Computer Modeling of Unburned Carbon as Part of Boiler Retrofits and Nitric Oxide Control

Bernard Breen, PhD

Joseph Urich, P.E.

Robert Schrecengost

Energy Systems Associates

564 Washington Avenue, Pittsburgh, PA 15106 - (412) 429-2713 - www.energysystemsassoc.com

Introduction

- Developed CFD modeling for Design of NO_x Controls

- NO_x control and Unburned Carbon intertwined

- Initially Used Predictions of CO and Fuel Richness at Model Exit to Estimate Impact on UBC

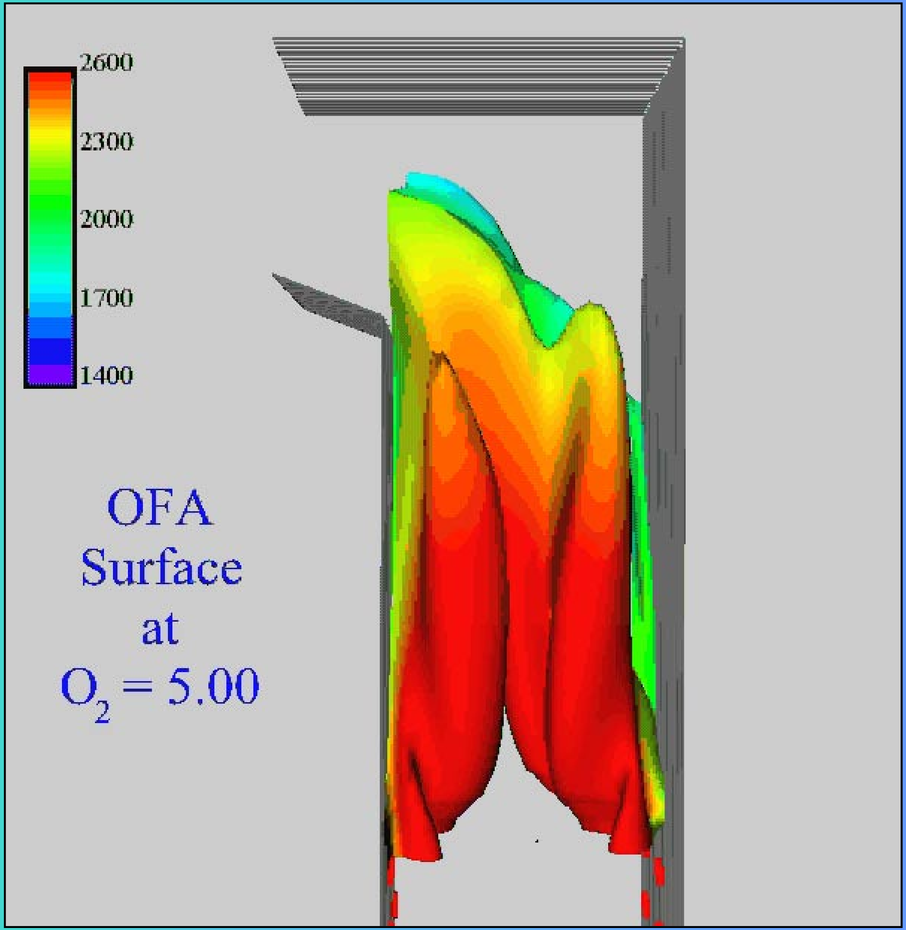
- Expanded to include Unburned Carbon Predictions

- Incorporates ESA Combustion Experience:
    - Controlling Mechanisms of Initial Modeling Effort
    - Incorporated into Modeling Improvement
    - Model Application is only as good as Experience Behind it

CFD Modeling for NO_x Control

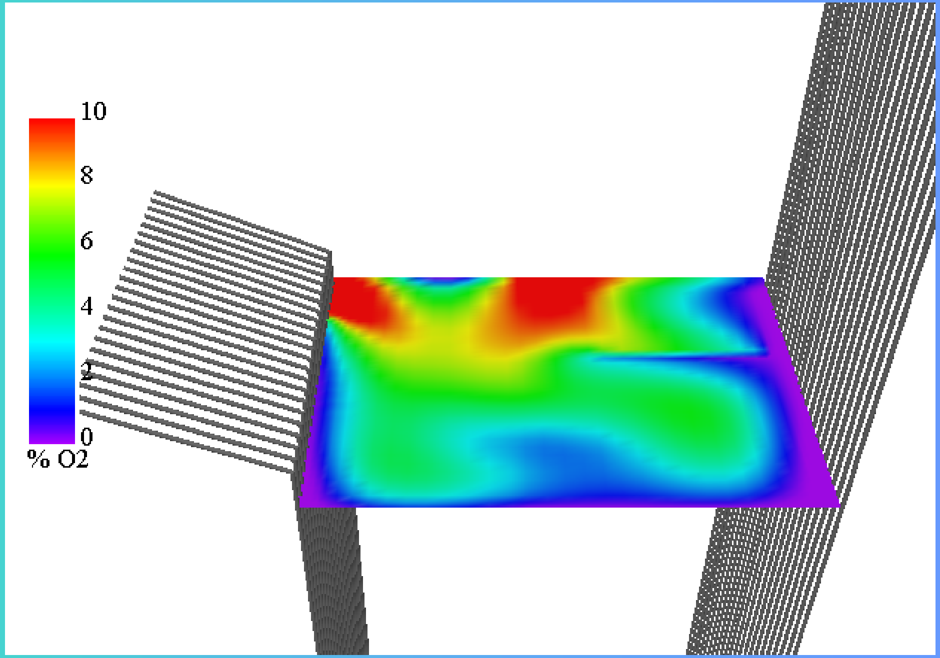
- Steady Navier-Stokes Equations
- Coal Devolatilization and combustion
- Turbulence, radiation, two-phase flow
- Commercial Software base

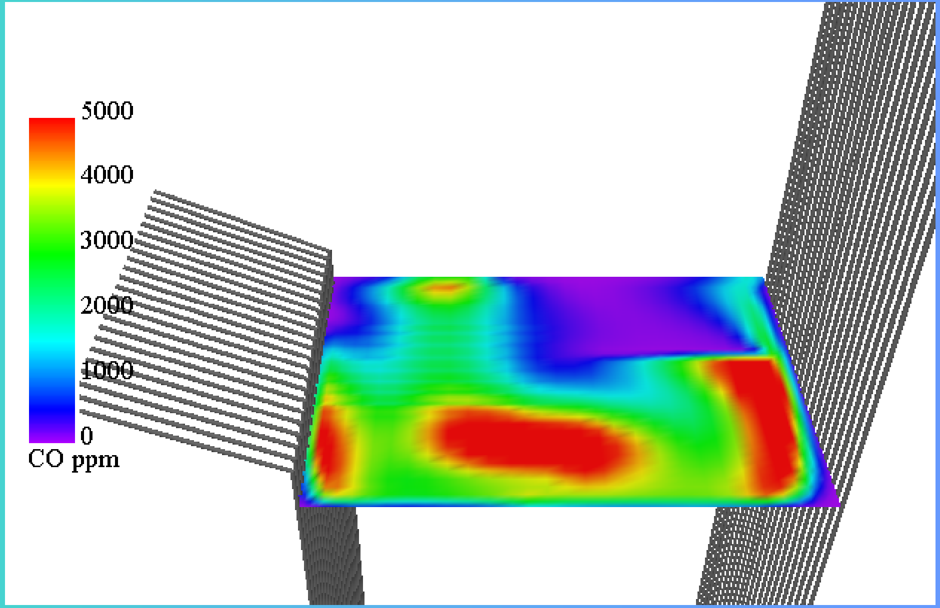
- NO_x Ports Block Furnace Flow
  - Temperature difference of 650 F vs 3200 F between gas
  - Hot Flames form bouyant bypass chimneys



NO_x Control effect on Exit CO and O_2

- NO_x Control Principle: Fuel-rich at Adiabatic Flame Peak Temperature
- O_2 and CO commonly predicted in CFD models
- CO good indicator of UBC Problems
- Integrate CO and/or fuel richness at Furnace Exit to estimate impact on UBC

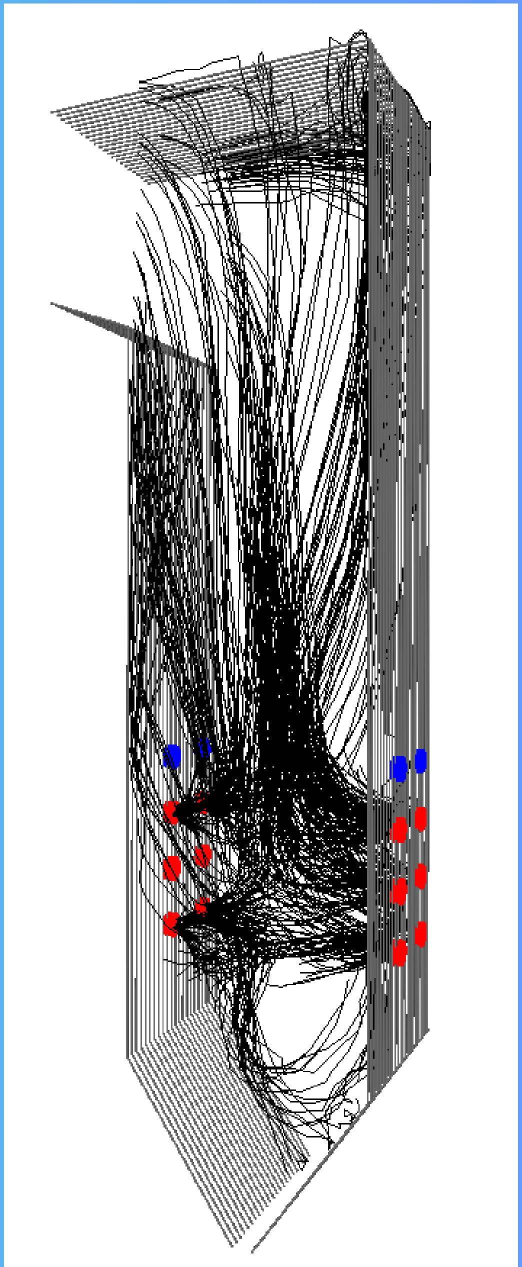




Energy Systems Associates
564 Washington Avenue, Pittsburgh, PA 15106 - (412) 429-2713 - www.energysystemsassoc.com

CFD Modeling of Coal Particles for UBC

- Directly track individual coal particles
- Simulate Volatilization and Char burn out for mass transfer
- Count particles still existing at model exit to determine UBC impact



NO_x Control Experience

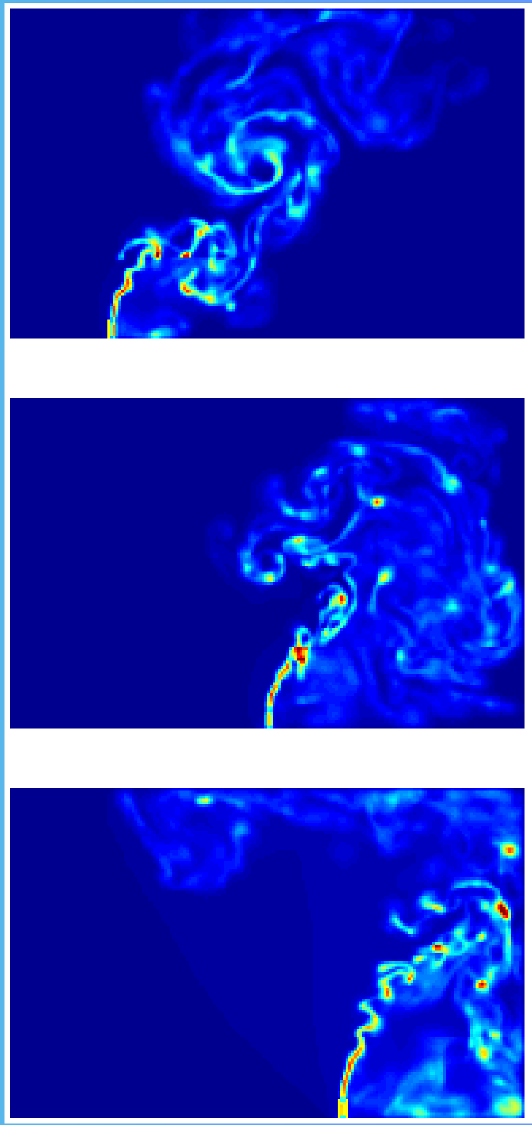
- Low Excess Air: LEA most important
- Superheat and Reheat Temperatures depend on Furnace Air Residence Time
- Corrosion Mechanisms Change in Reducing atmosphere
- Carbon: LOI dependent on LEA, Air balance, and Air profile

First Example: Lean Gas Reburning UBC

- CFD and LIM Modeling used to design Fuel Lean Gas Reburn System for Duke Energy Riverbend Unit 7 - 144 MW Tangential
- Models to Predict Expected NO_x Reduction and CO increase
- Models used to Select injector location and number
- Design Iteration of Natural Gas impact on CO and UBC
- Models and test data employed to re-analyze design to mitigate impact on CO and UBC

FLGR LIM Model for Injector Positioning

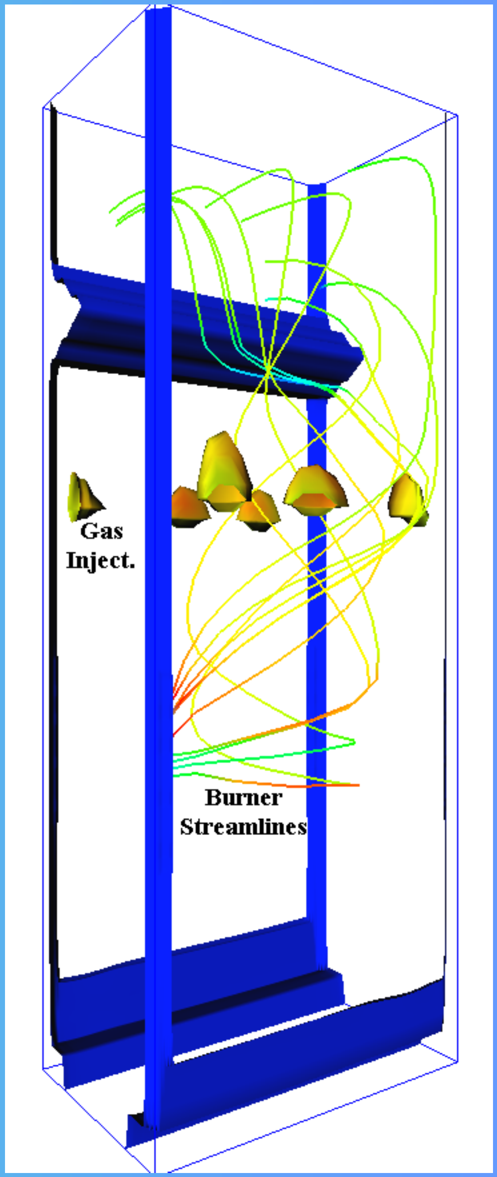
- Natural Gas as NO_x Reducing/Finishing Agent
- Riverbend Fuel Lean Gas Reburn
- High Excess Air near walls
- Reburn Mixing into Fireball
- Natural Gas burns easily, quenching O_2 availability for Carbon burnout



Energy Systems Associates
564 Washington Avenue, Pittsburgh, PA 15106 - (412) 429-2713 - www.energysystemsassoc.com

FLGR CFD Model

- Unexpected Impact on CO and UBC
- Initial Modeling focused on FLGR
- Missed impact on CO and UBC
- Modeling of Primary Coal Combustion interaction with OFA Separated from Secondary Reburn Combustion to Correct UBC impact



Second Example: Coal Quality

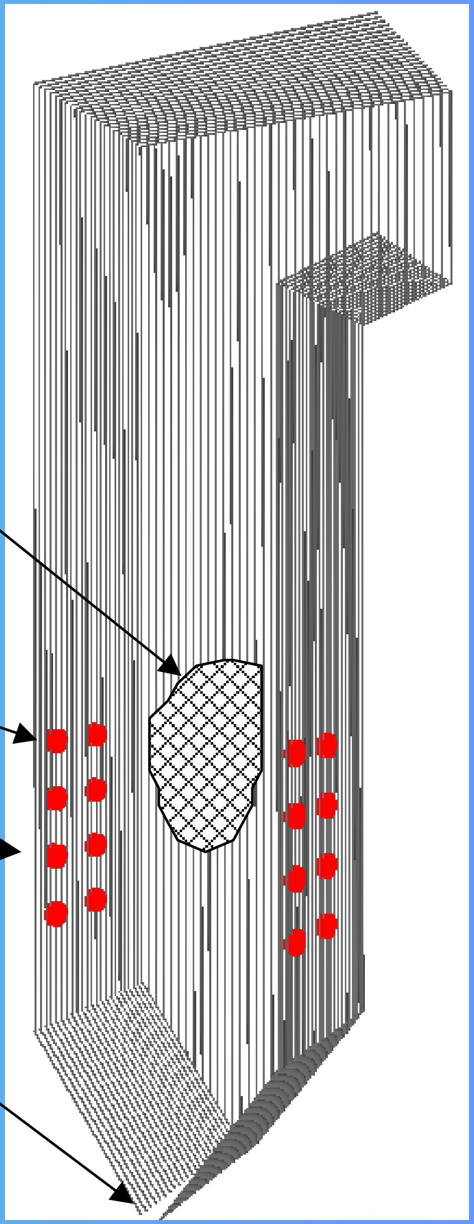
- Cinergy Gibson - Foster Wheeler, Opposed Fired, 650 MW
- Impact of Coal Quality
- Modeling to infer UBC effects
- Exit Plane Fouling Index
- Side Wall Corrosion Index
- Exit NO_x and reducing conditions on waterwalls

Calculate reducing conditions on walls

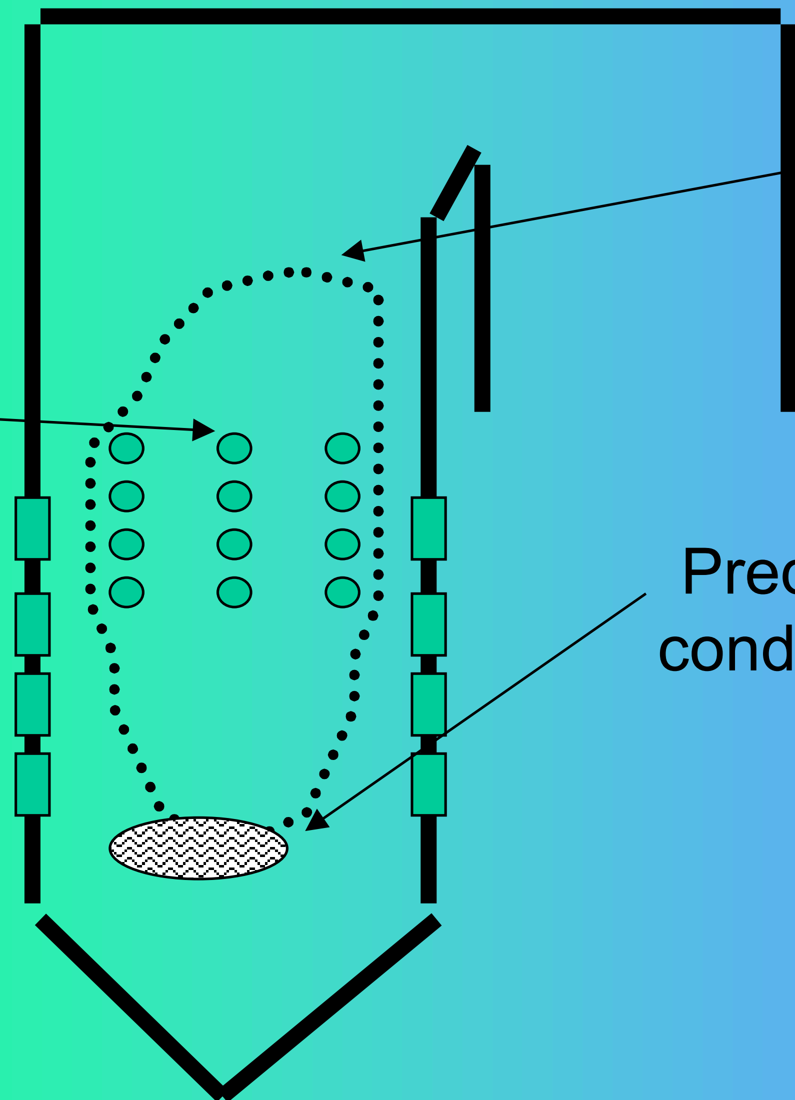
Model 2 of 4 OFA ports per row

Model 2 of 4 burners per row

Symmetry assumed at center

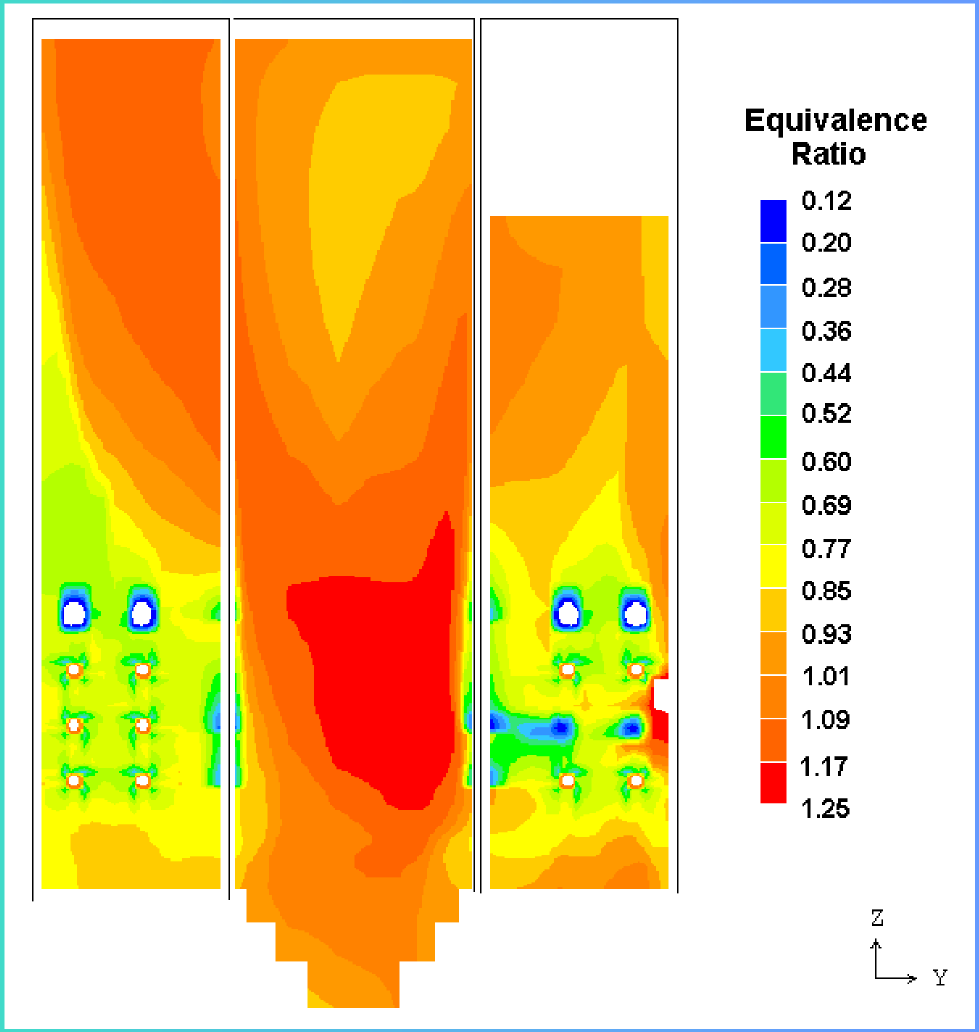


CFD Model Matching Observations



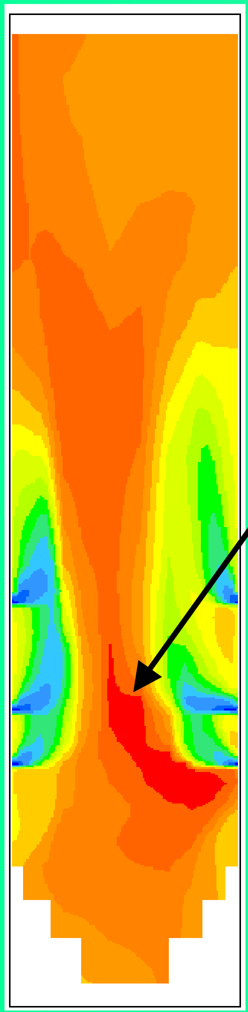
Energy Systems Associates
564 Washington Avenue, Pittsburgh, PA 15106 - (412) 429-2713 - www.energysystemsassoc.com

CFD Model Matching Observations



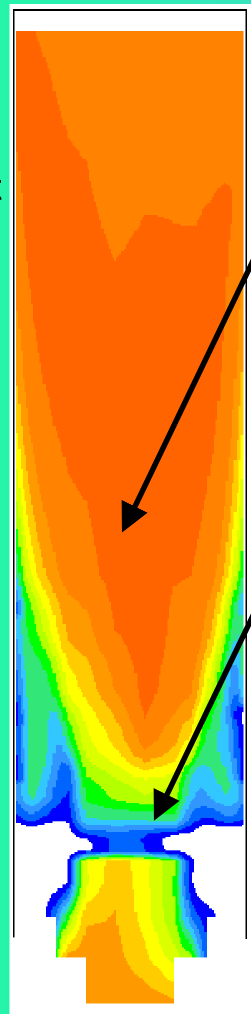
Energy Systems Associates
564 Washington Avenue, Pittsburgh, PA 15106 - (412) 429-2713 - www.energysystemsassoc.com

CFD Model Predictions



Squeezes reducing area to center, but cannot penetrate fully, leaving center at risk

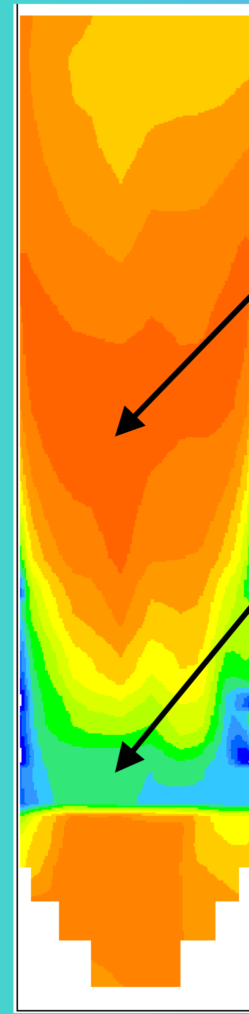
Increase Existing Port Flow



Limits reducing area and lowers magnitude of reducing conditions

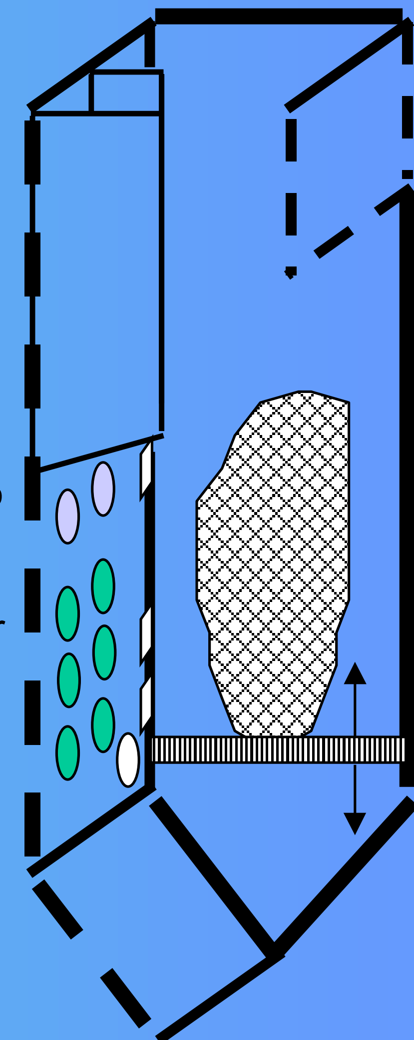
Boundary Air tends to mix into burner zone and defeat staging for NOx control

Large Boundary Air Ports



Limits reducing area and lowers magnitude of reducing conditions

Side Wall Air Slots



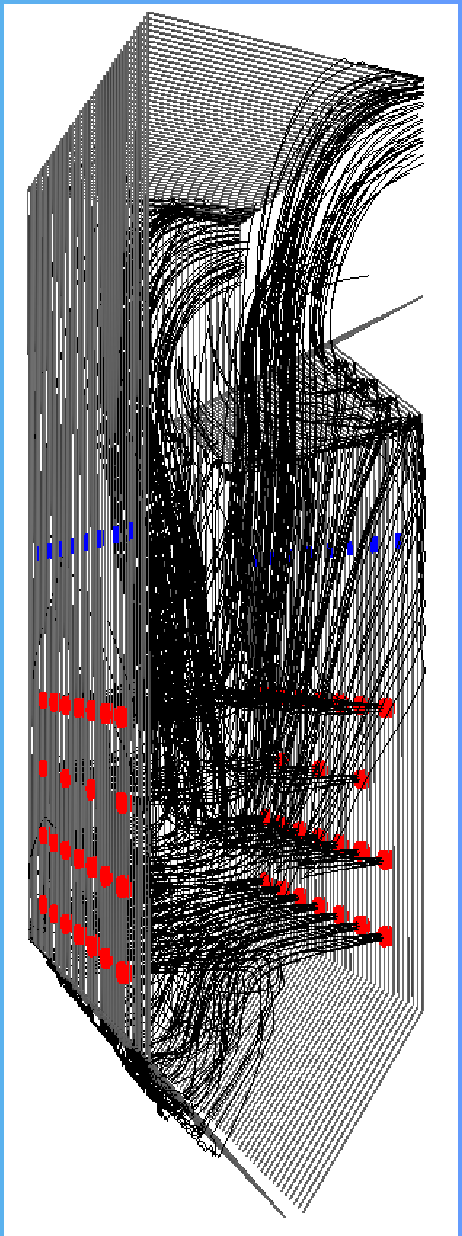
Slots positioned so that furnace flow field directs the air back against the side wall

Energy Systems Associates

564 Washington Avenue, Pittsburgh, PA 15106 - (412) 429-2713 - www.energysystemsassoc.com

Third Example: OFA Design

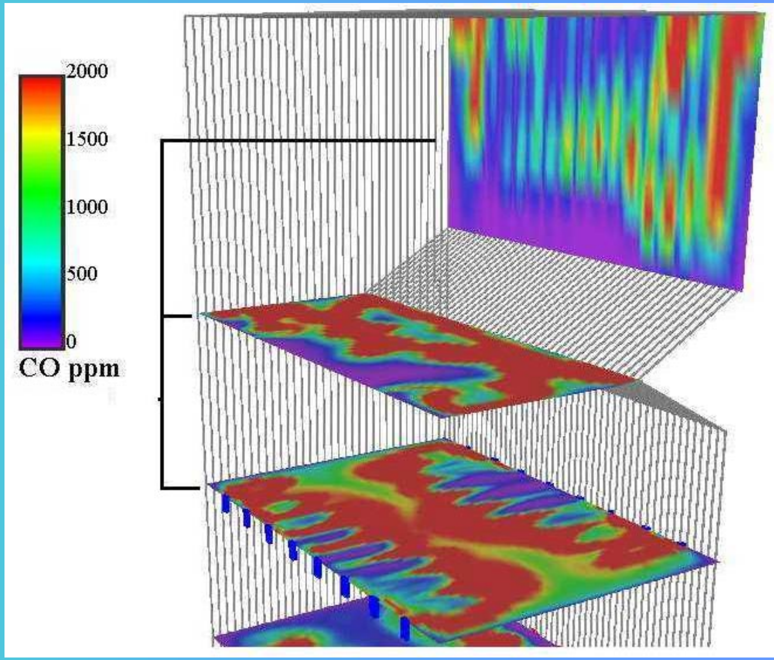
- B & W Oppossed Fired Unit OFA Design
- PRB Coal, Low UBC under current Operation
- Design OFA System for NO_x reduction
- Model to find Optimum of NO_x, CO and UBC



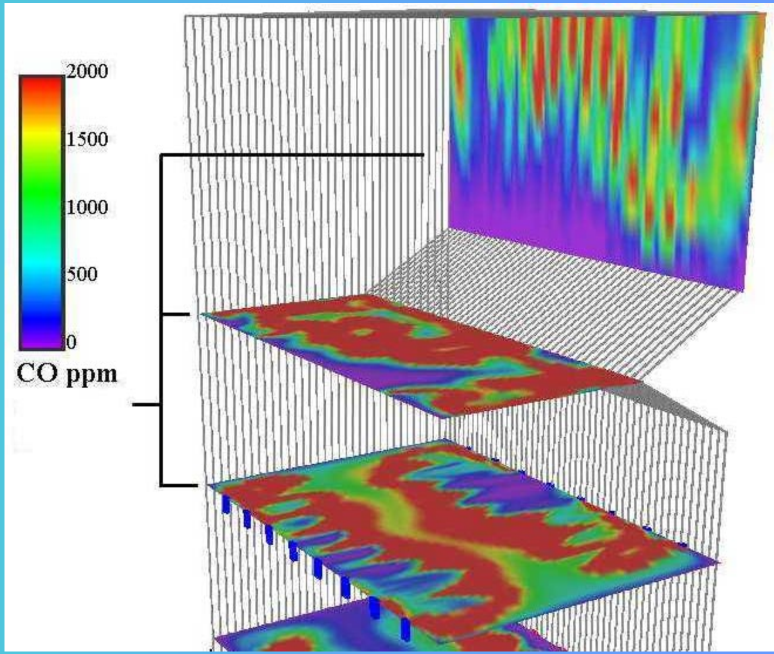
Example of Pre-Retrofit Analysis

- Model Multiple OFA Designs
- Address UBC During Design Phase
- Small Changes to Port Design improves UBC without effecting NO_x

Initial Design: UBC 2% above Baseline



Redesign Ports: UBC 1% above Baseline



CFD Use in Design

Computation Fluid Dynamics

Design

Computer Furnace Models

- Simulate unbuilt configuration

Experience

- Incorporate Operating Data and Experience of Approximately Similar Situation
- NO_x Reduced 50 %
- UBC maintained with LEA, OFA, or LNB

Operation

Fourth Example: Computer Optimization Model

- **NO_x Reduction and Heat Rate Improvement**
- **Demonstration of *QuickStudy* Adaptive Process Control (APC) software to determine the extent to which NO_x could be reduced without affecting boiler efficiency**
- **Involves spatial monitoring and balancing of furnace excess O_2 levels as measured by an O_2 grid in the boiler outlet**
- **Spatial balancing allows reduced excess O_2 levels without exceeding the "CO threshold"**
- **QuickStudy acts as a "silent sentry" for low O_2 operation that is transparent to the boiler operator**

Breen Energy Solutions

QuickStudy™ ADAPTIVE PROCESS CONTROLLER

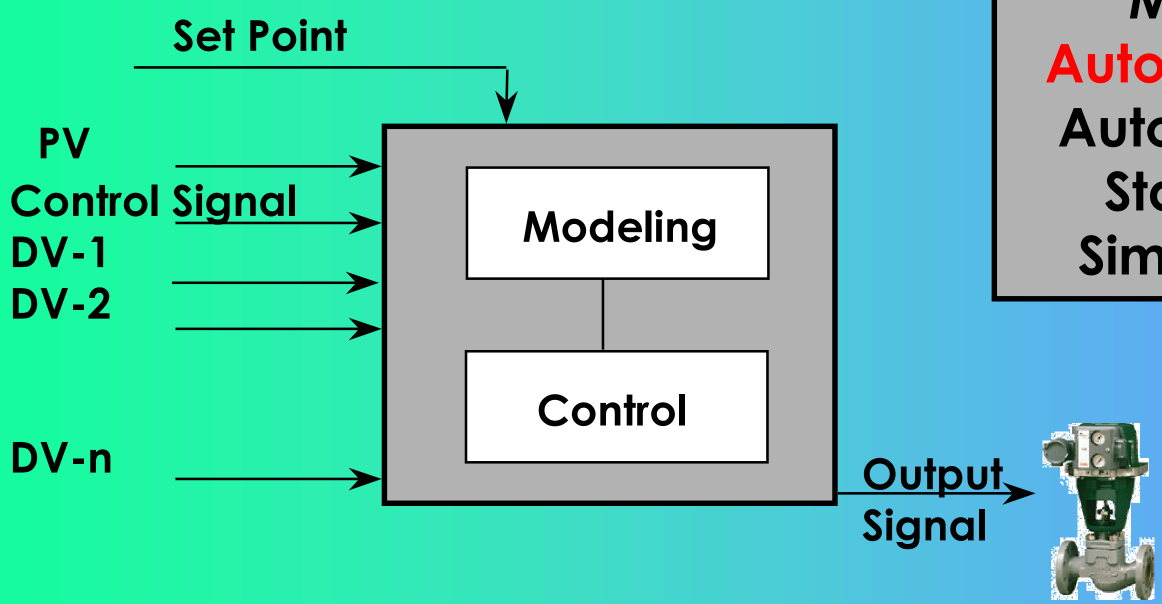
Test Unit: Albright #1

- Riley Stoker sub-critical, single reheat drum boiler with nominal rating of 80 MW
- Equipped with 12 Riley CCV-90 low NO_x Burners
- Fires eastern bituminous coal
- Burner array is three rows by four columns
- Each burner row supplied by one B&W E70 pulverizer
- Design conditions at rated load are 700K lb/hr steam flow, superheat outlet conditions of 910 psig and 905 °F

Breen Energy Solutions

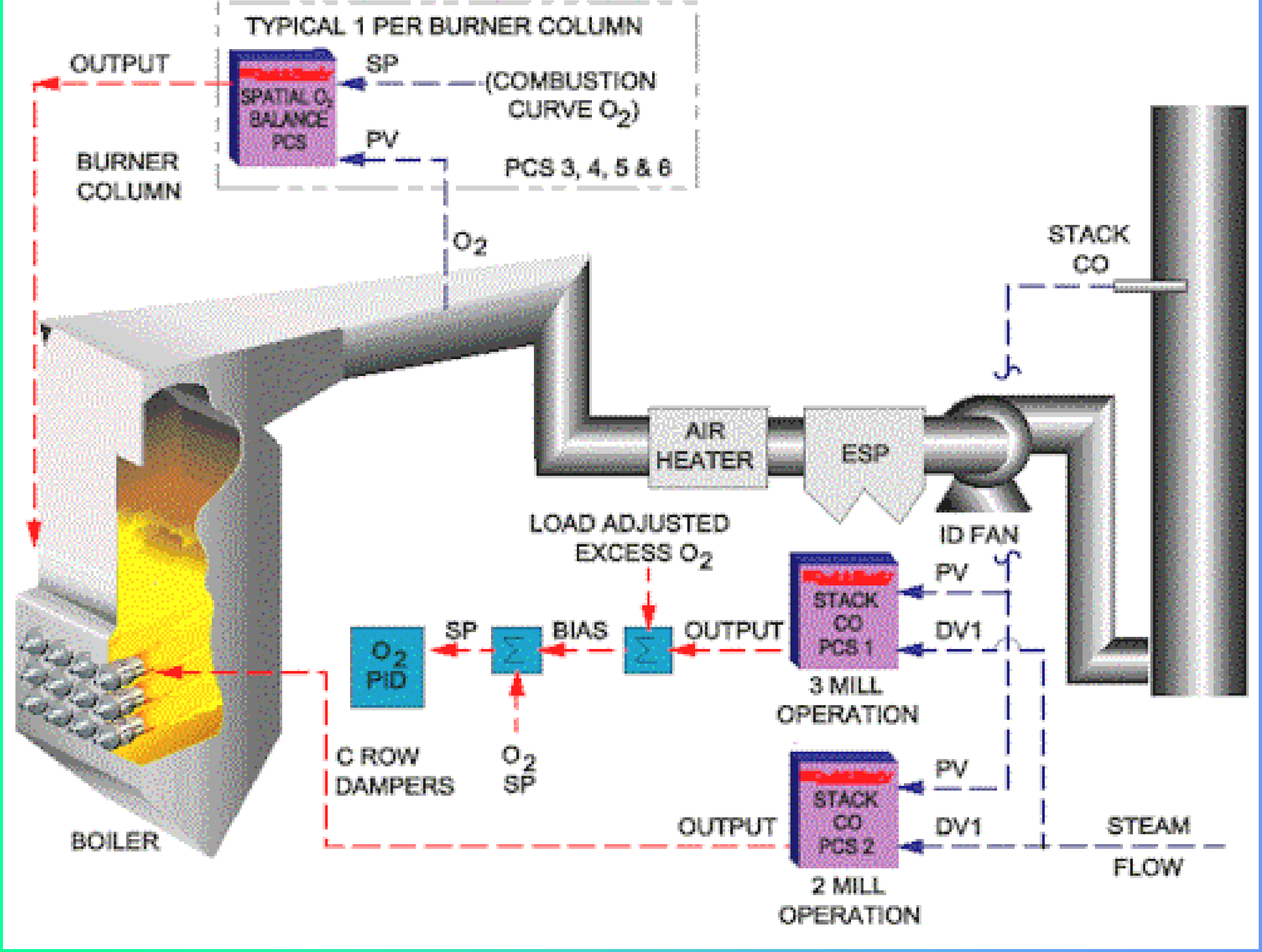
QuickStudy™ ADAPTIVE PROCESS CONTROLLER

PCS Block Operating Modes

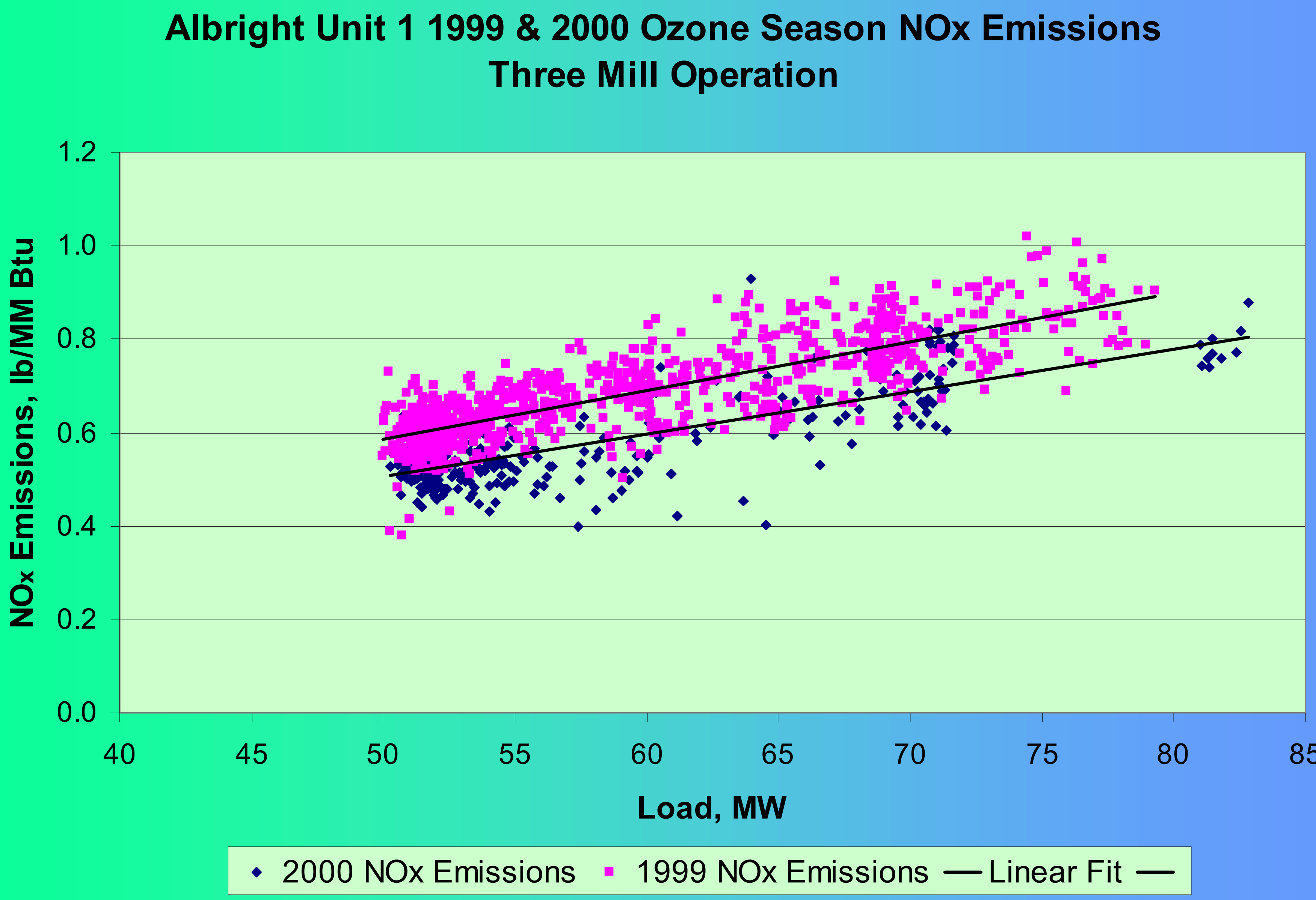


PCS Modes

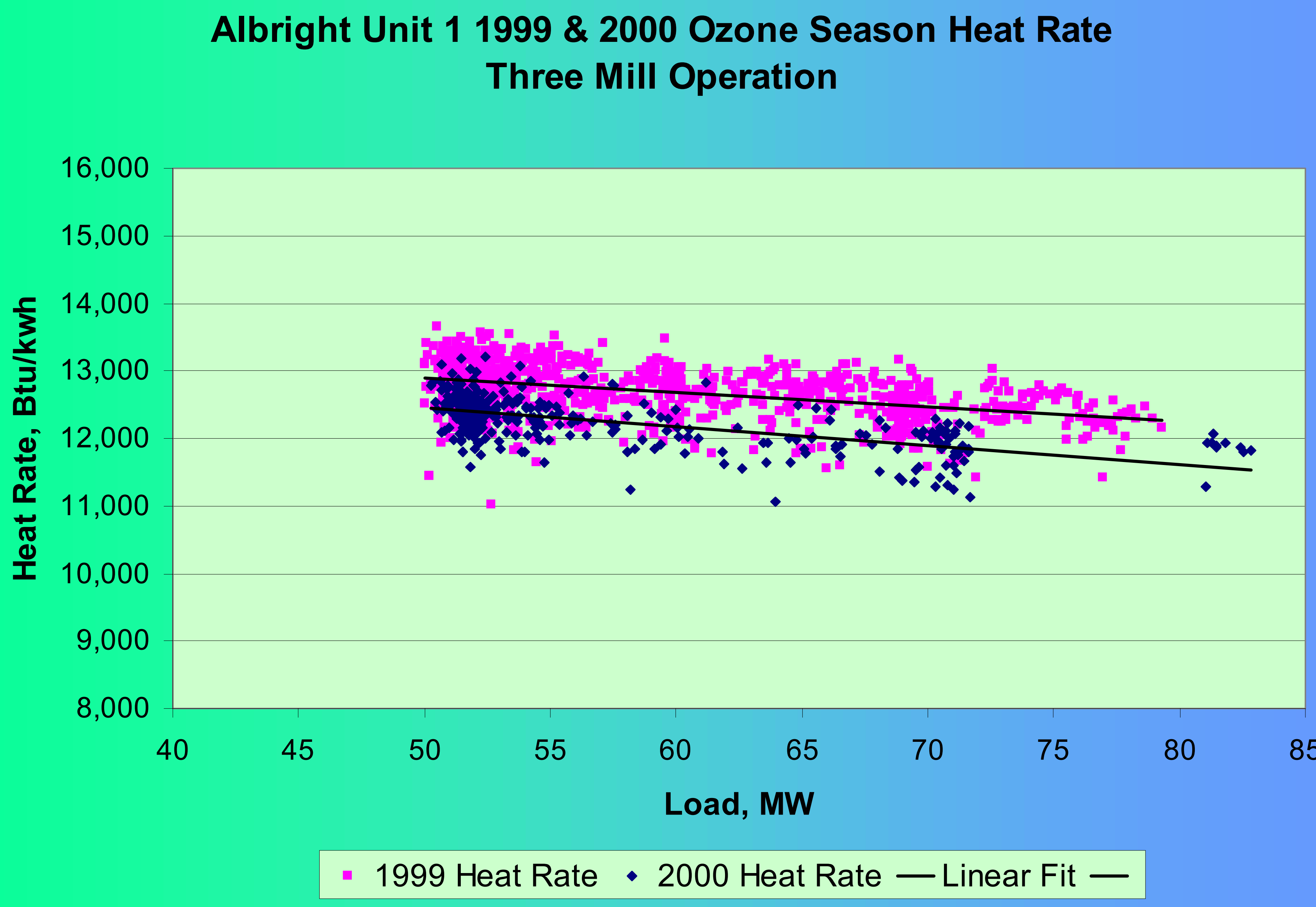
Model
Auto-Control
Auto-Adapt
Standby
Simulation



The Adaptive Process Control Strategy



Albright Unit 1 NO_x CEM Data with and without APC - 3 Mill Operation



Albright Unit 1 CEM Heat Rate Data with and without APC - 3 Mill Operation

QuickStudy Results: Albright #1

- **NO_x reduced by 15-17% on average, 18% with 3 mills**
- **CEM heat rate improved by minimum of 2%**
- **CO emissions controlled to below 250 ppm**
- **Average opacity levels were slightly improved**
- **Furnace slagging conditions were improved as a result of controlling air supplies to individual burners by means of spatial balancing of O_2**

Breen Energy Solutions

QuickStudy™ ADAPTIVE PROCESS CONTROLLER

Conclusions

Computation Fluid Dynamics

Dynamic Optimization Computer Models

Physical / Chemical Process

Design

Computer Furnace Models

- Simulate unbuilt configuration

Experience

- Incorporate Operating Data and Experience of Approximately Similar Situation
- NOx Reduced 50 %
- UBC maintained with LEA, OFA, or LNB

Operate

Learning and Recognition Systems

- Optimization Systems
- Adaptive Process Control

Experience

- Obtain Test Conditions under continuous operation
- NOx Reduced 15 to 25 %
- UBC maintained through balancing gains

Energy Systems Associates

564 Washington Avenue, Pittsburgh, PA 15106 - (412) 429-2713 - www.energysystemsassoc.com