height of 30 feet (9.14 meters).

The spray nozzle used in all the tests was a Turbotak 3x6 mm nozzle (Figure 3). The nozzle was supplied with compressed air controlled through an air pressure regulator. The liquid flow rate was controlled by varying the pump speed which was done automatically by the spray dryer control system. The spray dryer control system varied the pump speed to match the spray dryer outlet gas temperature to the set point using a PID control loop. The spray nozzle droplet size was set by adjusting the compressed air regulator based on the measured liquid flow rate needed to maintain the outlet temperature set point. A check with a Process Metrix Process Particulate Counter (PPC) probe showed the Sauter mean particle diameter to be about 40 micrometers, near the desired nozzle operating point. The liquid flow rate was measured with a rotameter.

Figure 2. Spray dryer photograph

Figure 3: Clean Turbotak atomizing spray nozzle and lance.

Results and Discussion

Pilot FGD Wastewater Evaporation Rate

In this test, 3 kinds of waters were tested: city water with very low chloride, 20,000 ppm chloride simulated water, and 40,000 ppm chloride simulated water. The simulated water is adjusted by adding $CaCl_2$ and $MgCl_2$ to city water, based on the component analysis of one FGD wastewater.

Figure 4 shows the sprayed liquid to flue gas ratio plotted versus the spray dryer temperature drop. The data are plotted for different levels of chlorides in the water. These levels varied from city water (nominally 0 ppm Cl) to 40,000 ppm Cl. Also plotted are the theoretical results for spraying pure water into clean dry 625°F air within a spray dryer having an infinite residence time. The liquid to exhaust gas ratio is expressed in U.S. gallons of liquid sprayed per thousand standard cubic feet of flue gas entering the spray dryer. Standard conditions are an absolute pressure of 760 tor and 20°C (68°F). The theoretical results show that the relationship between the temperature drop and liquid to flue gas ratio is nearly linear. In fact, if the specific heat at constant pressure of both air and water were constants and not functions of temperature then the theoretical relationship would be truly linear. It is important to note here that the spray dryer inlet temperature was nearly constant at about 625° and the temperature drop was varied by changing the spray dryer gas outlet temperature.

The results show good agreement with the simple theory for temperature drops between 250°F and 300°F but the experimental results show higher liquid-to-gas ratios as the spray dryer temperature drop increases. Furthermore, the results show that increasing chlorine concentration results in an increasing liquid to flue gas ratio for a given temperature drop. This is consistent with the observation made during the test program that, when switching over from city water to 40,000 ppm Cl water, the flow rate of liquid, as measured by rotameter, increased by about 10 percent for essentially the same spray dryer outlet gas temperature and inlet flue gas flow rate. This observation was counterintuitive as the forming of salt particles was expected to be an endothermic chemical reaction thereby requiring even more hot flue gas (or less sprayed liquid) to maintain the same exit temperature.

One hypothesis is that the salt particles leaving the spray dryer are not completely dry and some of the sprayed liquid is leaving the spray dryer as a liquid trapped within the salt particles. The slope of the experimental data points compared to the slope of the theoretical line is consistent with this hypothesis. As the spray dryer temperature drops, the liquid-to-flue gas ratio is lower than simple theory predicts. This is consistent with dry salt particles leaving the spay dryer and an endothermic salt particle drying process. These low spray dryer temperature drop data correspond to a high spray dryer outlet temperature and conditions under which complete drying of the salt particles is more likely. Conversely, the high spray dryer temperature drop data correspond to a low spray dryer outlet temperature and, therefore, conditions under which complete particle drying is less likely. This is supported by the ash conditions at the spray dryer hopper. At low spray dryer temperature drop (high outlet temperature >

375F), we observed that the solids collected at the spray dryer hopper are completely dry (shown in Figure 5); while at high spray dryer temperature drop (low outlet temperature < 350F), the collected mixture at the spray dryer hopper is damp solids or even solution.

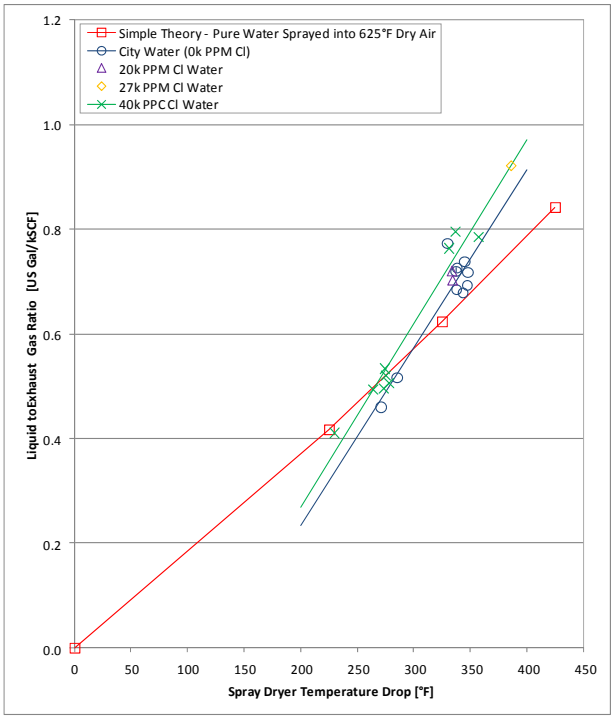

Figure 4. Liquid Flow Rate versus Spray Dryer Temperature Drop

Figure 5. Dry mixture of salt and fly ash flowing freely from bottom of spray dryer

Figure 6. Damp mixture of salt and fly ash being removed from bottom of spray dryer

Figure 7. Liquid solution of salt and fly ash draining from bottom of spray dryer

Full Scale Enthalpy Balance Model

The overall enthalpy balance used to calculate enthalpy for the pilot experiments was used for the full-scale design. In this case the flue gas flow required for various flue gas and outlet temperatures were calculated (see Figure 8). The design wastewater flow was 200 gpm with 40,000 ppm Cl FGD wastewater. Compressed air was not included in the full-scale design enthalpy balance because a rotary atomizer will likely be used. The air in-leakage and vessel heat loss were assumed to be 100^(2/3) of the pilot scale values. This is based on the idea that the full scale spray

dryer is expected to have a volume approximately 100 times greater than the pilot unit, and that air in-leakage and vessel heat loss will scale with surface area which is estimated to be 100^(2/3) greater in the full scale unit in comparison with the pilot unit.

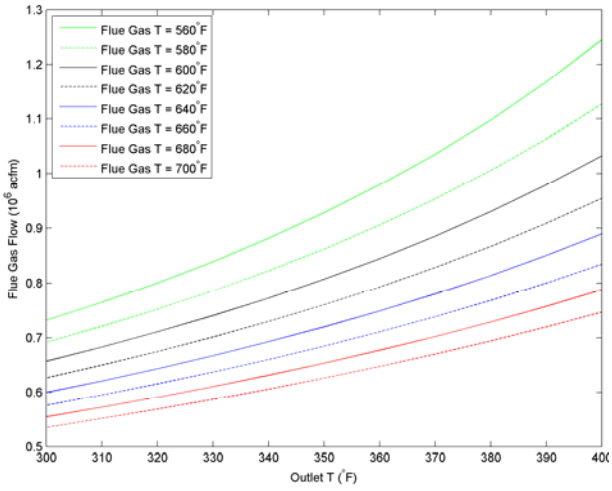

Figure 8: Flue gas flow rate required to dry 200 gpm of 40,000 ppm Cl wastewater in a full scale spray dryer.

Based on the above model, for an inlet and outlet gas temperatures of 620°F and 400°F, the required flue gas flow was estimated to be 0.95 million acfm.

Mercury Mobility

The high temperatures required to spray dry FGD wastewater have the potential to cause mercury contained in the FGD liquid to be volatilized. To evaluate the potential for mercury reemission, measurements were made at the inlet and outlet of the spray dryer using standard carbon traps. Also, the oxidation state of mercury was measured using speciated traps during spray drying of a simulated FGD wastewater spiked with 800 ppb of oxidized mercury. If the spray drying process causes mercury to become mobile, increased mercury levels should be observed in the outlet spray dryer gas stream.

Actual FGD wastewater spiked with 800 ppb dissolved mercury and containing 1% to 3% FGD suspended solids was introduced into the spray drying system. Figure 9 shows mercury removal and speciation. All the mercury dissolved into the FGD wastewater partitioned to the solid phase, and no reemission was observed. Further removals of oxidized and elemental mercury were also achieved during spray drying. The data also showed that oxidized mercury was more likely to be removed from the flue gas during spray drying and no significant reduction of elemental mercury was observed.

The effect that activated carbon injection has on the mercury removal through spray dryer was tested. The carbon was injected directly into the inlet flue gas stream where it was expected to adsorb mercury. Three activated carbon feed rates were tested: 5, 2, and 0.5 lb/hr. Average mercury removal rates of 35% to 55% were observed while spray drying without activated carbon injection. During testing with activated carbon injection, additional gas phase mercury removals were calculated as 91%(5lb/hr), 46% (2 lb/hr), and 10% (0.5 lb/hr).

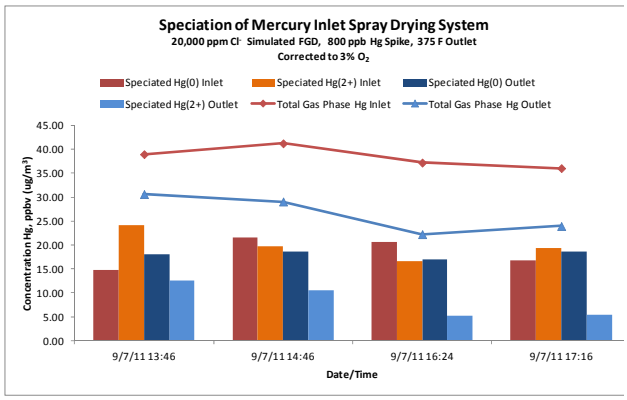

Figure 9. Mercury oxidation during spray drying of 800 ppb mercury spiked FGD wastewater. The left was city water; all others are simulated FGD water.

Chloride Mobility

The chloride content of FGD wastewater ranges from hundreds up to 50,000 ppm from scrubbing the HCl present in the flue gas. Chloride concentration in scrubbing liquors can be controlled through the blow down rate. With a lower rate of blow down, chloride concentration will increase, producing less FGD wastewater, but higher TDS in the liquor. One objective of the spray drying process is to cause the dissolved chloride in the FGD wastewater to crystallize into the solids through the spray drying process, but there is the potential they could be vaporized and re-emitted as HCl during the spray drying process. A series of tests were performed to determine the fate of dissolved chlorides when spray drying FGD wastewater.

Figure 10 are excerpts taken from the FTIR data collected at the outlet of the spray dryer. There was very little mobility of SO2 from the FGD wastewater to the gas phase. Over 99% of chlorides in the FGD wastewater deposited as solids for both 20,000 ppm Cl and 40,000 ppm simulated FGD wastewater. We observed outlet HCl concentrations increasing about 89% for 20,000 ppm Cl simulated FGD wastewater and about 138% for 40,000 ppm Cl simulated FGD wastewater. Any HCl that is volatilized is expected to be captured by FGD systems.

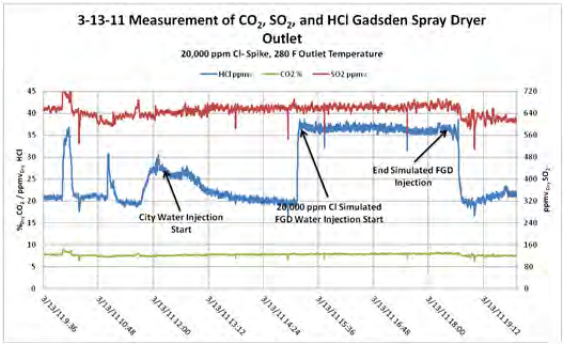

Figure 10: Gas phase measurements during spray drying. City water Sprayed at end of 20,000 ppm Cl simulated FGD test.

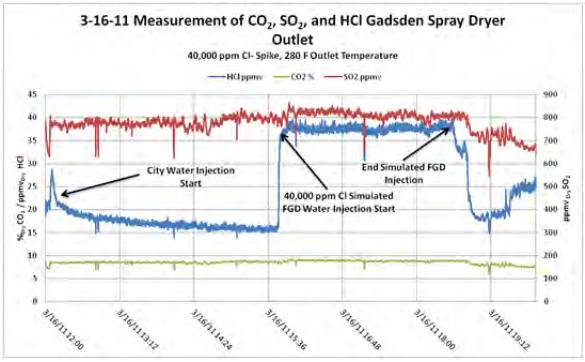

Figure 11: Gas phase FTIR measurements during spray drying. City water Sprayed at end of 40,000 ppm Cl simulated FGD test.

BagHouse Performance

The test facility is equipped with a Flex-Kleen Model 100 BVBS 16 III G pulse jet baghouse fitted with sixteen 102 inch-long, 14 oz Aramid/Nomex bags. The baghouse has a cloth area of 203 ft². A new set of bags and clamps was installed just before the tests began.

The baghouse filters about 10 percent of the flow coming out of the spray dryer and about 60 percent of the particulate matter as the upstream ElectroCore unit separates and concentrates the particulate matter before sending it to the baghouse. The ElectroCore precharger and separator modules were not energized during this test program and, therefore, acted as a purely mechanical separator/concentrator.

The moisture fraction of the ash/salt mixture collected from the baghouse hopper was between 0 - 5%. The baghouse ash/salt mixture was found to be both dry and free flowing after every run.

Figure 12 shows the normalized baghouse pressure drop versus test date to show how the pressure drop changed over time. The testing was not continuous and the sprayed water composition varied during each testing period. However, enough data was gathered to show trends of increased pressure drop across the baghouse during periods of continuous operation. The graph shows how the normalized pressure drop essentially doubles during each testing period but seems to recover somewhat during the intervals when the unit is shut down.

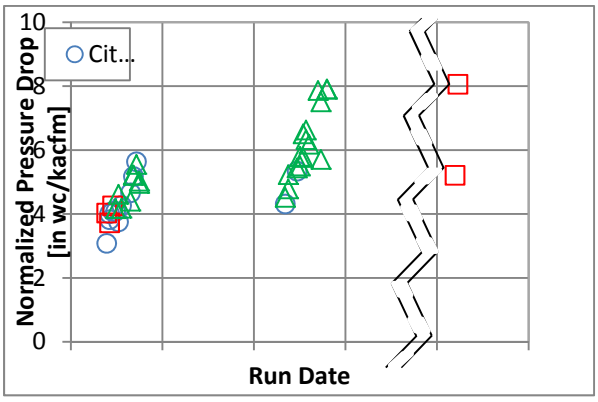

Figure 12. Baghouse pressure drop versus time

There are two reasons for the increased baghouse pressure drop: elevated moisture levels and a concentrated particulate stream. During testing periods the exhaust gas moisture levels at the baghouse inlet increased to 10 to 15% by volume during daylight hours and returned to the more typical 5% at night when the unit was kept warm with Buell outlet gas. Also contributing to the increased baghouse pressure drop was a higher than normal particulate loading. The baghouse saw 10% of the flue gas flow while experiencing 60% of the largest particle fraction of total flue gas particulate.

In the full scale application the spray dryer flue gas would be diluted by the main flue gas stream. Moisture increase would not be a problem because the spray dryer stream would only compose 5% to10% of the total flue gas flow. Moisture levels in the main flue gas stream would only increase about 10%. The solids from the FGD spray drying process are also expected to be diluted in the main stream. The impact to the baghouse pressure drop could be less than what was observed in the pilot testing.

Since the continuous test lasted no more than 14 days, it is hard to draw a conclusion about the baghouse pressure drop in a long time run. In addition, it is not known to what extent the daily moisture and temperature cycling of the baghouse contributed to the rate of pressure drop increase.

SUMMARY

While further study is recommended, this pilot-level report indicates that a spray drying system is likely capable of evaporating FGD wastewater, leaving behind a solid waste. The modeling performed in this study suggests that an

operating unit can dry 200 gpm of 40,000 ppm Cl FGD wastewater to dryness, using around 0.95 million ACFM of flue gas at 620°F inlet temperature and 400°F outlet temperature. The spray dryer outlet temperature should be operated at higher than 375°F with the current design to completely dry the solids. Additional heat is not required to spray dry higher TDS FGD wastewater than lower TDS waters.

No mercury in the FGD wastewater was volatilized, and all the dissolved mercury precipitated to the solids. Mercury removals of 35% - 55% from the flue gas were achieved with both 20,000 ppm Cl simulated FGD wastewater and 40,000 ppm Cl simulated FGD wastewater. Activated carbon injection also appears to be a promising means of removing mercury in the flue gas in the spray drying system, with additional removals of 91%(5lb/hr), 46% (2 lb/hr), and 10% (0.5 lb/hr) observed.

An increase in baghouse normalized pressure drop was observed during a 14 day continuous operation of the spray drying system. The baghouse pressure drop nearly doubled during the continuous testing period. This condition is believed to be caused by the increased moisture content and a concentrated particulate stream. In full scale operation, these conditions are not expected to cause as significant issues as seen in the pilot test, but it is not clear whether these conditions will be.

Chlorides dissolved in the FGD wastewater were dried with 99% of the chlorides partitioning to the solid phase. There was an increase in gas phase HCl in the spray dryer exit gas. The presence of HCl can degrade fabric filters and cause blinding of the bags because of interactions with ash particles. Any HCl that is remitted from the sprayed FGD wastewater should be taken out by FGD scrubbing systems.

Future work should include studies on solids handling and landfilling of spray dryer solids. Impacts on baghouse performance during continuous operation, including pressure drop, fouling, and bag life require more study. Volatilization of trace metals, such as selenium, boron, etc, requires further study. Optimization of the droplet size to maximize the amount of FGD wastewater that can be dried is also an area that is not fully studied. In short, more study on varied systems is necessary to develop this spray drying system for routine commercial use.

REFERENCES

[1] Steam Electric Power GeneratinPoint Source Category: Final Detailed Study Report, EPA, Oct, 2009