Flue Gas Aerosol Pretreatment Technologies to Minimize Post-Combustion CO_2 Capture (PCC) Solvent Losses

DOE funding award DE-FE0031592

Devin Bostick & Krish Krishnamurthy

2020 NETL CO_2 Capture Technology Meeting

October 5, 2020

Making our world more productive

Acknowledgement and Disclaimer

Acknowledgement: This presentation is based on work supported by the Department of Energy under Award Number DE-FE0031592. We want to thank DOE-NETL for their sponsorship.

Project Overview

Objectives, Participants, Timeline & Funding

Making our world more productive

Project Objectives

Overall Objective

Demonstrate and evaluate two innovative flue gas aerosol pretreatment technologies identified to significantly reduce high aerosol particle concentrations (>10^7 particles/cm^3) in the 70-200 nm particle size range:

1) A high velocity water spray-based system[1] with unique design features
2) A novel electrostatic precipitator (ESP) device[2] with optimized design and operating conditions

In addition, a non-regenerative sorbent technology[3] for SO_x and NO_x removal developed by InnoSepra will be evaluated for its aerosol removal potential.

Specific Objectives

- Complete an aerosol mechanism literature review and develop a mechanistic model characterizing aerosol formation and interaction with amine solvent in the absorber of a PCC plant
- Design, build, install, commission, and operate technologies for flue gas aerosol pretreatment at a coal-fired power plant host site providing flue gas as a slipstream at a flow rate of 500-1000 scfm
- Complete parametric testing and analysis to demonstrate achievement of target performance
- Complete a benchmarking study to identify the optimal aerosol pretreatment system for commercial deployment and integration with solvent-based PCC technology

1. Developed by RWE
2. Developed by Washington University in St. Louis
3. Developed by InnoSepra

Project Team

Abbott Power Plant Host Site
- 2 operating coal-fired boilers
- 15 MWe output

PRIME CONTRACTOR
Linde Gas North America LLC
PI: Devin Bostick
- Prime contract
- Overall program management
- High velocity water spray-based aerosol pretreatment technology owner*

U.S. Department of Energy Sponsorship
Project Manager: Andy Aurelio

SUBAWARDEE
University of Illinois (UIUC)
Dr. Kevin O'Brien
- Aerosol mechanisms review
- Host site liaison
- Flue gas & liquid effluent analysis

SUBAWARDEE
Affiliated Construction Services (ACS)
Greg Larson
- Detailed engineering and procurement management for high-velocity water spray-based system and sorbent filter vessel
- Construction management for site modifications & module installation

SUBAWARDEE
Washington University in St. Louis (WUSTL)
Dr. Pratim Biswas
- Aerosol mechanisms modeling lead
- ESP pretreatment technology owner
- Aerosol particle characterization

SUBAWARDEE
InnoSepra
Dr. Ravi Jain
- Sorbent material validation tests
- Sorbent material procurement for pilot tests & test result analysis

*licensed from RWE

Project Timeline & Milestones

BP1: Design & Engineering
6/1/2018 - 2/28/2019

BP2: Procurement, Fabrication & Installation
3/1/2019 - 11/29/2019

BP3: Testing & Analysis
12/2/2019 - 5/31/2021

Task	ID	Milestone	Completion Date
1	A	Updated PMP	06/29/18
1	B	Kick-Off Meeting	07/27/18
2	C	Mechanisms review & modeling complete	10/31/18
3	D	Design & engineering complete	01/31/19
3	E	Test plan complete	01/31/19
4	F	Fabrication & procurement complete	08/26/19
5	G	Installation & commissioning complete	11/29/19
6	H	Parametric testing complete	5/1/20
7	I	Benchmarking analysis complete	05/31/21*
8	J	Removal of equipment complete	05/31/21*

*expected completion date

Technology Development

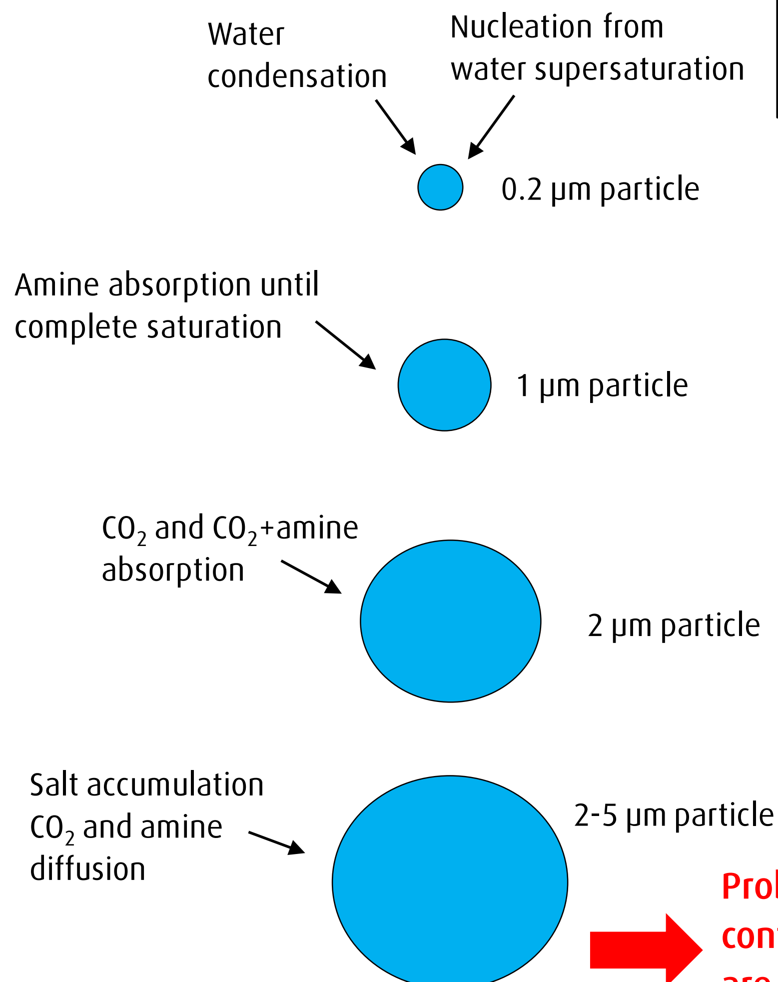
Rationale, Background & Previous Research

Making our world more productive

Aerosol particle interaction with amine solvent inside PCC absorbers → leads to solvent losses in treated gas

Linde

Phase I Aerosol growth and nucleation from water in absorber
Phase II Aerosol growth from amine in absorber
Phase III Buildup of captured CO_2 and amine bound to CO_2 in aerosols
Phase IV Salt accumulation inside particles causing further amine and CO_2 diffusion into aerosols

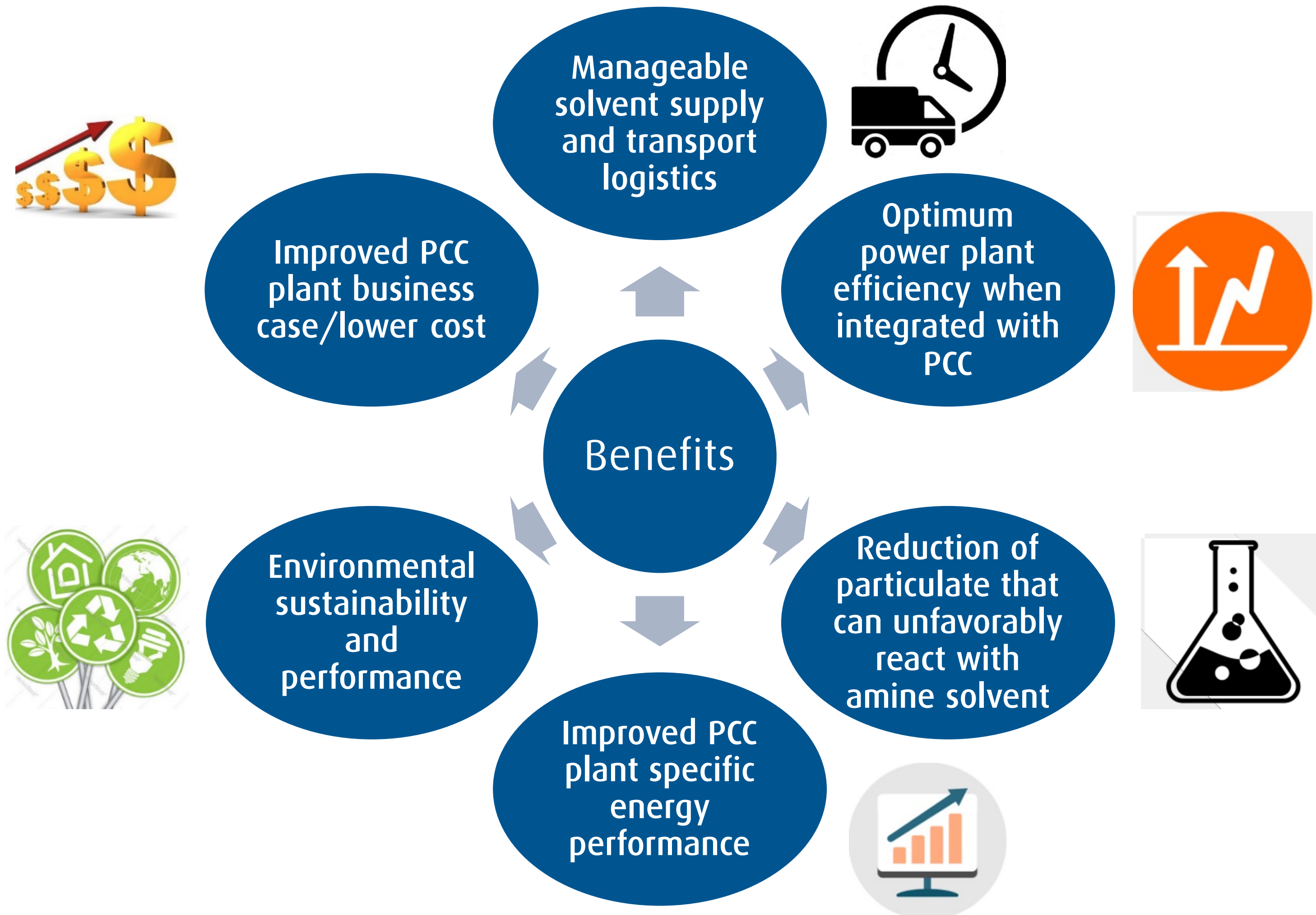


$$d^* = \frac{4\sigma M}{\rho RT \ln(p/p_0)}$$

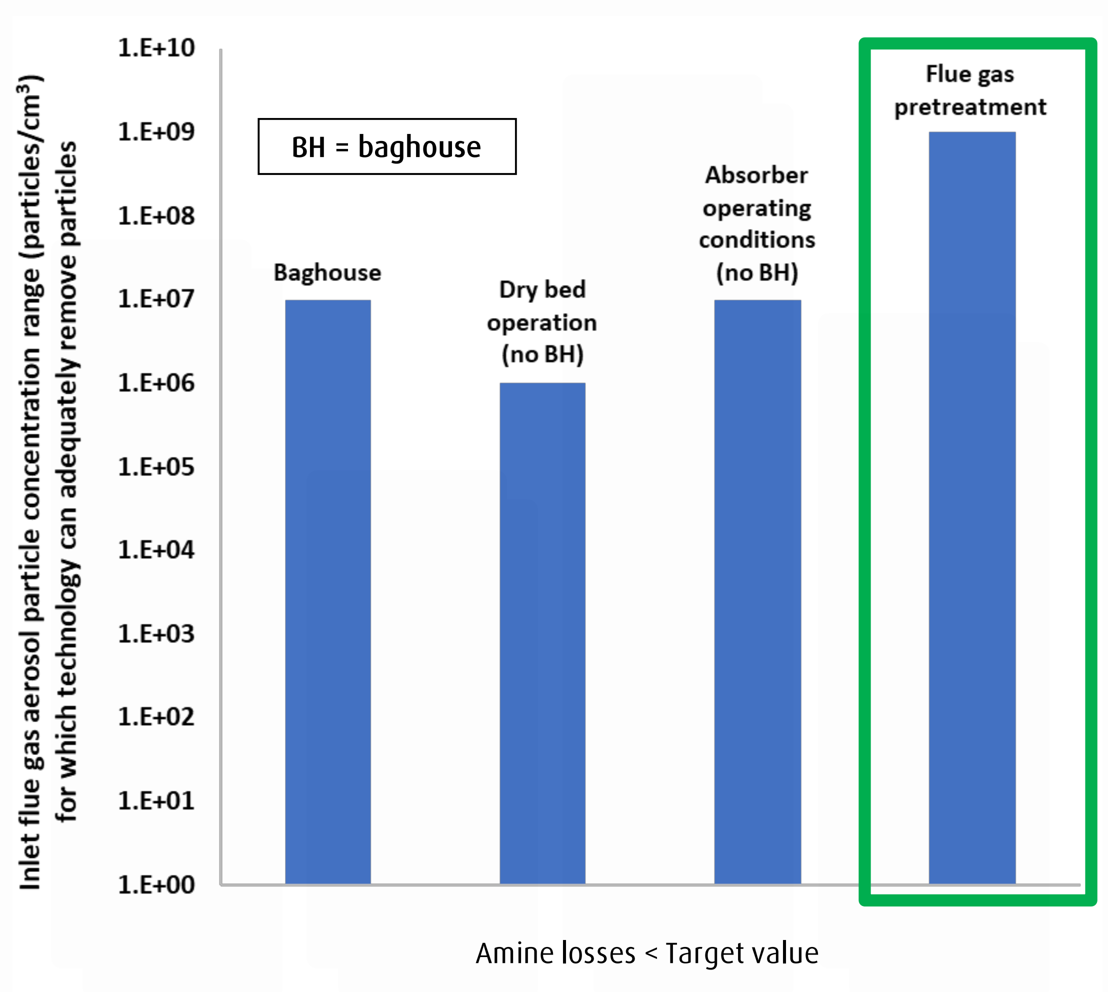
The Kelvin equation gives the minimum particle diameter, d*, of a liquid → supersaturation leads to nucleation of smaller particles

Problem: Amine compounds contained in aerosol particles are then emitted from PCC absorber in treated gas stream

Benefits of aerosol particle reduction upstream of PCC plant (pretreatment)



Methods to reduce aerosol-driven solvent losses: Flue gas aerosol pretreatment provides optimum solution[1]



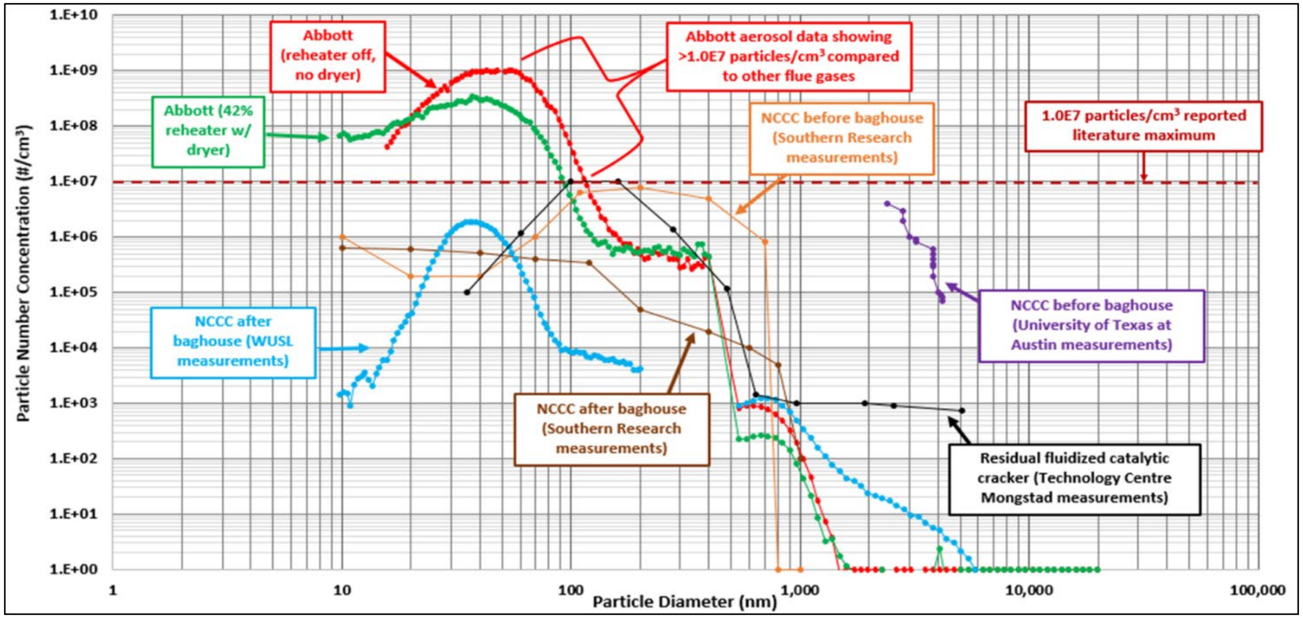
1. Based on single point experience, some options e.g. dry bed conf. may handle higher particle concentrations than others

- For power plants integrated with solvent-based PCC **without an existing baghouse**, optimized flue gas aerosol pretreatment is the only viable option to reduce aerosol concentrations from $>10^9$ particles/cm^3 to manageable levels near 10^4-10^6 particles/cm^3 for particles with diameters in the range of 70-200 nm.
- Pretreatment has traditionally been performed using simple ESPs and Brownian filters.
- Few systematic studies have been conducted to evaluate performance of different technologies over a full range of conditions.

Technical Approach

Making our world more productive

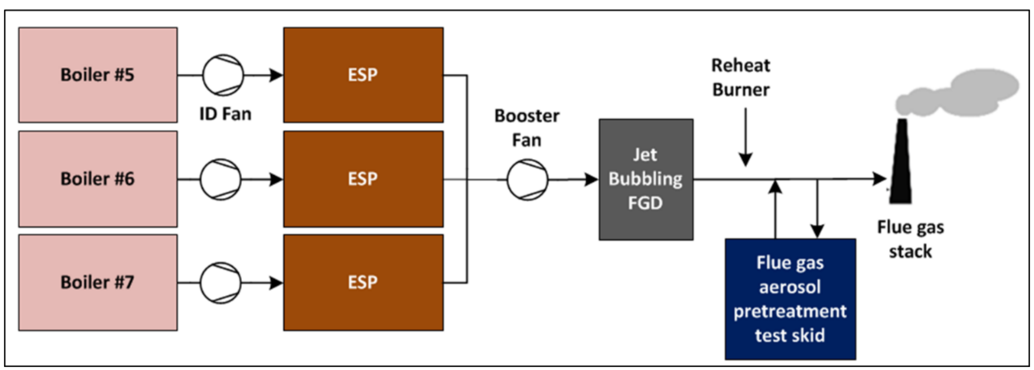
Pilot host site: Abbott Power Plant at UIUC in Champaign, IL



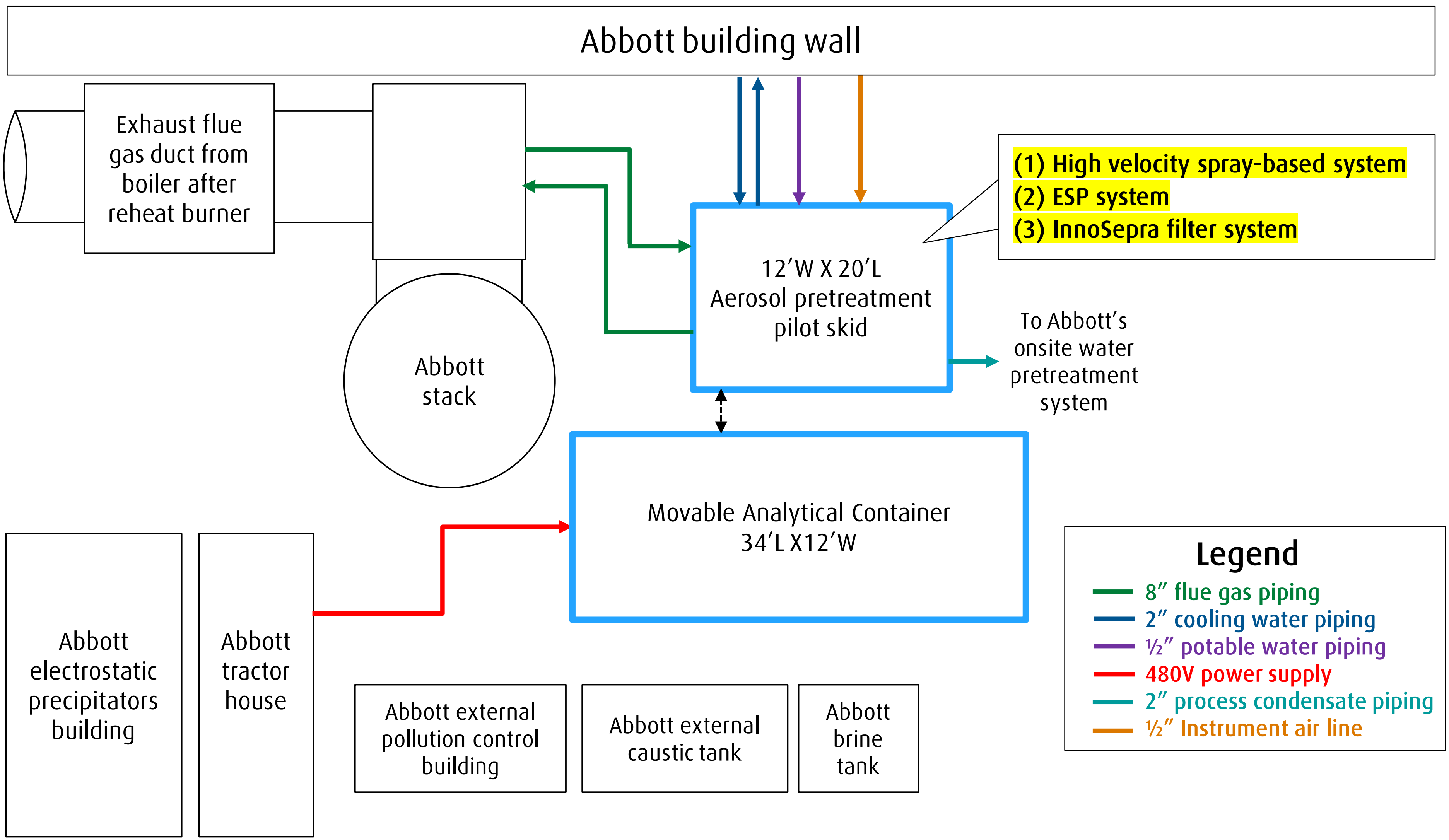
Abbott chosen as optimal host site for testing since aerosol concentrations were measured to be among the highest found in scientific literature

Abbott plant aerial view

Abbott plant schematic and tie-in points to pilot skid



Pilot skid layout at Abbott Host Site



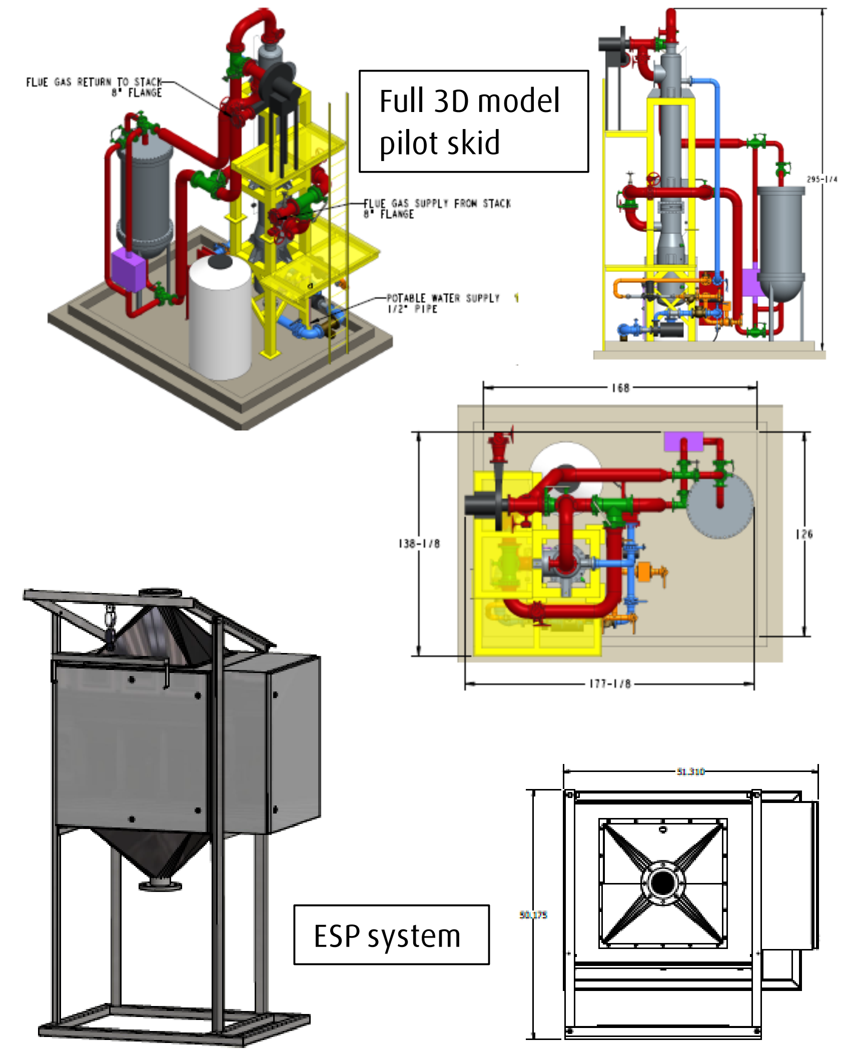
Progress and Current Project Status

Making our world more productive

Successful completion of design, engineering and cost estimate in Budget Period 1 (Jun 2018 – Feb 2019)

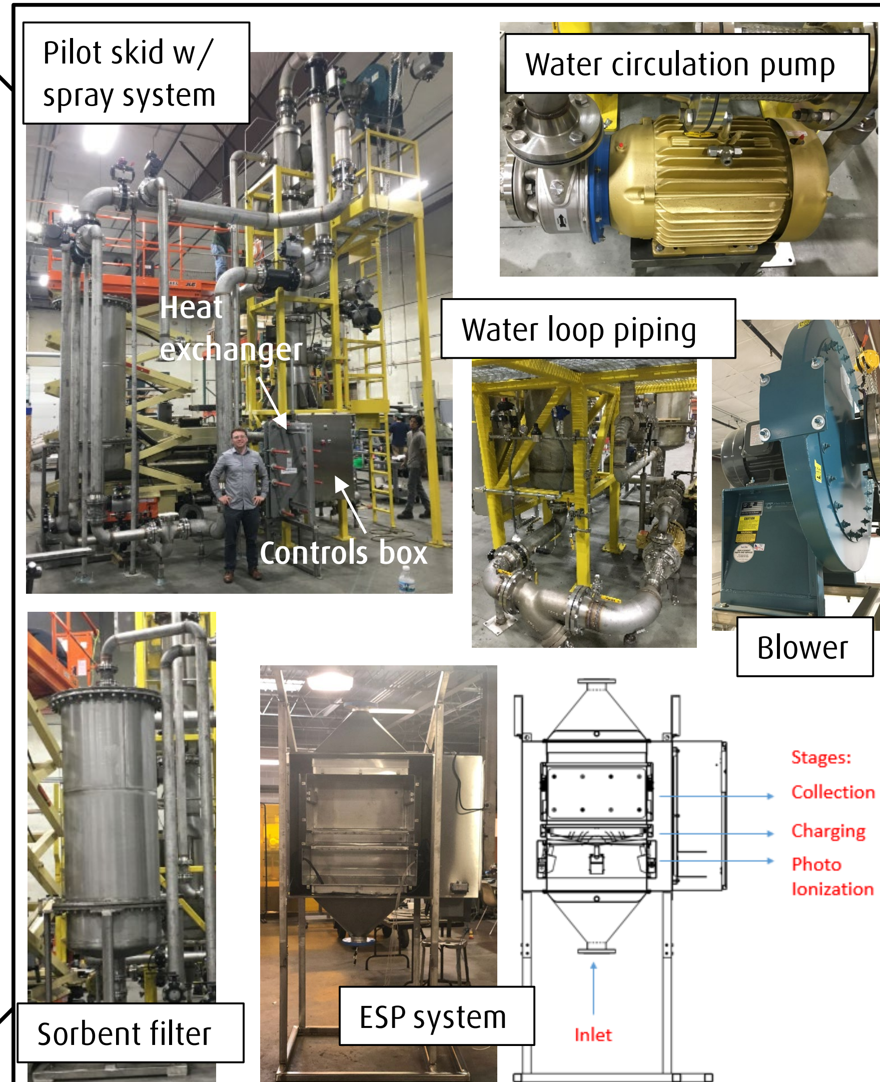
- Task 2: Review of aerosol-driven amine loss mechanisms for PCC plants
  - Review and modeling work completed, report submitted & presentation made to DOE-NETL
  - Pilot plant operating conditions informed from modeling study

- Task 3: Pilot plant design and engineering
  - Design basis completed with Abbott Power Plant (UIUC)
  - Basic design & engineering for spray-based system completed by Linde
  - Basic design & engineering for ESP system completed by WUSTL. Sorbent filter system designed by InnoSepra.
  - Detailed engineering completed:
    1) ACS: spray-based system & sorbent filter vessel
    2) WUSTL: ESP system
  - Hazard and operability study (HAZOP) completed with project team in Oct 2018 and host site in Dec 2018
  - Host site agreement executed in Jan 2019
  - Pilot plant cost estimation completed and budget updated



Successful completion of procurement & fabrication in Budget Period 2 (Mar 2019 – Nov 2019)

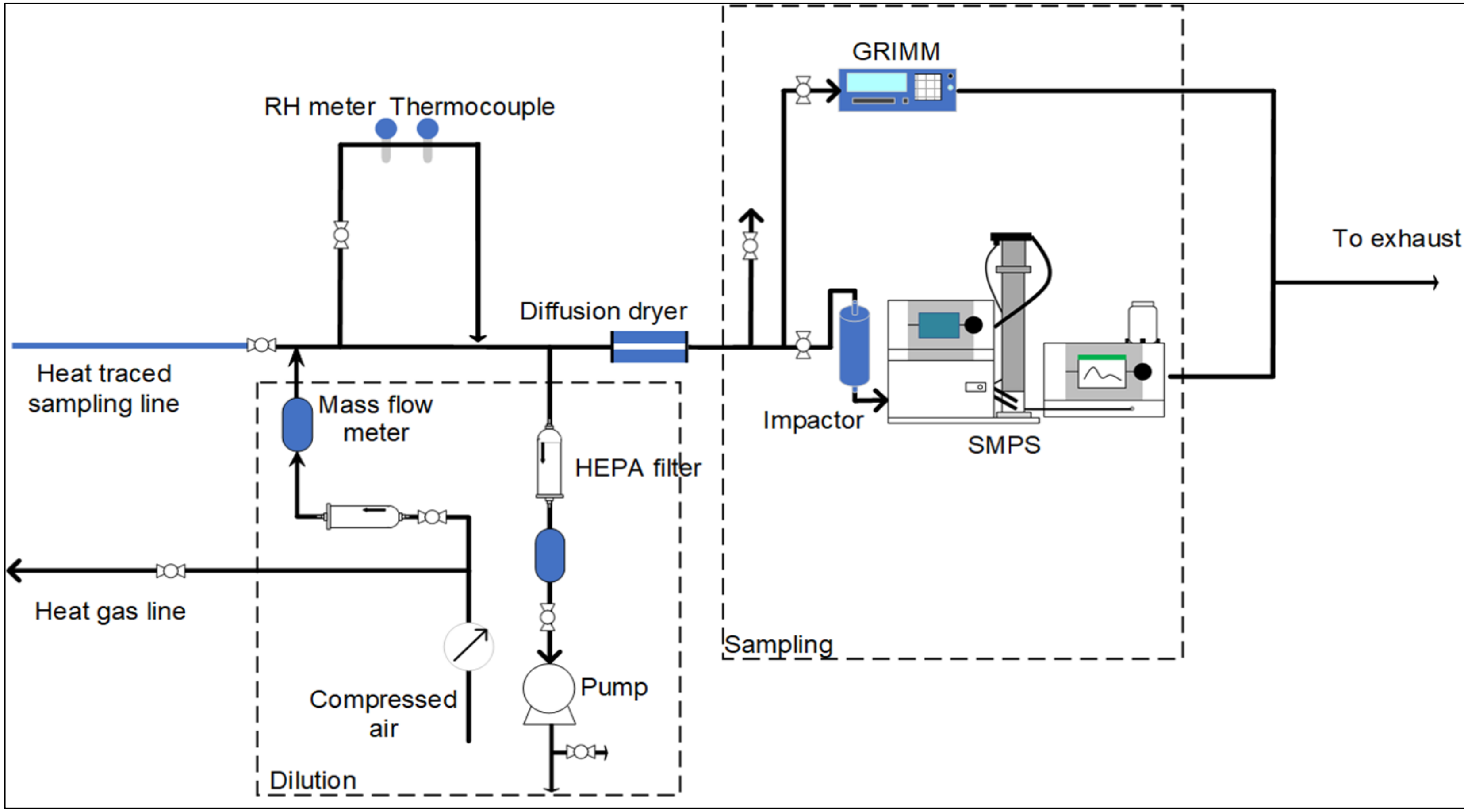
- Task 4: Pilot equipment procurement and fabrication
  - All inside battery limit (ISBL) pilot equipment & raw materials procured
  - Spray system, ESP system, and sorbent filter vessel fabrication complete. Spray tower system factory acceptance test will be completed by 8/30/19.
  - Local contractors selected for outside battery limit (OSBL) piping fabrication. OSBL piping installation to begin after module installation in September 2019.
  - Contract executed with local construction firm to install flue gas supply & return ports in Abbott plant duct; port fabrication work in progress
  - Aerosol measurement equipment and gas composition analysis system procured
  - Vendor packages prepared for shipment & installation at Abbott host site
  - Control logic and safety matrix developed based on HAZOP review and action items
  - Control system signals from ESP, InnoSepra filter, and gas analyzer rack incorporated into final design
- Task 5: Pilot plant installation planned to begin on 9/3/2019



Completed Pilot Skid

Completed Pilot Skid

Aerosol measurement equipment - WUSTL

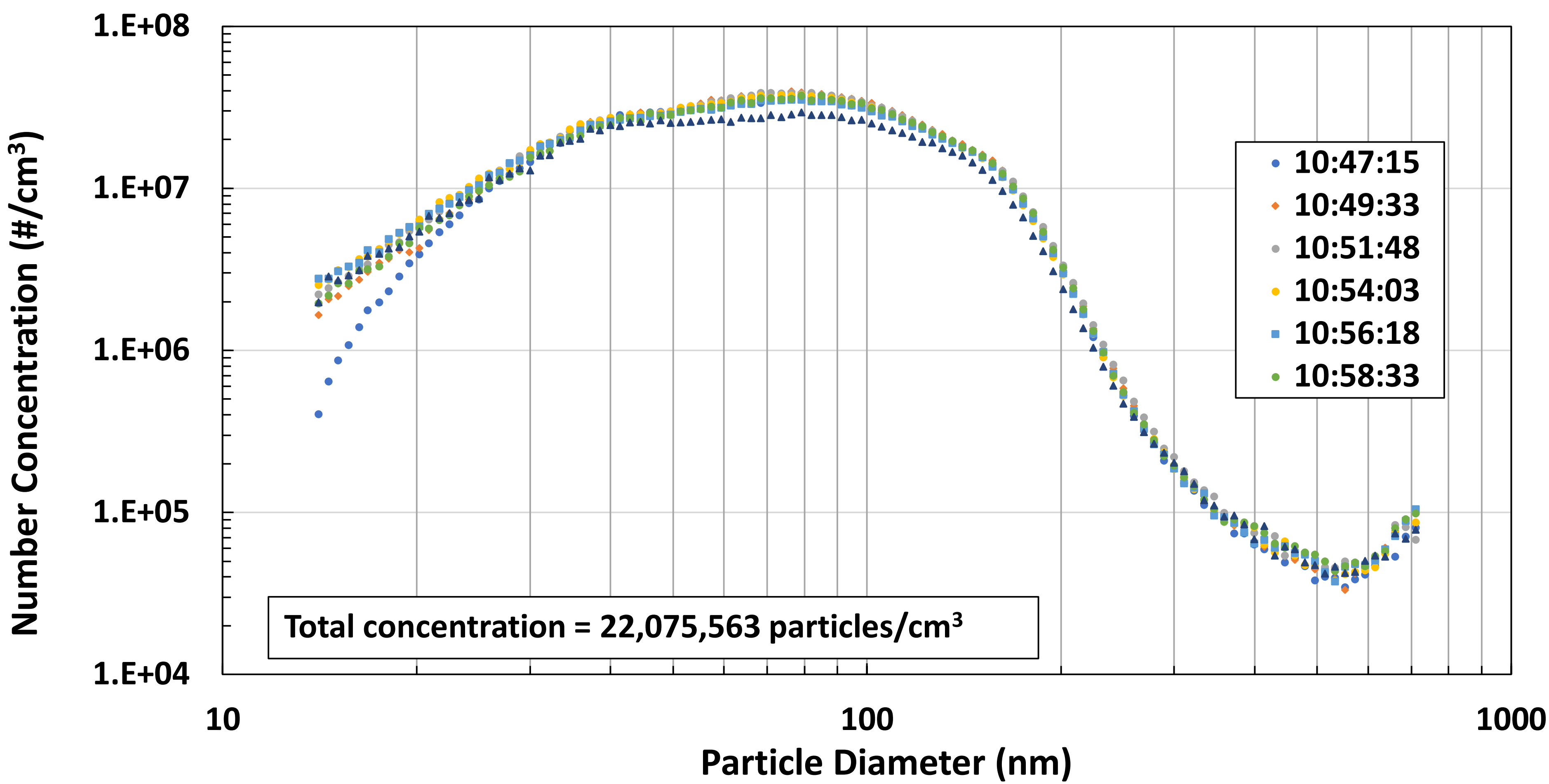


Technology Pilot Test Results

Making our world more productive

High Velocity Spray Tower Tests - January & February 2020

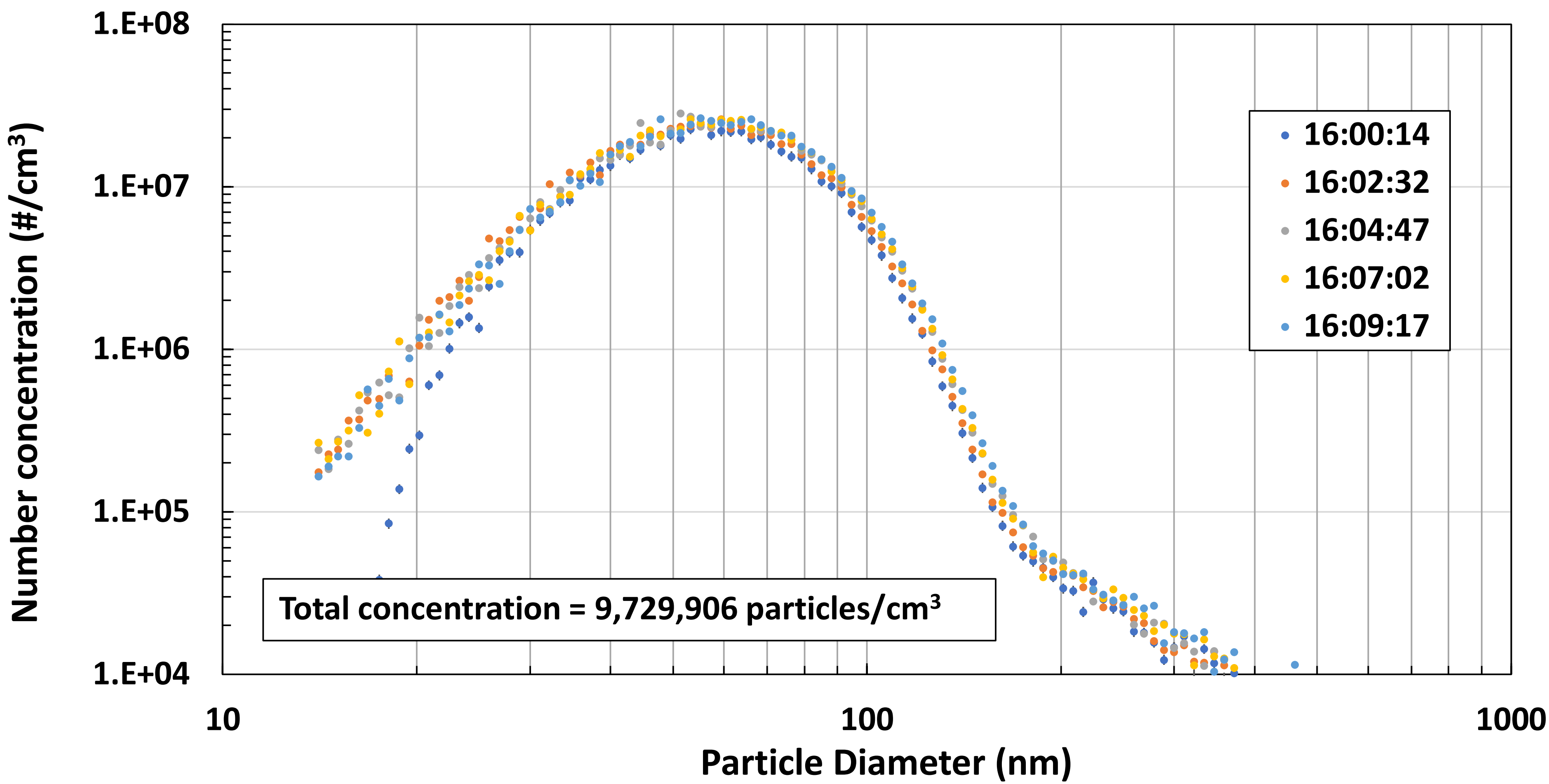
Supply Flue Gas Particle Size Distributions



Sample aerosol particle size distribution results as a function of time (date: 2/5/2020)
Two coal boilers: 187,000 lb/hr steam rate
1,000 scfm flue gas flow

High Velocity Spray Tower Tests - January & February 2020

Supply Flue Gas Particle Size Distributions



Sample aerosol particle size distribution results as a function of time (date: 1/30/2020)

One coal boiler: 96,000 lb/hr steam rate

1,000 scfm flue gas flow

High Velocity Spray Tower Aerosol Removal Performance Conditions

Design Features:

LPP: Large Hole Perforated Plate

MPP: Medium Hole Perforated Plate

N1: Water Spray Nozzle Type 1

N2: Water Spray Nozzle Type 2

Conditions:

Flue gas flowrate (0-1,000 scfm)

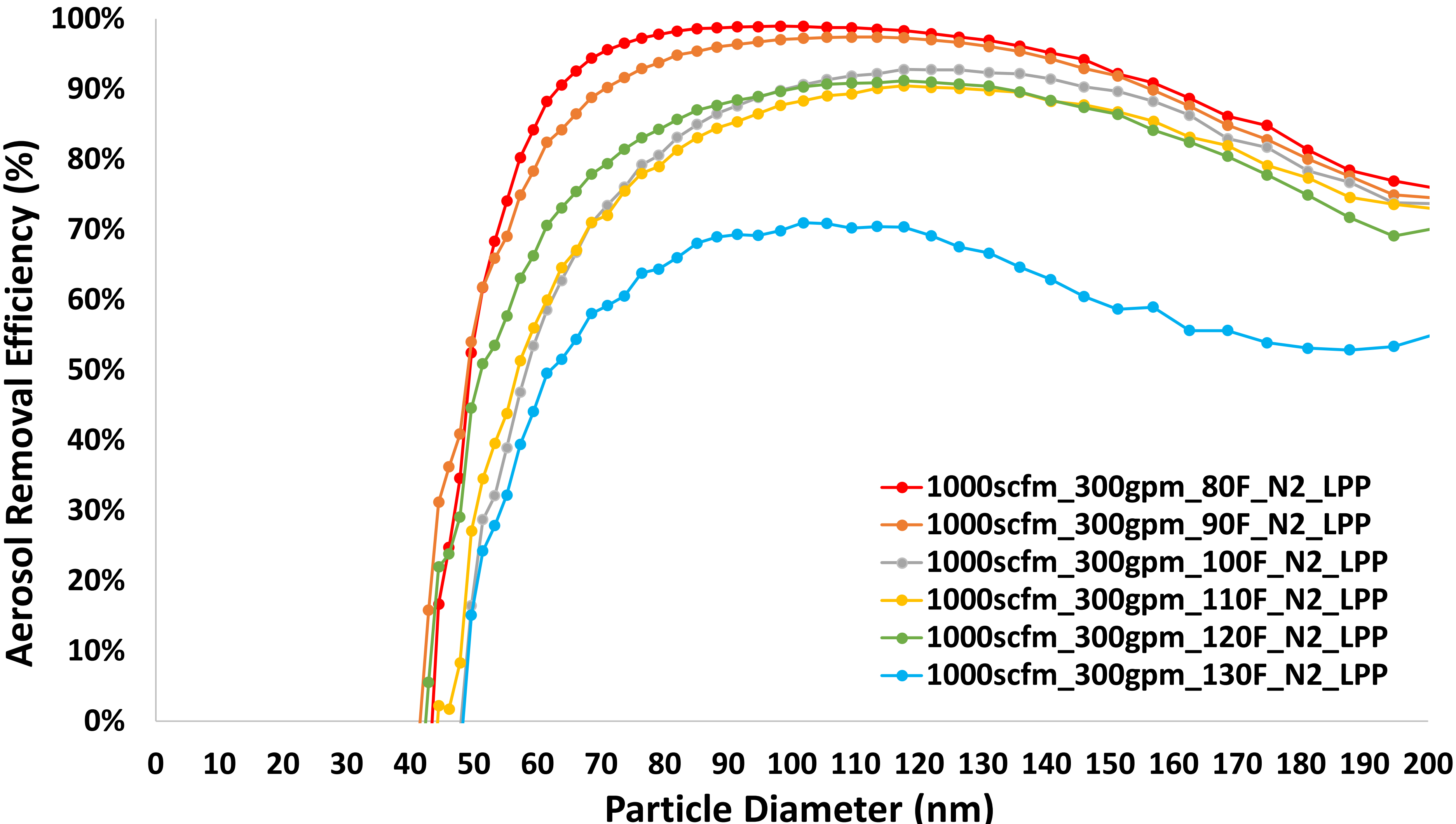
Water circulation rate (0-300 gpm)

Water circulation temperature (80-130°F)

Boiler Steam Rate: 93,000 lb/hr to 190,000 lb/hr

Tested from 1/14/20 through 2/19/20

High Velocity Spray Tower Aerosol Removal Performance Plots
Effect of Water Circulation Temperature (°F)
Nozzle 2, Large Perforated Plate

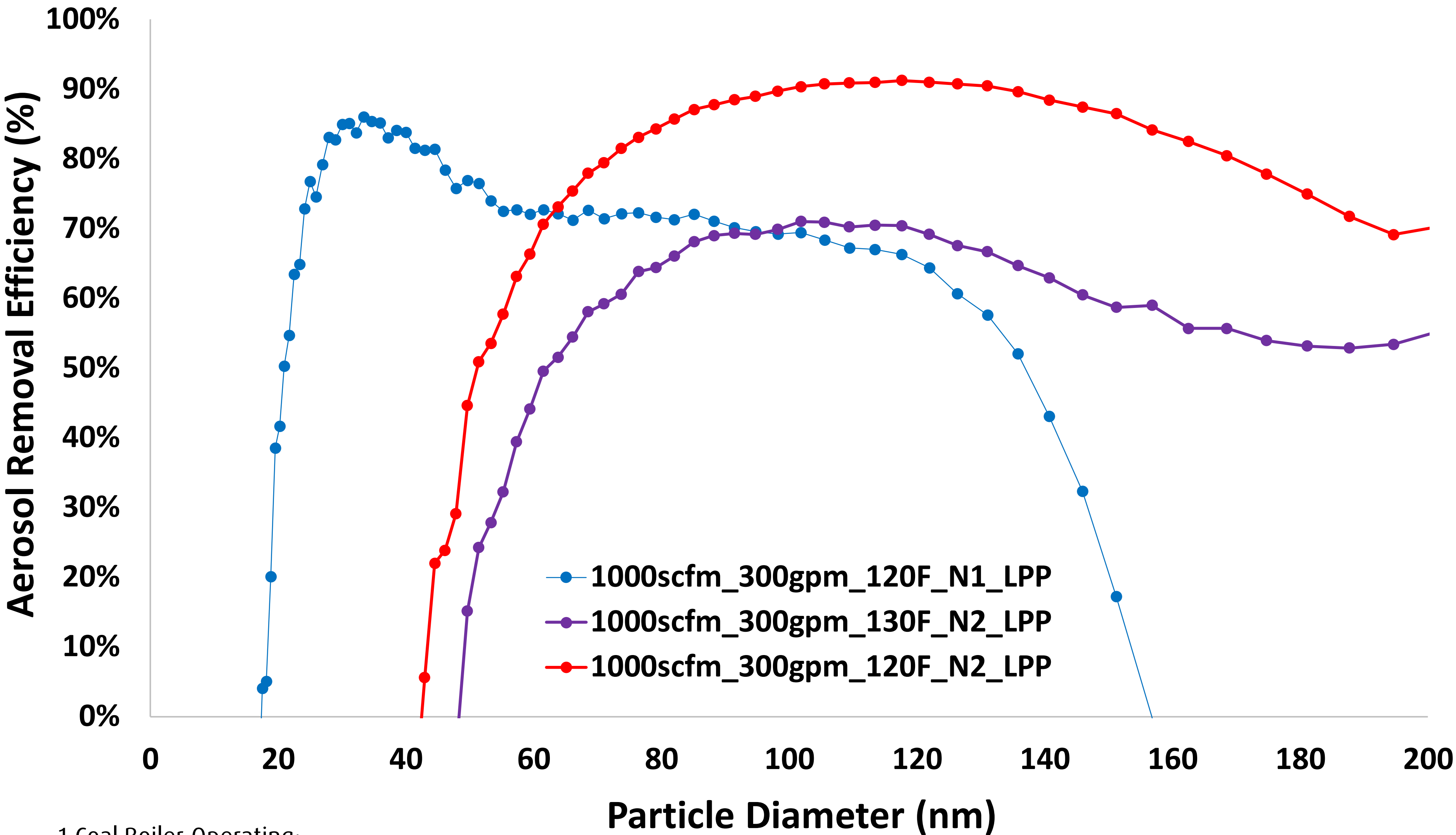


1 Coal Boiler Operating:
Coal Boiler Steam Rate: 96,000 lb/hr

High Velocity Spray Tower Aerosol Removal Performance Plots

Effect of Nozzle Type at Varying Temperature

120°F, 130°F (w/ Large Perforated Plate)

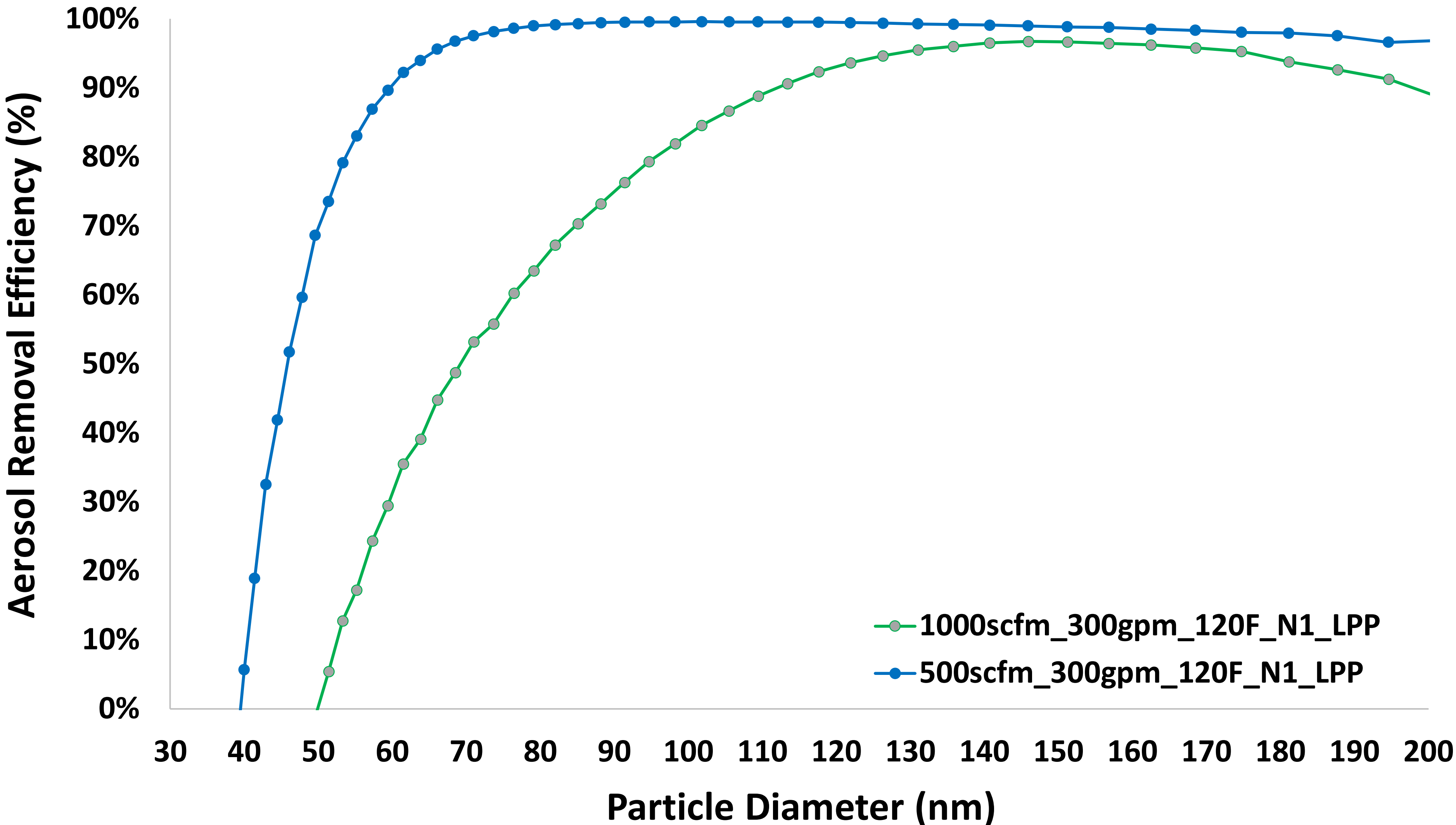


1 Coal Boiler Operating:
Coal Boiler Steam Rate: 96,000 lb/hr

High Velocity Spray Tower Aerosol Removal Performance Plots

Effect of Flue Gas Flowrate

Nozzle 1, Large Perforated Plate, 120°F



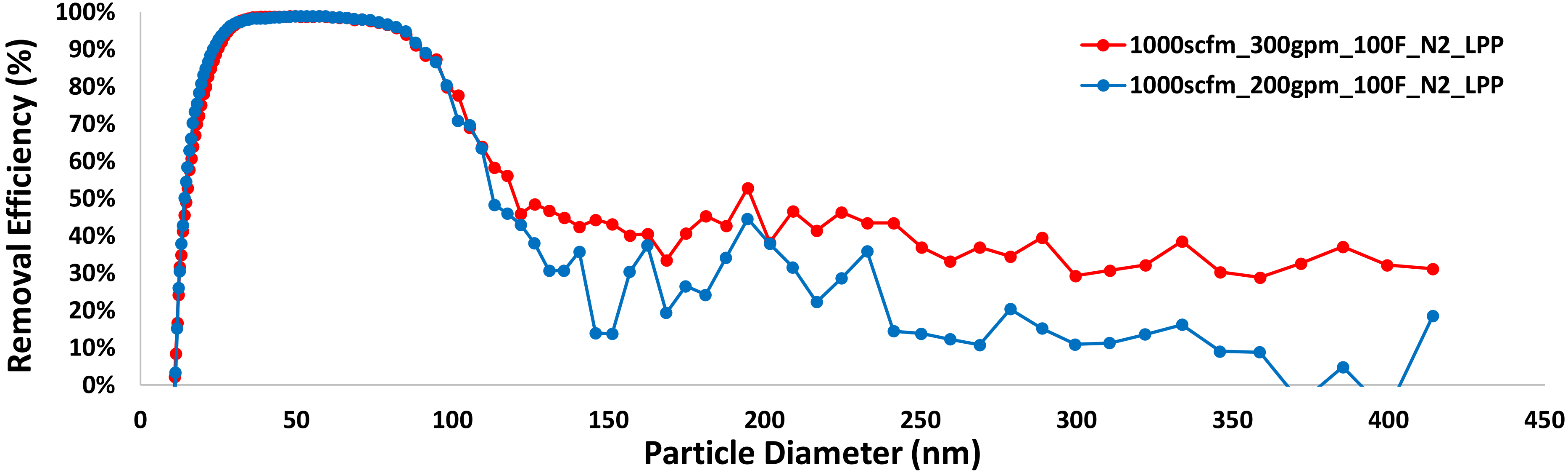
1 Coal Boiler Operating:

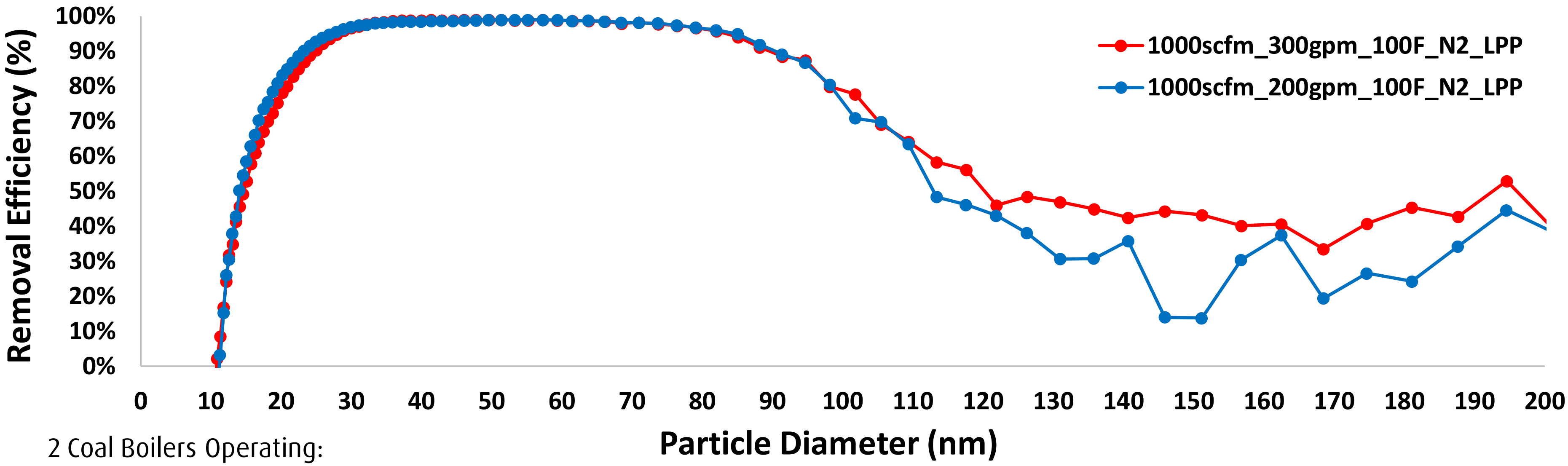
Coal Boiler Steam Rate: 96,000 lb/hr

High Velocity Spray Tower Aerosol Removal Performance Plots

Effect of Water Circulation Rate

Nozzle 2, Large Perforated Plate, 100°F water temp.





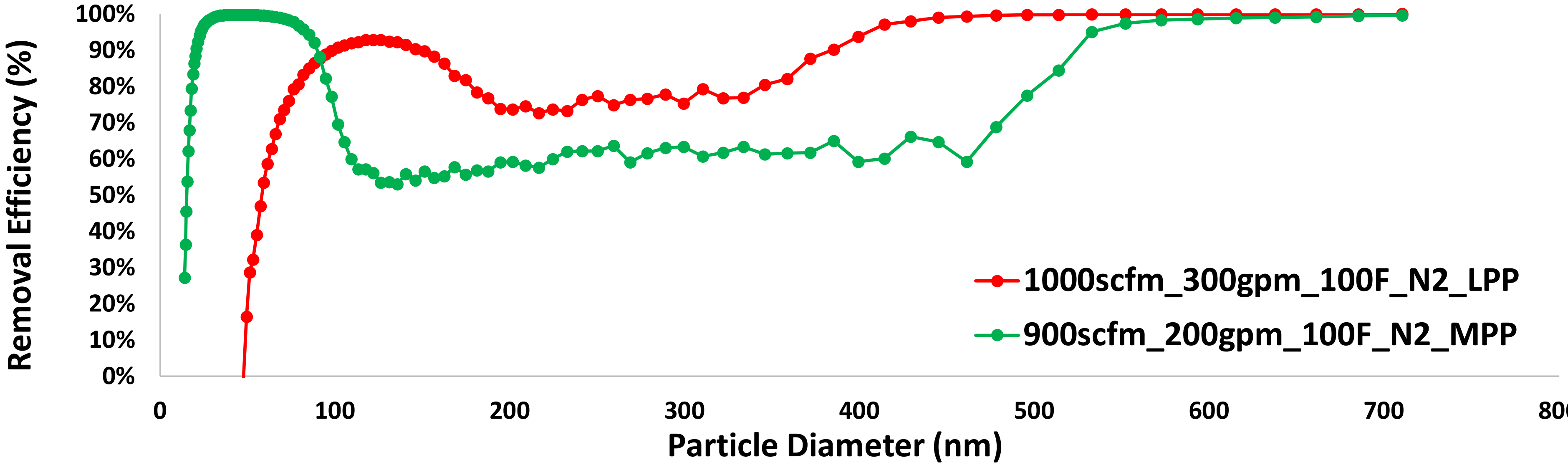
2 Coal Boilers Operating:

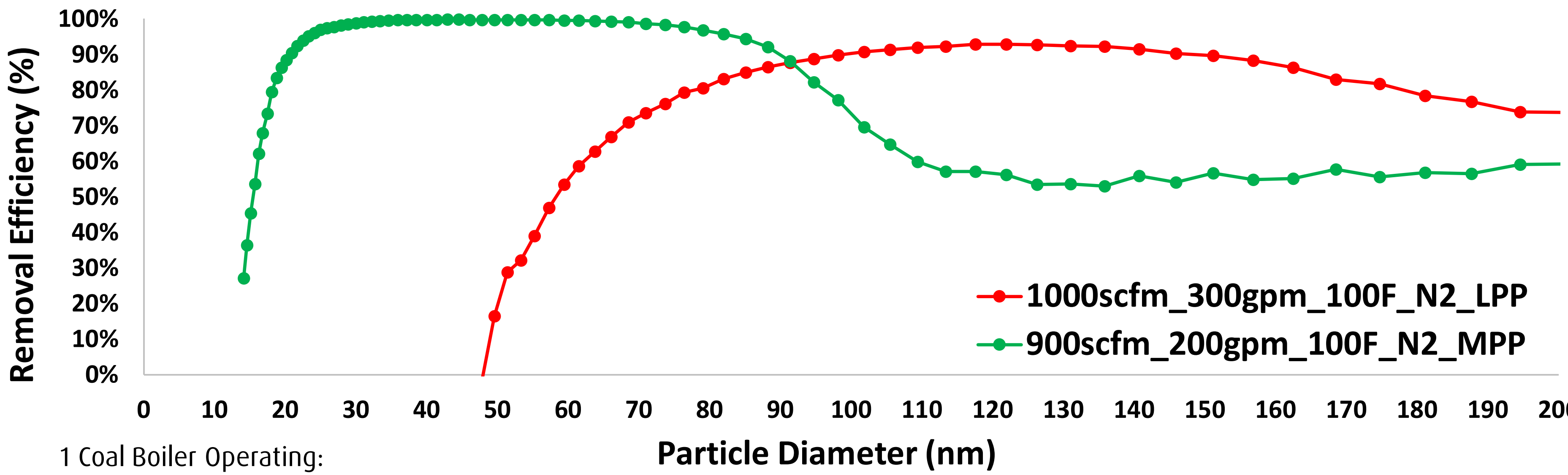
Coal Boiler Steam Rate: 190,000 lb/hr

High Velocity Spray Tower Aerosol Removal Performance Plots

Effect of Perforated Plate Type (LPP = Large, MPP = Medium)

Nozzle 2, 100°F



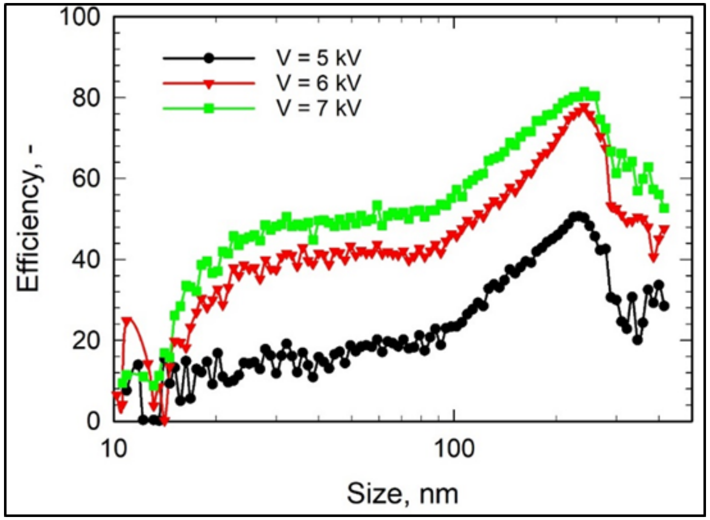


1 Coal Boiler Operating:
Coal Boiler Steam Rate: 99,000 lb/hr

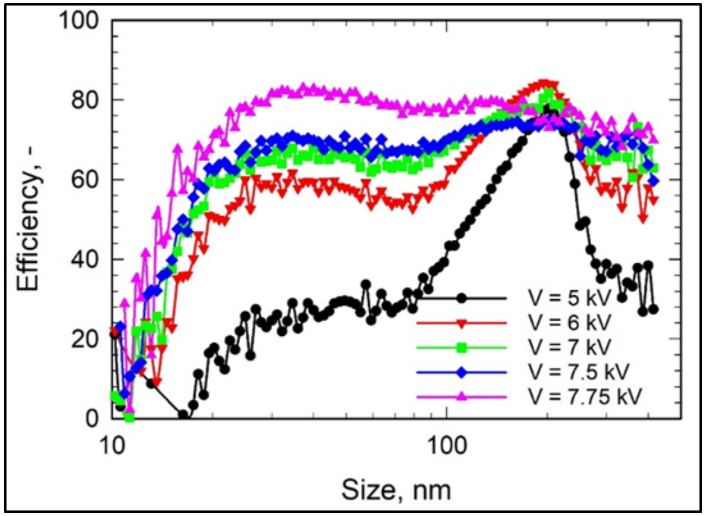
ESP Aerosol Removal Performance Conditions

Section	Range/condition	Description
Effect of charging stage voltage	Air flow rate: 300, 400, 500, 600 scfm Charging stage voltage: 5, 6, 7, 7.5, 7.75, 8 kV	Investigate the influence of charging stage voltage on collection efficiency at different operating conditions.
Effect of Soft X-Rays	Air flow rate: 500, 600 scfm Charging stage voltage: 5, 6 kV	Investigate the influence of soft X-rays on collection efficiency at different operating conditions to establish conditions at which soft X-rays enhance collection efficiency.
Effect of air flow rate	Air flow rate: 300, 400, 500, 600 scfm, Charging stage voltage: 5, 6, 7, 7.5, 7.75, 8 kV	Investigate the influence of air flow rate and thereby the particle velocity on collection efficiency at different operating conditions.

ESP Aerosol Removal Performance Plots



Flue gas flowrate: 500 scfm
Aerosol particle concentration: 2 x 10^7 #/cm^3
Single coal-fired boiler operation
(~100,000 lb/hr steam rate)
Voltage shown is charging stage voltage (kV)



Flue gas flowrate: 500 scfm (repeat)
Aerosol particle concentration: 2 x 10^7 #/cm^3
Single coal-fired boiler operation
(~100,000 lb/hr steam rate)
Voltage shown is charging stage voltage (kV)

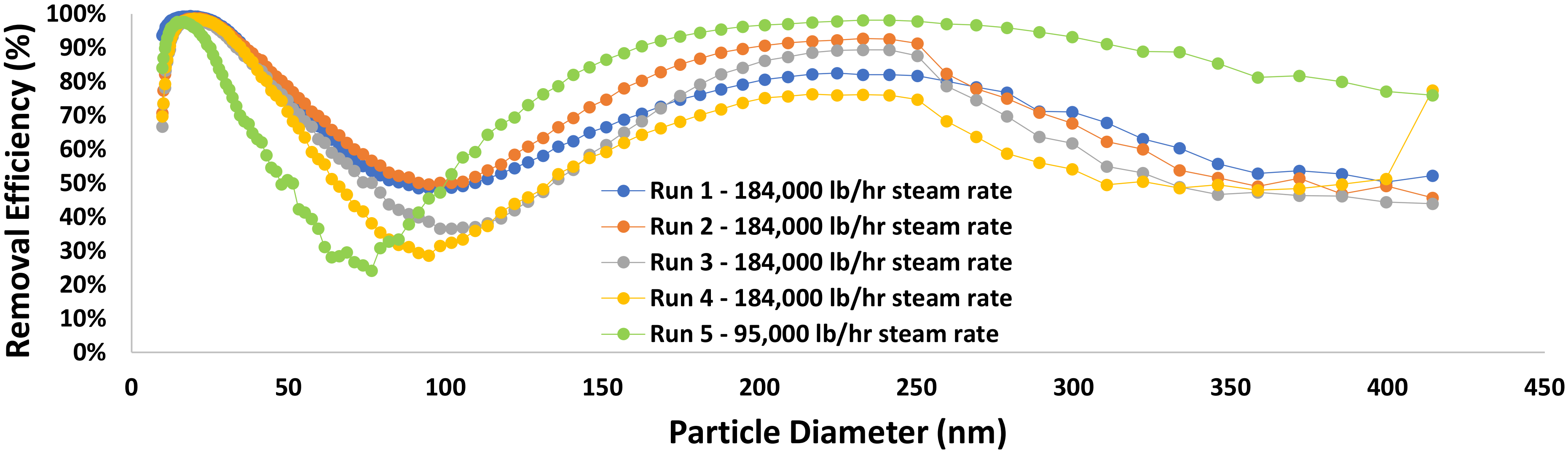
InnoSepra Sorbent Filter Aerosol Removal Conditions

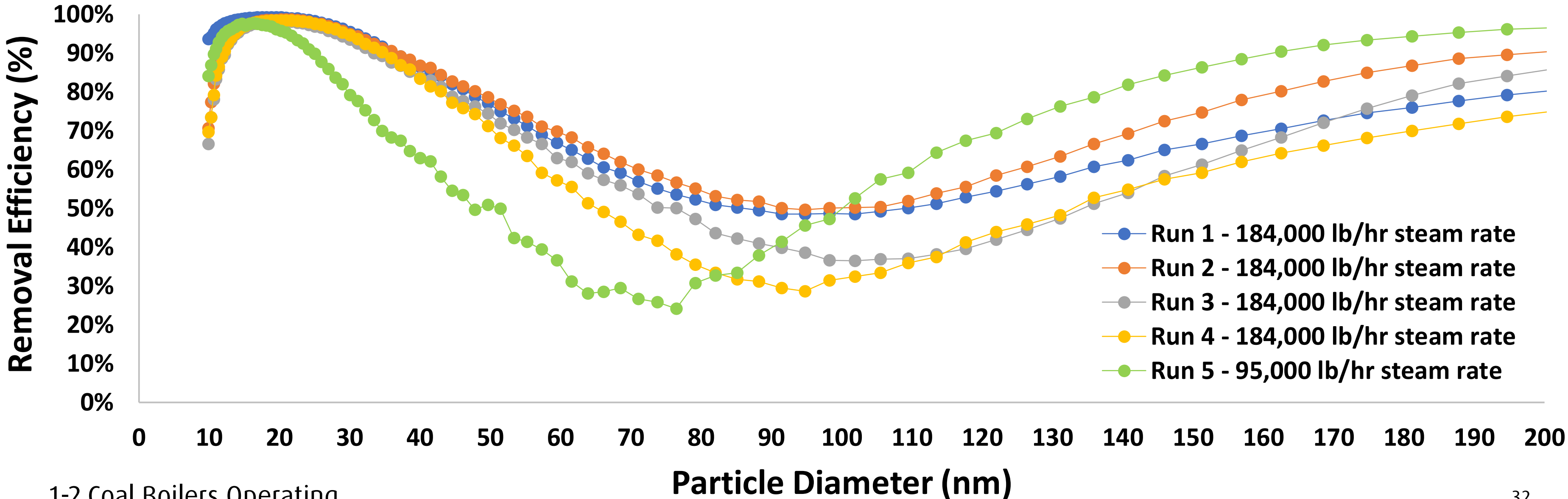
Design Features:
Non-regenerative sorbent material for SO_x & NO_x removal from flue gas before entering PCC plant

Conditions:
Flue gas flowrate (0-500 scfm)
Varying inlet SO_2 concentration (60-130 ppmv, dry)
5 gas sample ports along bed height (top port closest to inlet is port #5)
Boiler Steam Rate: 95,000 lb/hr to 184,000 lb/hr

Tested on 2/19/20 through 2/21/20, 3/10/20, 3/4/20, 3/7/20, 3/10/20 through 3/17/20

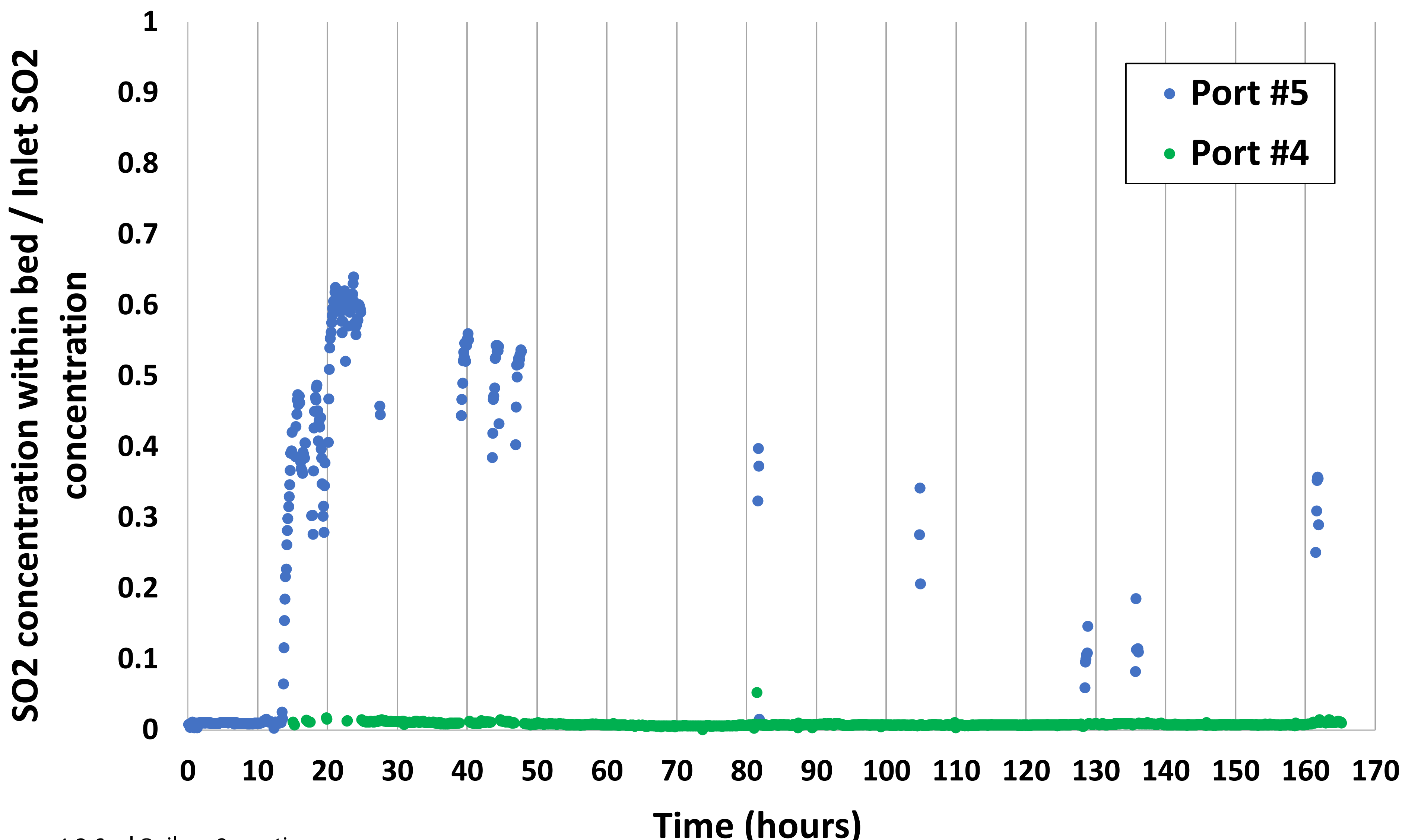
InnoSepra Sorbent Filter Aerosol Removal Performance Plots





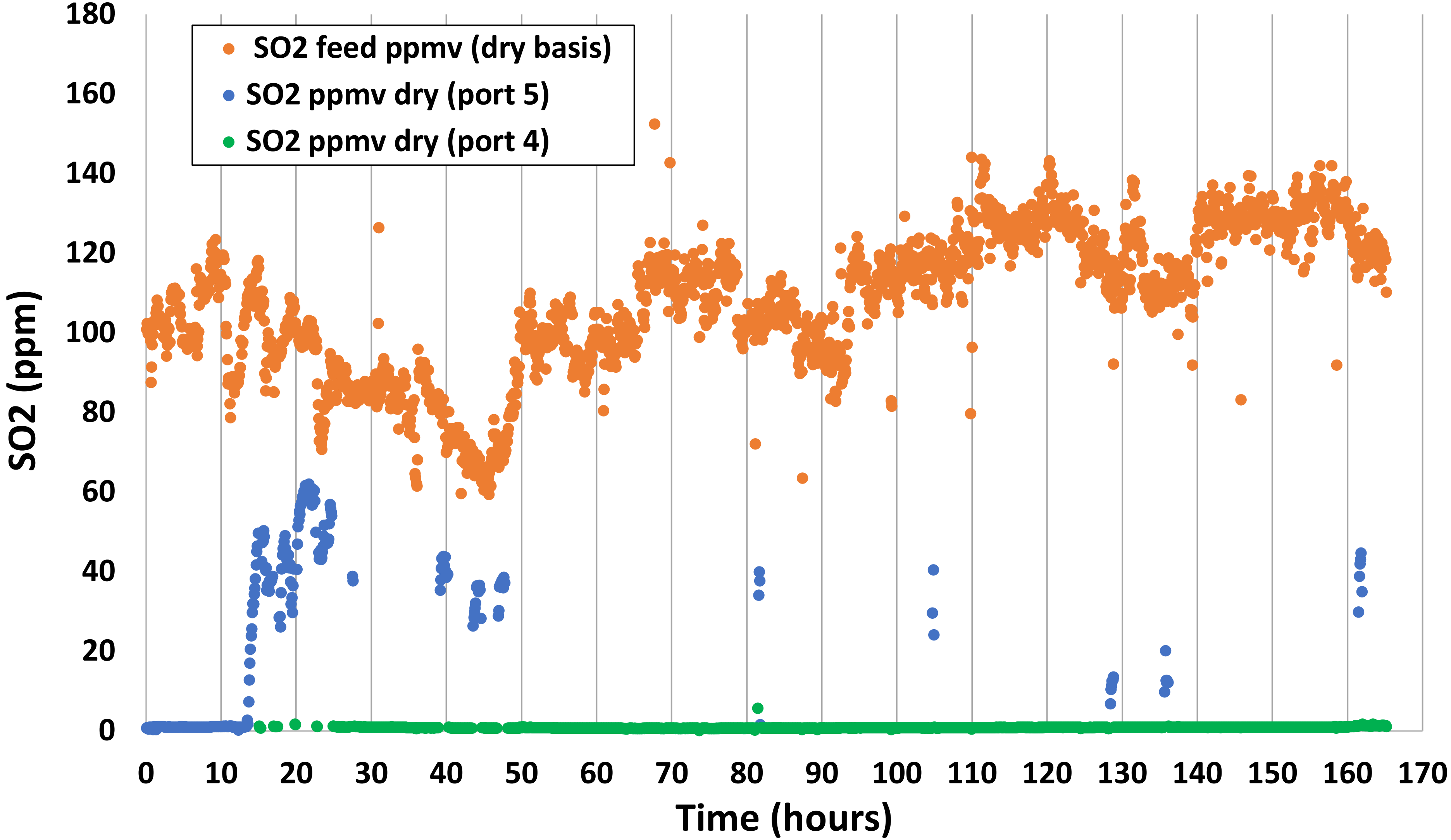
1-2 Coal Boilers Operating

InnoSepra Sorbent Filter
Flue Gas SO_x Removal Performance Plots



1-2 Coal Boilers Operating

InnoSepra Sorbent Filter
Flue Gas SO_x Removal Performance Plots



1-2 Coal Boilers Operating

Thank you for your attention

Making our world more productive