Flue Gas Aerosol Pretreatment Technologies to Minimize PCC Solvent Losses

primary project goal

Linde Gas North America, LLC and their project partners evaluated three flue gas aerosol pretreatment technologies that have the potential to significantly reduce high flue gas aerosol concentrations, which have been shown to contribute to amine losses in solvent-based post-combustion carbon dioxide (CO_2) capture (PCC) processes. The objectives of this project were to design, build, and independently test these technologies at a coal-fired power plant host site using a slipstream of flue gas containing high concentrations of aerosol particles (greater than 10^7 particles/cm^3). The impact of this reduction in aerosol concentrations could be leveraged across a variety of solvent-based PCC systems to minimize solvent losses.

technical goals

- Perform a literature study to identify mechanisms that contribute to aerosol particle nucleation and growth in flue gas streams.
- Develop a model to simulate the mechanisms and assess the impact of aerosols on amine losses based on particle size distribution and particle number concentration.
- Complete basic engineering and design and provide cost estimates for the three aerosol pretreatment technologies selected for testing at the Abbott Power Plant.
- Fabricate, install, and commission the high-velocity water spray-based system, ESP system, and sorbent technology system at the host site.
- Perform independent parametric testing of each aerosol pretreatment technology, evaluate test results, and identify the optimum operating and design conditions for maximum performance of each technology.
- Compare test results against predefined targets and standard capabilities of conventional aerosol treatment methods described in literature and complete a techno-economic evaluation for each system to compare system costs at scale.
- Dismantle and remove pilot equipment from the host site.

technical content

Aerosol mitigation methods to reduce aerosol-driven amine losses include: (1) baghouse installation in the flue gas upstream of the PCC plant; (2) amine wash sections and wash section operating conditions for the PCC plant absorber; (3) specific absorber operating temperature and pressure conditions that can also negatively impact specific regeneration energy; and (4) flue gas aerosol pretreatment, which is the focus of the proposed technologies and testing.

Three options were evaluated in this project: (1) a novel high-velocity water spray concept previously tested at a Rheinisch-Westfälische Elektrizitätswerk (RWE) power plant in Niederaussem, Germany; (2) an innovative electrostatic precipitator (ESP) with optimized operating conditions; and (3) a non-regenerative sorbent-

program area:
Point Source Carbon Capture

ending scale:
Small Pilot

application:
Post-Combustion Power Generation PSC

key technology:
Solvents

project focus:
Flue Gas Aerosol Pretreatment

participant:
Linde Gas North America, LLC

project number:
FE0031592

predecessor projects:
N/A

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start date:
06.01.2018

percent complete:
100%

based sulfur oxide (SO_X) and nitrogen oxide (NO_X) removal technology with potential for aerosol particle reduction.

Figure 1 shows the range of upstream flue gas aerosol particle number concentrations able to be managed by current methods used today to achieve less than 0.3 kg amine emitted per tonne of CO_2 captured for solvent-based PCC processes. For power plants without baghouses producing flue gas containing particle concentrations greater than 10^7 particles/cm^3, the only realistic option available to mitigate aerosol-driven amine losses from PCC plants is flue gas aerosol pretreatment. Flue gas aerosol pretreatment has traditionally been performed using simple ESPs and Brownian filters, but no systematic study has been performed to evaluate the performance of these systems over the complete range of possible operating conditions, aerosol particle number concentrations, and aerosol particle sizes. It is important to note that even with lower flue gas aerosol number concentrations (fewer than 10^7 particles/cm^3), there is still a sizeable benefit to using pretreatment systems to minimize amine losses for the entire range of solvent-based PCC operating conditions. Hence, this project focused on evaluation of flue gas aerosol pretreatment solutions to determine an optimum technology that can minimize aerosol-driven amine losses for any power plant, including plants producing flue gas with the highest range of possible flue gas aerosol concentrations and size distributions. Based on previous 1.5-megawatt-electric (MWe) pilot-scale tests of the Linde-BASF PCC technology at the National Carbon Capture Center (NCCC) in Wilsonville, Alabama, from 2015–2016, high aerosol concentrations in the size range of 70–200 nm contributed most significantly to amine losses. Hence, this technology development project targeted high removal efficiency for particles in and around this size range. Additionally, previous aerosol number concentration measurements performed at the Abbott Power Plant host site, a power generating unit without a baghouse, showed the presence of very high aerosol concentrations (greater than 10^7 particles/cm^3). The ability to apply pretreatment technologies on the wide range of aerosol concentrations measured at Abbott will enable demonstration of the performance of each technology as applied at most coal-fired power plants in the world based on aerosol measurement data collated from scientific literature.

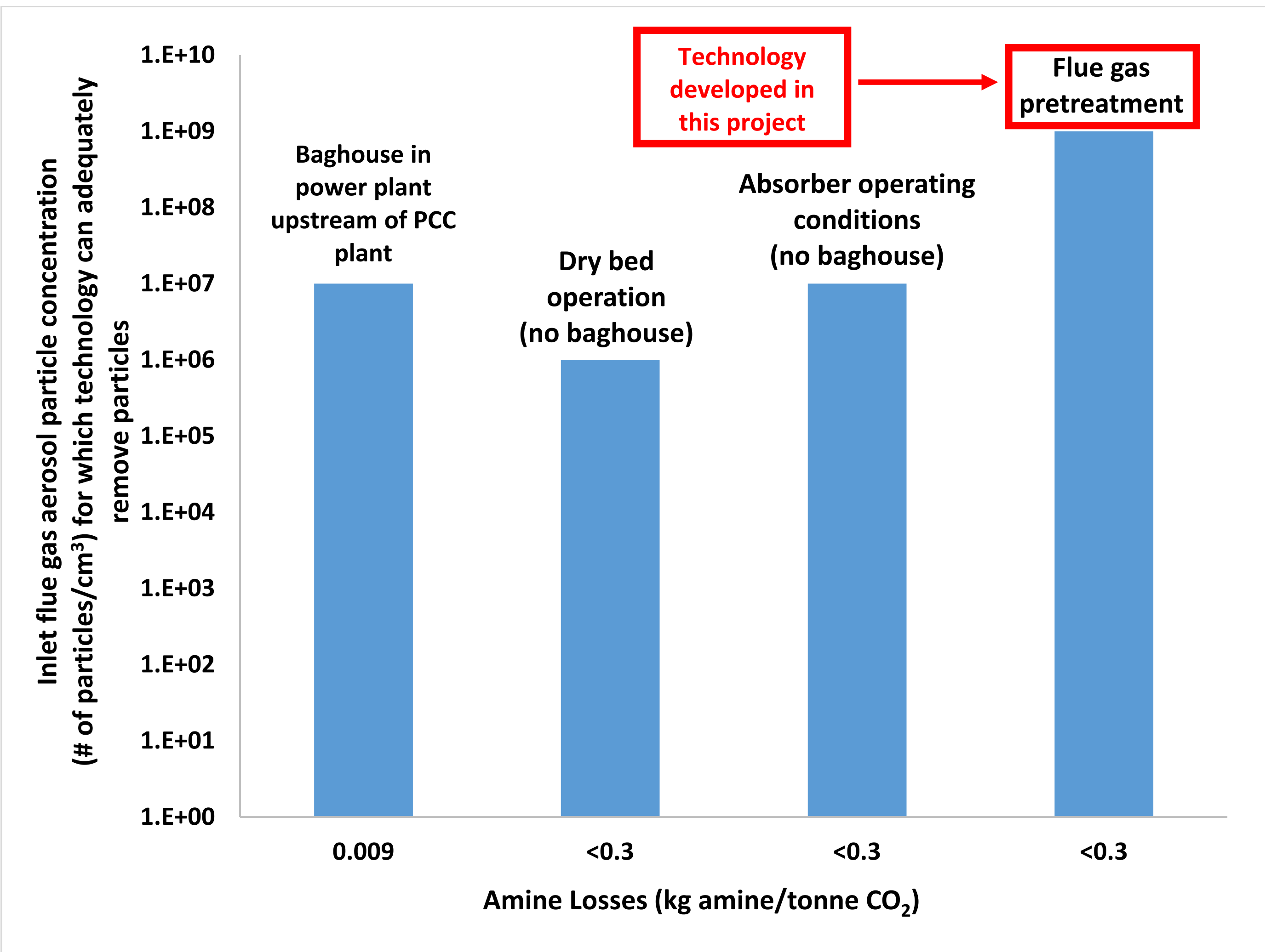

Figure 1: Flue gas aerosol particle number concentration ranges for which aerosol mitigation technologies are applicable and sufficient.

The first aerosol pretreatment technology tested in this work was a novel high-velocity water spray-based system originally developed by RWE and previously tested by RWE in Niederaussem, Germany. A process flow diagram of this system is shown in Figure 2. The high-velocity water spray provided by the specialized nozzle distributor design enables rapid growth and collection of aerosol particles in the liquid phase through water condensation before further removal by the demister at the top of the spray column. In addition, the perforated tray at the midsection of the column optimizes vapor-liquid distribution to enhance aerosol removal. Aerosol particles collected in the liquid phase are discharged in the process condensate removed from the column, effectively removing the aerosols from the treated flue gas exiting the top of the vessel. The project team has designed, constructed, and tested the water spray-based system on up to 1,000 standard cubic feet per minute (scfm) of actual flue gas emitted from two coal-fired boilers at the Abbott Power Plant host site. Parametric tests have been performed evaluating the impact of specific spray nozzle and perforated tray designs and operating conditions to determine the optimal system configuration and design conditions maximizing aerosol particle removal efficiency for very high flue gas particle concentrations (up to and greater than 10^7 particles/cm^3) for aerosol particles in the 70–200 nm diameter size range.

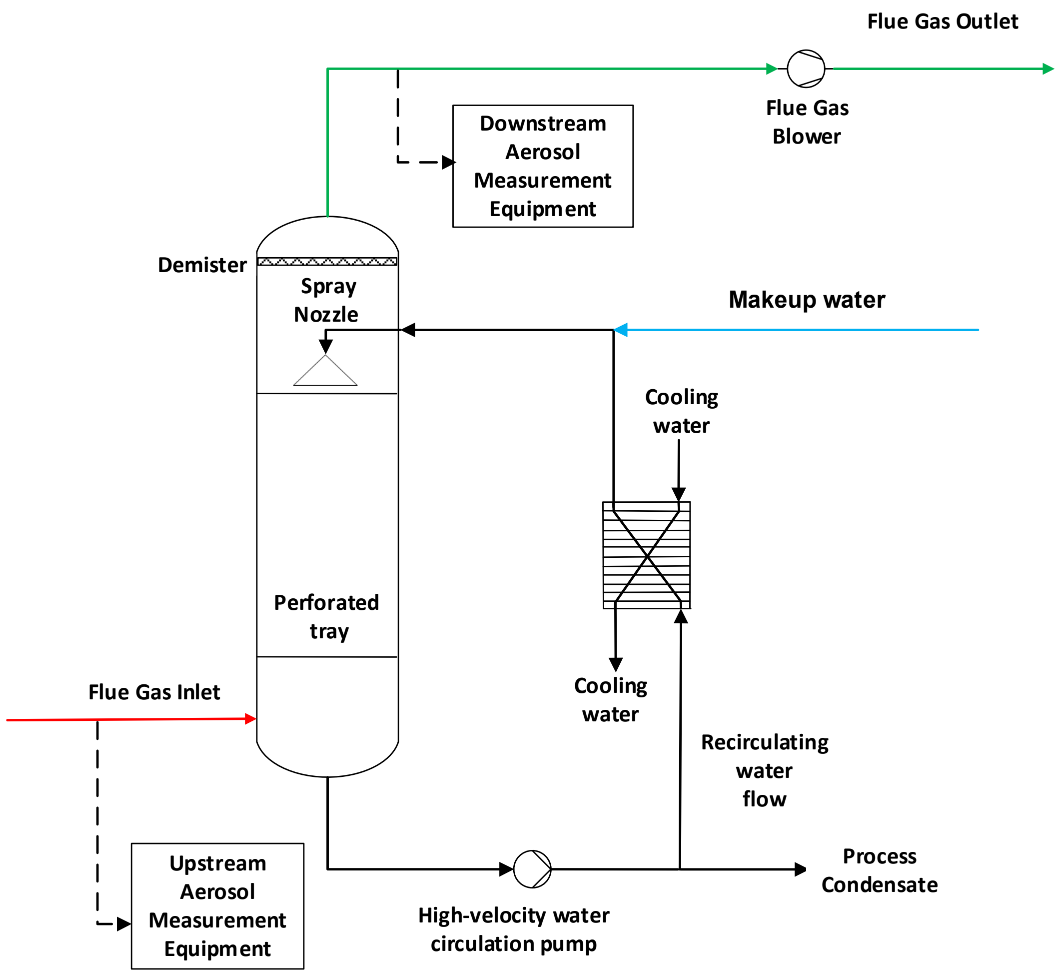

Figure 2: Process flow diagram of high-velocity water spray-based aerosol pretreatment system.

The second aerosol pretreatment technology tested in this project was an advanced ESP system developed by Washington University in St. Louis (WUSTL) that incorporated a patented photo-ionizer technology to enhance aerosol removal efficiency. The ESP functions by applying a high voltage between a plate and a wire. This voltage ionizes aerosol particles in the entering flue gas. Due to electrostatic force, ionized particles are diverted from the gas towards collecting plates, removing them from the gas. The specific collection area (SCA) of an ESP was the most important design parameter in terms of achieving required aerosol removal efficiency. A typical SCA for an ESP capable of obtaining 98–99% removal efficiency for 1,000 scfm gas flow is approximately 95 $m^2/(m^3/s)$; the area can be increased further to remove particles in the range of 10–500 nm at very high efficiencies. The pilot-scale ESP system will be tested to remove aerosol particles from flue gas at a capacity of 500 scfm. The photo-ionizer device is expected to greatly enhance the capture efficiency of nano-sized particles. In full-scale applications, the photo-ionizer developed by WUSTL can be retrofitted to existing ESPs at commercial power plants, reducing the capital costs of implementation.

A process flow diagram of the WUSTL ESP is shown in Figure 3. Specific ESP voltages may increase particle concentrations for certain particle sizes due to secondary aerosol generation inside the ESP from nucleation of water-sulfuric acid (H_2O-H_2SO_4) aerosols when sulfur dioxide (SO_2) present in the flue gas is oxidized. Hence, the ESP voltage needs to be carefully optimized during pilot tests. This project will determine the optimum design and operating conditions for the ESP system to treat flue gas with high aerosol concentrations. Through parametric testing, the performance of the advanced ESP was compared against predefined aerosol removal efficiency targets. In addition, the costs to incorporate the ESP technology upstream of a PCC plant was assessed.

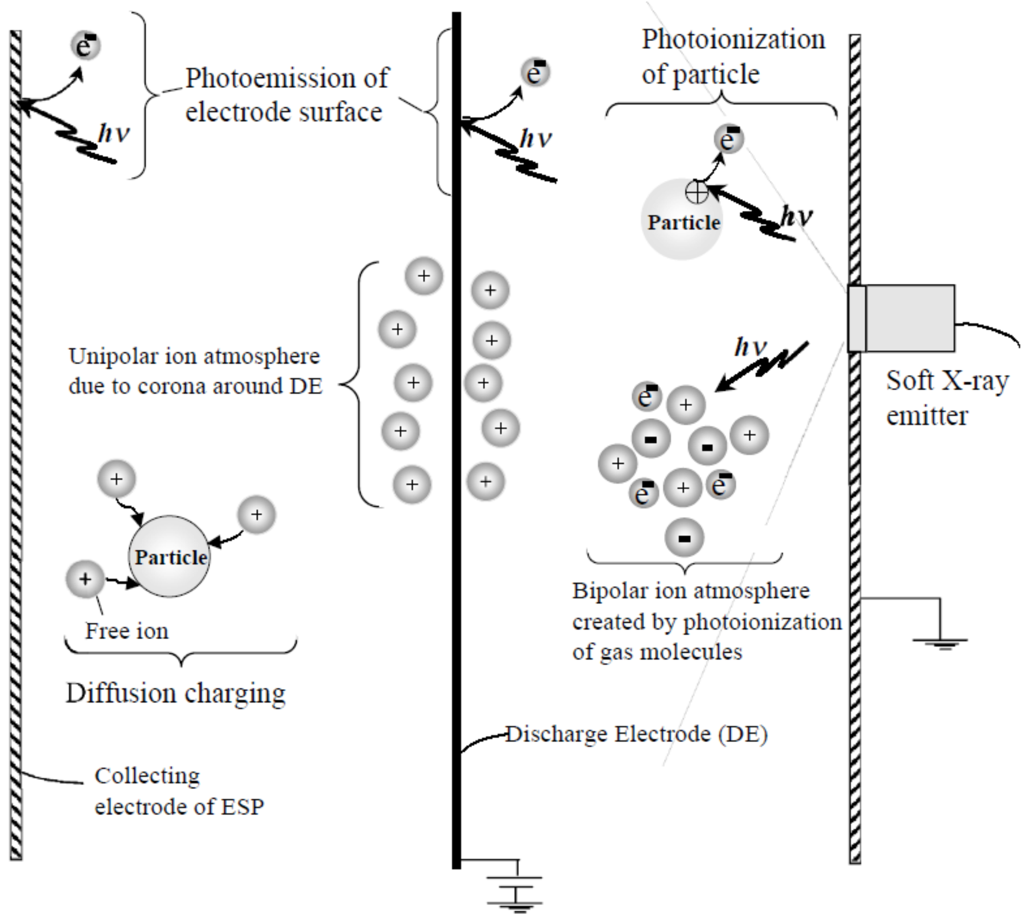

Figure 3: Conceptual flow diagram of the advanced ESP system developed by WUSTL.

The third technology tested in this project was a non-regenerative sorbent filter system developed by InnoSepra LLC. It has been proven to remove residual sulfur trioxide (SO_3), SO_2, nitrogen dioxide (NO_2), hydrogen chloride (HCl), and hydrogen fluoride (HF) from flue gas after the power plant flue gas desulfurization (FGD) unit to limit the detrimental impact of PCC solvent components reacting with flue gas contaminants. In addition to contaminant removal, the aerosol removal efficiency of the InnoSepra sorbent filter technology was evaluated as a potential means to limit aerosol-driven amine losses. A process flow diagram of the InnoSepra sorbent-based filter technology is depicted in Figure 4.

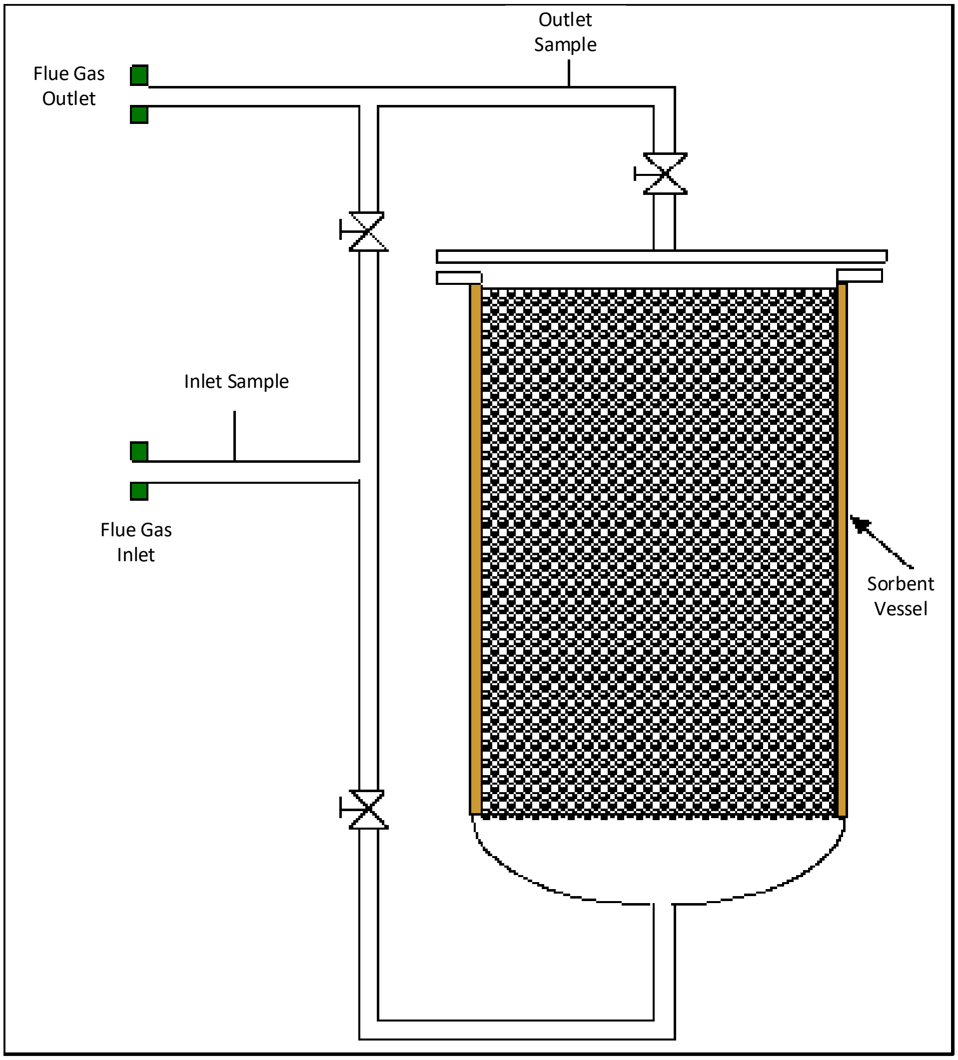

Figure 4: Process flow diagram of the InnoSepra sorbent-based filter technology.

The host site chosen for the testing was the University of Illinois' Abbott Power Plant located in Champaign, Illinois. As shown in Figure 5, Abbott's own ESPs and a wet jet bubbling FGD scrubber are used to remove some SO_2 and large particulate matter from the flue gas. The pilot testing withdraws the flue gas from the outlet of the reheat burner at the flue gas stack and returns it downstream, as Figure 5 depicts. Abbott flue gas composition, temperature, and pressure at the inlet to the aerosol pretreatment units are listed in Table 1 (based on data collected when two out of three boilers are in operation). Each technology will be built in modules and installed at the Abbott site connected to common flue gas inlet and outlet piping.

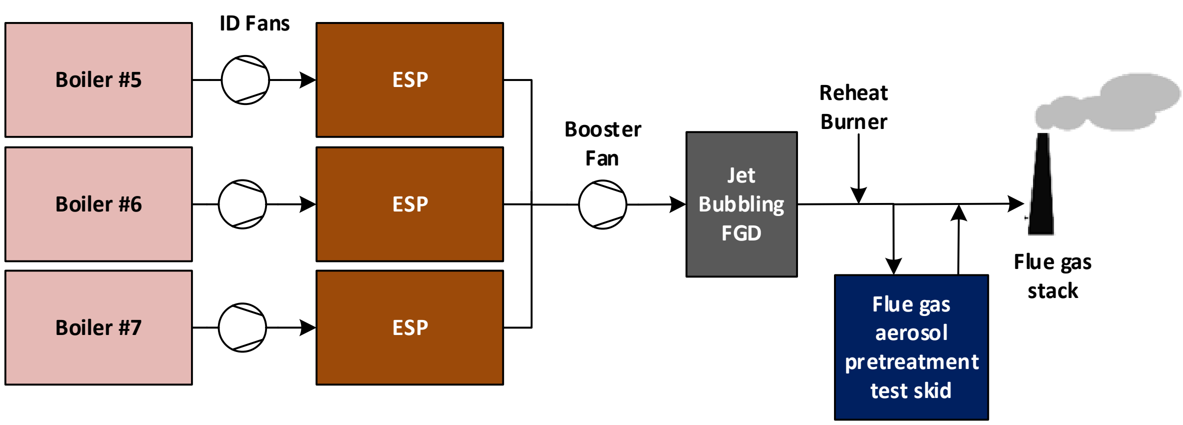

Figure 5: Abbott Power Plant layout and connection to flue gas aerosol pretreatment test skid.

TABLE 1: ABBOTT FLUE GAS PROPERTIES

Parameter	Unit	Value
Temperature	°F	200
Pressure	psig	0.75
Gas composition		
H_2O	vol%	19.2
CO_2	vol %, dry	9.2
O_2	vol%, dry	7.35
SO_2	ppmv, wet	177
NO_X	ppmv, wet	211

Preliminary performance targets for the three flue gas aerosol pretreatment systems are listed in Table 2. Cost competitiveness and environmental sustainability targets were based on scaled-up commercial versions of each technology for performance comparison with the U.S. Department of Energy's (DOE) National Energy Technology (NETL) Case B12B reference excluding baghouse capital and operating costs. From an allotted test period of eight weeks, four consecutive weeks of parametric testing were planned for the water spray-based system, two consecutive weeks of testing were planned for the ESP system, and one to two weeks of testing were planned for the InnoSepra sorbent filter system. Each technology underwent parametric testing to examine their impact on particle removal efficiency, overall capital and operating costs, and environmental sustainability performance.

TABLE 2: PRELIMINARY PERFORMANCE TARGETS FOR AEROSOL PRETREATMENT TECHNOLOGIES TESTED AT ABBOTT

Performance Parameter	Target for High-Velocity Water Spray Aerosol Pretreatment Technology	Target for ESP-Based Aerosol Pretreatment Technology	Target for InnoSepra Filter Aerosol Pretreatment Technology
Particle removal efficiency (%)[1] for 500–1,000 scfm flue gas slipstream	>98% for aerosol particles 70–200 nm in diameter		
Cost of Electricity[2]	<$133.20/MWh		
Cost of CO_2 Captured[3]	<$58/tonne CO_2		
Energy consumption	<14 MWe		
Environmental sustainability[4]	process condensate adequately removed and treated	ESP solids adequately removed	sorbent material inventory safely managed

Definitions:

STP – Standard temperature and pressure (15°C, 1 atmosphere [atm]).

Flue Gas Assumptions – Unless noted, flue gas pressure, temperature, and composition leaving the FGD unit (wet basis) should be assumed as:

[1] (# of particles/cm^3 before aerosol treatment - # of particles/cm^3 after aerosol treatment) / (# of particles/cm^3 before aerosol treatment)

[2] when integrated with PCC technology for 550-MWe pulverized coal supercritical power plant without a baghouse

[3] when compared to DOE-NETL Case B12B without a baghouse

[4] when integrated with PCC technology for 550-MWe pulverized coal supercritical power plant without a baghouse

Pressure	Temperature	Composition						
		vol%, wet					ppmv, wet	
psia	°F	CO_2	H_2O	N_2	O_2	Ar	SO_X	NO_X
15.45	200	7.4	19.2	66.6	5.9	0.80	200	211

Other Parameter Descriptions:

Flue Gas Pretreatment Requirements – The proposed work will provide as a test option effective flue gas SO_X and NO_X removal achieved using the already pilot-validated, low-cost, high-capacity, non-regenerative InnoSepra sorbent material installed in a packed bed upstream of the test skid. In addition to the physical effects of the sorbent bed on aerosol removal, the InnoSepra sorbent can improve aerosol reduction performance by reducing nucleation of H_2SO_4 aerosols in the flue gas by minimizing its SO_X content.

Waste Streams Generated – Acidic process condensate is generated by the high-velocity water spray-based system in a similar manner to how a direct contact cooler operates upstream of a solvent-based PCC plant. This condensate contained nitric acid (HNO_3) and H_2SO_4 from reaction of NO_X and SO_X in the flue gas with the circulated process water used in the spray column. This water was sent to Abbott's onsite water pretreatment facility where it was neutralized. The ESP plates collected a very small mass of solid particles during operation on coal-fired flue gas. The solids collected include metal oxides, dust, and other contaminants. These were easily removed from the plates and discarded in the power plant's gypsum pile. The InnoSepra sorbent material must be removed after use and sent to the vendor's processing facility to either be specially processed for reuse or discarded in an approved manner compliant with all waste management regulations.

Process Design Concept – See above.

technology advantages

- Mitigates a wide range of flue gas aerosol concentrations and size distributions, including very high concentrations (up to and above 10^7 particles/cm^3) in the 70–200 nm particle size range.
- Reduced solvent makeup requirements lower operating expenditures for solvent-based PCC processes, enhance PCC performance in terms of energy consumption, reduce the need for solvent reclamation units, and improve solvent inventory logistics for full-scale operations.
- Reduced solvent emissions to the environment and aerosol contaminant exposure to personnel and environment.
- Smaller process footprint, more cost-effective, flexible operation, and higher aerosol removal efficiency compared to installing a baghouse at a coal-fired power plant.

R&D challenges

- Waste management.
- Effects of variability in flue gas composition, temperature, and pressure, as well as power plant load changes on aerosol measurements.
- Material compatibility with corrosive flue gas contaminants.

status

A comprehensive summary of the results from the aerosol-driven amine loss mechanisms study and modeling effort, as well as the environmental health and safety (EHS) analysis, were completed. Basic and detailed engineering for the Linde spray-based system, ESP-based system, and InnoSepra filter system were completed by Affiliated Construction Services (ACS), WUSTL, and InnoSepra, respectively. All pilot equipment procurement and fabrication activities were completed, and all pilot system components were delivered to the Abbott site and installed on a concrete pad. Pilot system commissioning and test-readiness checks were completed.

Pilot tests have shown that the RWE high-velocity water spray tower technology can achieve 85–90% aerosol removal efficiency within the 70–200 nm size range of interest for mitigating aerosol-driven amine losses from solvent-based PCC plant. The WUSTL ESP technology demonstrated removal efficiencies up to 80% at the highest voltage tested, but the

ESP field tests were limited by the actual voltage that could be applied due to electrical arcing as a result of insufficient insulation. The InnoSepra sorbent filter was able to achieve greater than 99% SO_2 removal from the flue gas and aerosol removal efficiencies of 30–90% within the 70–200 nm size range.

available reports/technical papers/presentations

Bostick, D. "Flue Gas Aerosol Pretreatment Technologies to Minimize PCC Solvent Losses," Project Kickoff Meeting, Pittsburgh, PA, July 2018. *http://www.netl.doe.gov/projects/plp-download.aspx?id=10433&filename=Flue+Gas+Aerosol+Pretreatment+Technologies+to+Minimize+(PCC)+Solvent+Losses.pdf*.

Bostick, D. "Flue Gas Aerosol Pretreatment Technologies to Minimize PCC Solvent Losses," NETL CO_2 Capture Technology Project Review Meeting, Pittsburgh, PA, August 2018. *https://netl.doe.gov/sites/default/files/netl-file/D-Bostick-Linde-Flue-Gas-Aerosol-Pre-Treatment.pdf*.

Bostick, D. "Flue Gas Aerosol Pretreatment Technologies to Minimize Post-Combustion CO_2 Capture (PCC) Solvent Losses," Budget Period 1 Review Meeting, Pittsburgh, PA, January 2019. *http://www.netl.doe.gov/projects/plp-download.aspx?id=10440&filename=Flue+Gas+Aerosol+Pretreatment+Technologies+to+Minimize+Post-Combustion+CO2+Capture+(PCC)+Solvent+Losses.pdf*.

Bostick, D. "Flue Gas Aerosol Pretreatment Technologies to Minimize Post-Combustion CO_2 Capture (PCC) Solvent Losses," NETL CO_2 Capture Technology Project Review Meeting, Pittsburgh, PA, August 2019. *https://netl.doe.gov/sites/default/files/netl-file/D-Bostick-Linde-Aerosol-Pretreatment.pdf*.

Bostick, D. "Flue Gas Aerosol Pretreatment Technologies to Minimize Post-Combustion CO_2 Capture (PCC) Solvent Losses," BP2 Review Meeting, Pittsburgh, PA, November 2019. *http://www.netl.doe.gov/projects/plp-download.aspx?id=10438&filename=Flue+Gas+Aerosol+Pretreatment+Technologies+to+Minimize+Post-Combustion+CO2+Capture+(PCC)+Solvent+Losses.pdf*.

Devin Bostick, Krish Krishnamurthy, "Flue Gas Aerosol Pretreatment Technologies to Minimize Post-Combustion CO_2 Capture (PCC) Solvent Losses," NETL Project Review Meeting – Carbon Capture, Pittsburgh, PA, October 2020. *https://netl.doe.gov/sites/default/files/netl-file/20VPRCC_Bostick.pdf*.

Devin Bostick, "Flue Gas Aerosol Pretreatment Technologies to Minimize Post-Combustion CO_2 Capture (PCC) Solvent Losses," Final Project Presentation, Pittsburgh, PA, May 2021. *http://www.netl.doe.gov/projects/plp-download.aspx?id=10436&filename=Flue+Gas+Aerosol+Pretreatment+Technologies+to+Minimize+Post-Combustion+CO2+Capture+(PCC)+Solvent+Losses.pdf*.