Reinhold Environmental Ltd.

2007 NOx Round Table & Expo Presentation

February 5-6, 2007 in Cincinnati, OH

Mixing Issues at Power Plants

Robert Mudry, P.E.
V.P. Engineering
Airflow Sciences Corporation
rmudry@airflowsciences.com
734-525-0300

From Webster's Dictionary

Mix (verb):

(1) : to combine or blend into one mass
(2) : to combine with another
(3) : to bring into close association
(4) : to form by mixing components
(5) : to confuse -- often used with *up*

Outline

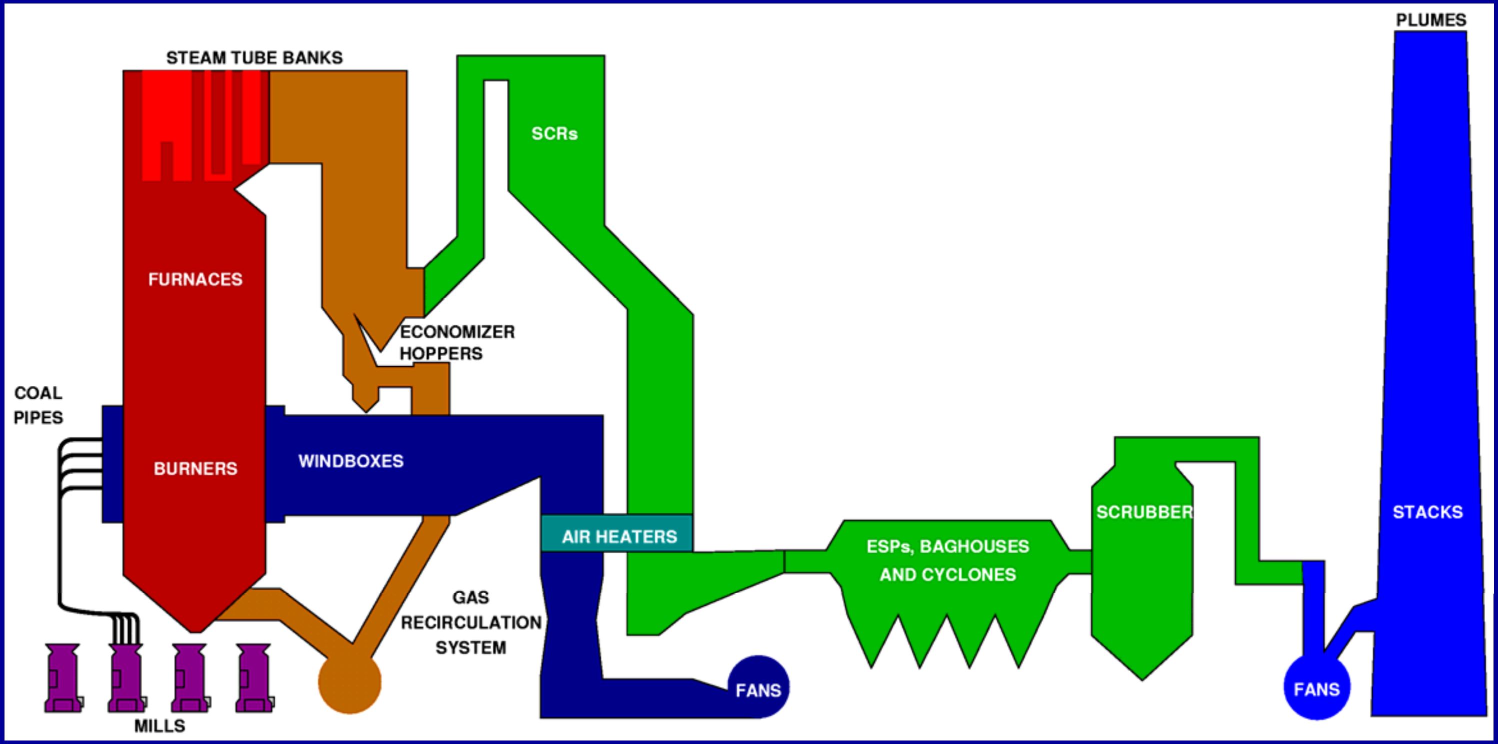
- Introduction
- Mixing and SCR Performance
- SCR Case Studies
- Other Power Plant Mixing Issues
- Summary

Outline

- Introduction
  - Why is mixing important?
  - How do you mix?
  - Mixer design
- Mixing and SCR Performance
- SCR Case Studies
- Other Power Plant Mixing Issues
- Summary

Why Is Mixing Important?

- Many processes at power plants involve the merger of different flow streams



- The performance of plant equipment is influenced by non-uniformities in the flow

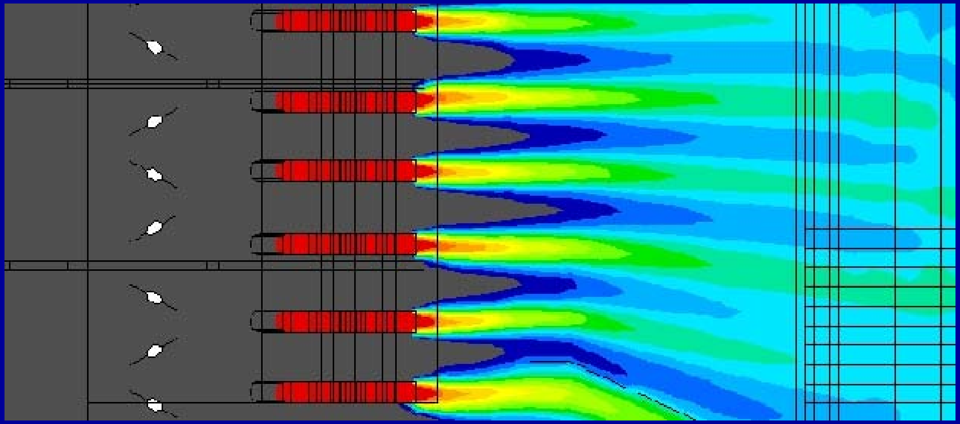
Why Is Mixing Important?

- Pulverizer performance and safety
- Combustion optimization in the furnace
- Air pollution control (APC) equipment
  - SCRs
  - ESPs
  - Fabric Filters

Why Is Mixing Important?

- For optimal performance of APC equipment, “uniformity” goals for certain flow characteristics must be met
  - Temperature
    - Generally want to have a “uniform” temperature entering the SCR, baghouse, ESP, FGD, etc.
  - Chemical species
    - Ideally, a “uniform” condition for flue gas or any injected species is desired at the inlet to APC equipment

How Do You Mix?



- Control the flow streams at the merger location
  - Multi-point injection
  - Layered injection
- Churn up the flow after the merger
  - Induce turbulence
  - Create shear forces
  - Generate swirl or vortices

Mixer Design

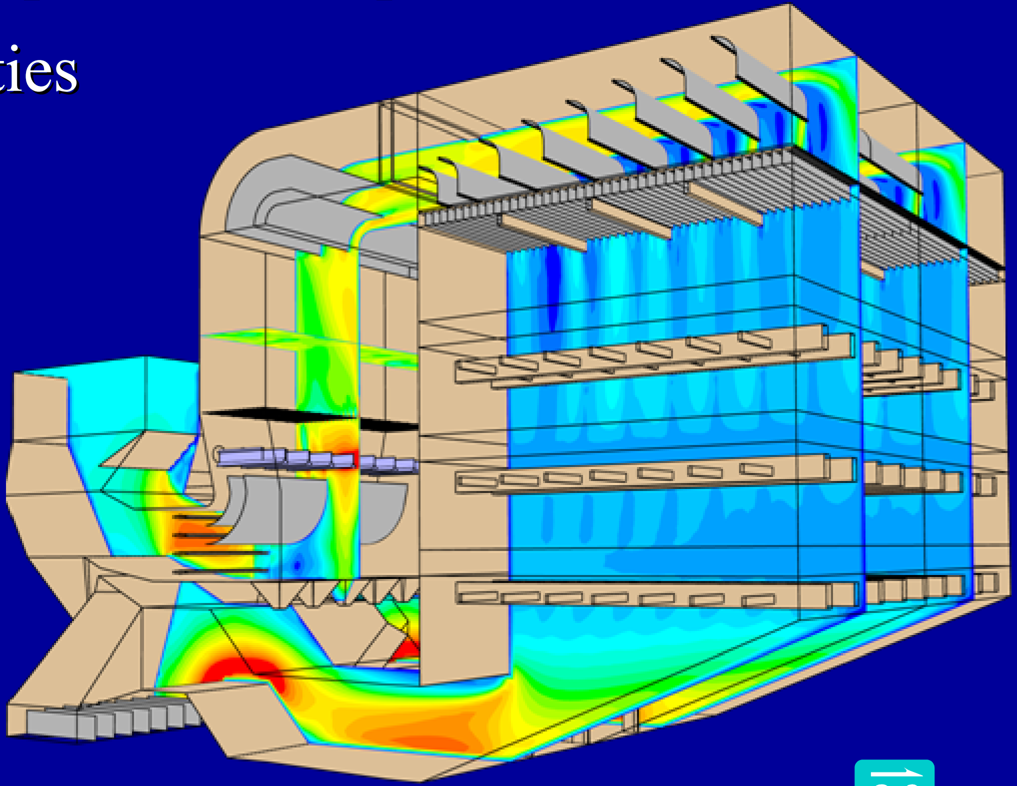
- Design criteria
  - Uniformity goals
  - Pressure loss
  - Cost
  - Construction method, supplier
- Engineering methods
  - Physical flow modeling
  - Computational Fluid Dynamics (CFD)
  - Field testing

Physical Flow Modeling

- Lab representation of geometry
- Typical scale 1:8 to 1:16
- “Cold flow” modeling
- Visualize flow with smoke
- Simulate ash deposition
- Measure flow properties
  - Velocity
  - Pressure
  - Chemical species via tracer gas

Flow Modeling Methods

- Computational Fluid Dynamics (CFD)
  - Numerical simulation of flow
  - Utilize high speed computers and sophisticated software
  - Calculate flow properties
    - Velocity
    - Pressure
    - Temperature
    - Ammonia
    - Particle streamlines



Outline

- Introduction
- Mixing and SCR Performance
  - Ammonia-to-NOx ratio
  - NOx stratification
  - Ammonia injection
  - Temperature mixing
- SCR Case Studies
- Other Power Plant Mixing Issues
- Summary

Ammonia-to-NOx Ratio

- Ammonia-to-NOx ratio at the catalyst inlet plane should be “uniform”
- Typical goal is %RMS < 5-10%
- Allows optimal NOx reduction with minimum NH_3 slip

NOx Stratification

- NOx is not necessarily uniform at the boiler exit; it is a function of
  - Boiler design
  - Burner air flow balance
  - Coal pipe balance
  - Mills out-of-service
- Solutions
  - Mix the NOx prior to the NH3 injection
  - Mix the NOx and the NH3
  - Tune the NH3 to the NOx profile

Ammonia Injection

- Two basic strategies are used for ammonia injection in SCRs
  - Dense grid of injection pipes
  - Coarse grid of injection pipes with mixers

Dense Grid Ammonia Injection

- Many injection lances with multiple nozzles per lance
  - Depending on SCR size, could have 50-200 lances per reactor inlet duct
  - Typically 6-10 nozzles per lance
  - Hundreds of discrete injection points
- Lances grouped into zones for tuning

Coarse Grid Ammonia Injection

- Few injection lances with multiple nozzles per lance
  - Depending on SCR size, could have 5-30 lances per reactor
  - Typically 6-10 injection nozzles per lance
- Lances located immediately upstream of a static mixer
- Often multiple stages of static mixers

Achieving NH3-to-NOx Uniformity

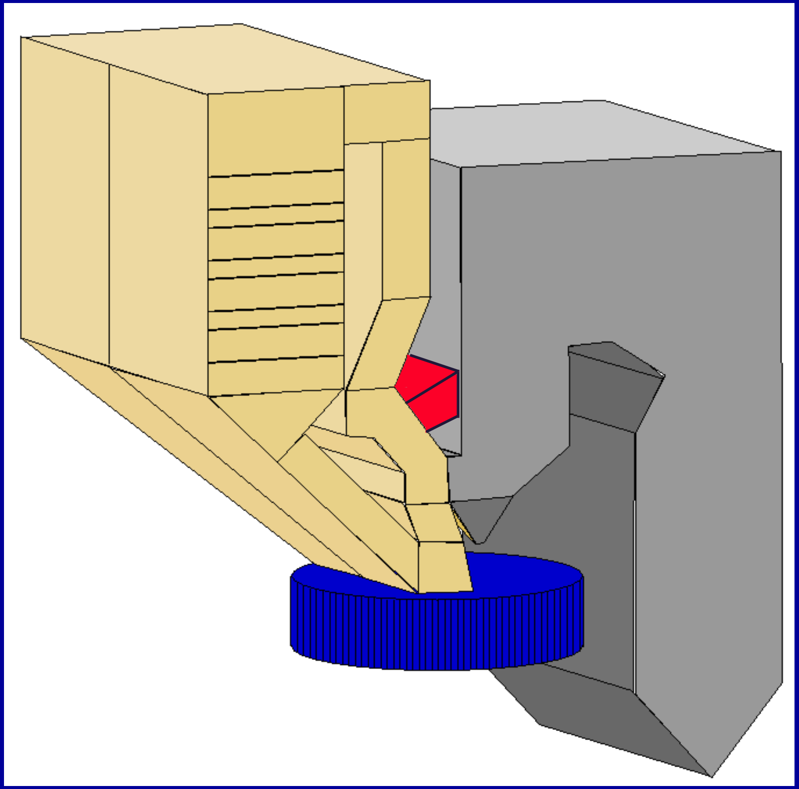
- Dense grid AIG
  - Measure inlet or outlet NOx profile
  - Establish spatial correlation of NH3 zones to catalyst inlet
  - Tune NH3 injection to the NOx profile via zone control valves
  - Verify over the load range
- Coarse grid AIG
  - Design the mixer system properly
  - Inject NH3
  - Verify performance over the load range
  - Tune AIG if possible

SCR Temperature Mixing

- Temperature gradient at the catalyst inlet should be minimized
  - Typical goal is +/- 20 °F maximum variation from average
  - Reduces areas of potential ABS formation on catalyst
- What causes temperature stratification?
  - Economizer bypass systems
  - Boiler exit plane non-uniformities

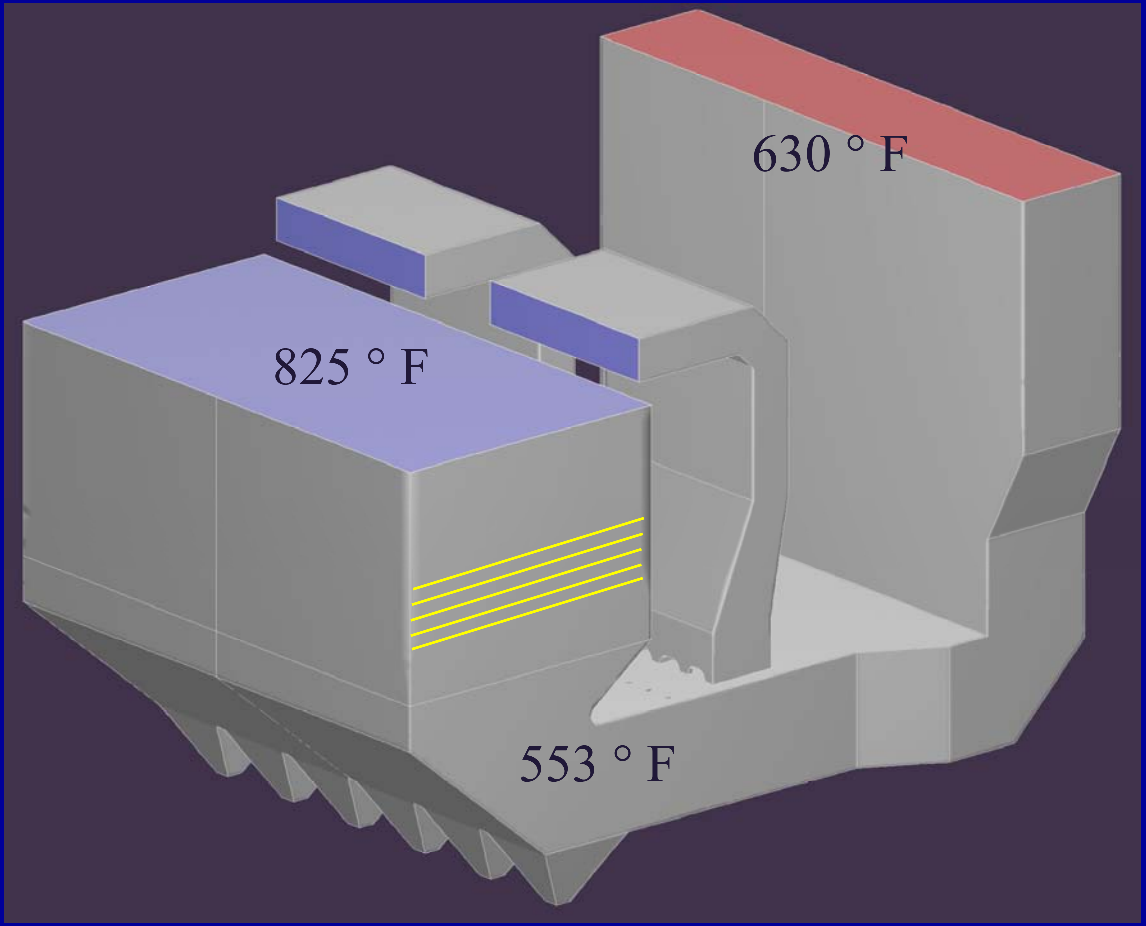
Economizer Bypass Systems

- Used to boost SCR inlet gas temperature under low load operation
- Extract hot gas at econ inlet
- Inject into cooler econ outlet stream
- Sounds simple enough, but there are many options and competing design elements



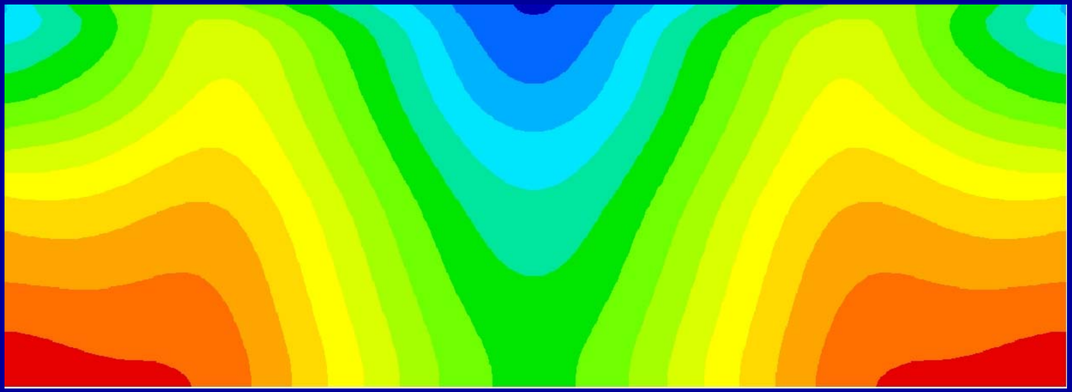
Economizer Bypass Design Features

- Ductwork
  - Size
  - Layout
  - Waterwall opening
  - Materials
- Dampers
  - Type
  - Location
- Static mixers
  - Design
  - Location



Economizer Bypass Issues

- Not enough bypass flow
  - Difficulty attaining desired minimum load
- Sub-optimal mixing
  - Thermal gradient at catalyst
- Damper operation
  - Draft control problems
  - Damper erosion

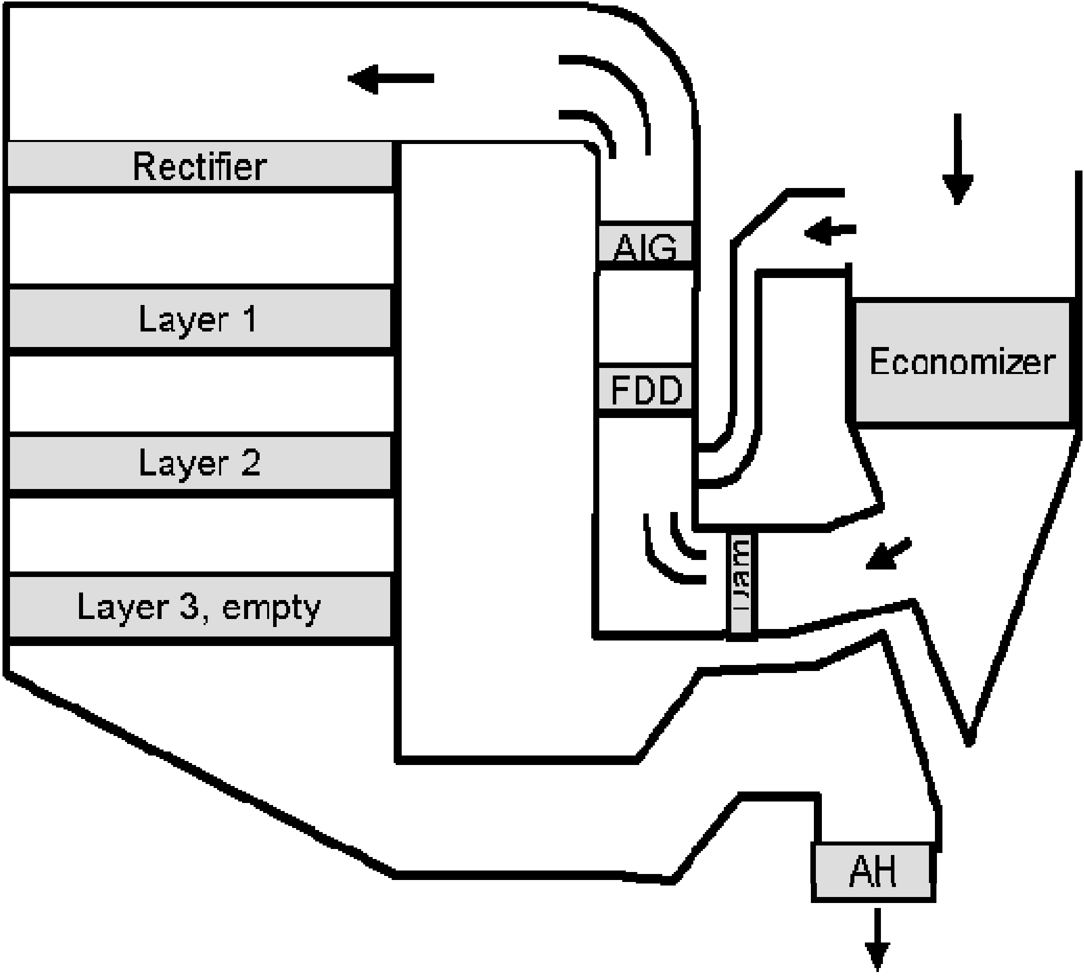


Outline

- Introduction
- Mixing and SCR Performance
- SCR Case Studies
  - IPL Harding Street 7
  - Midwest SCR
- Other Power Plant Mixing Issues
- Summary

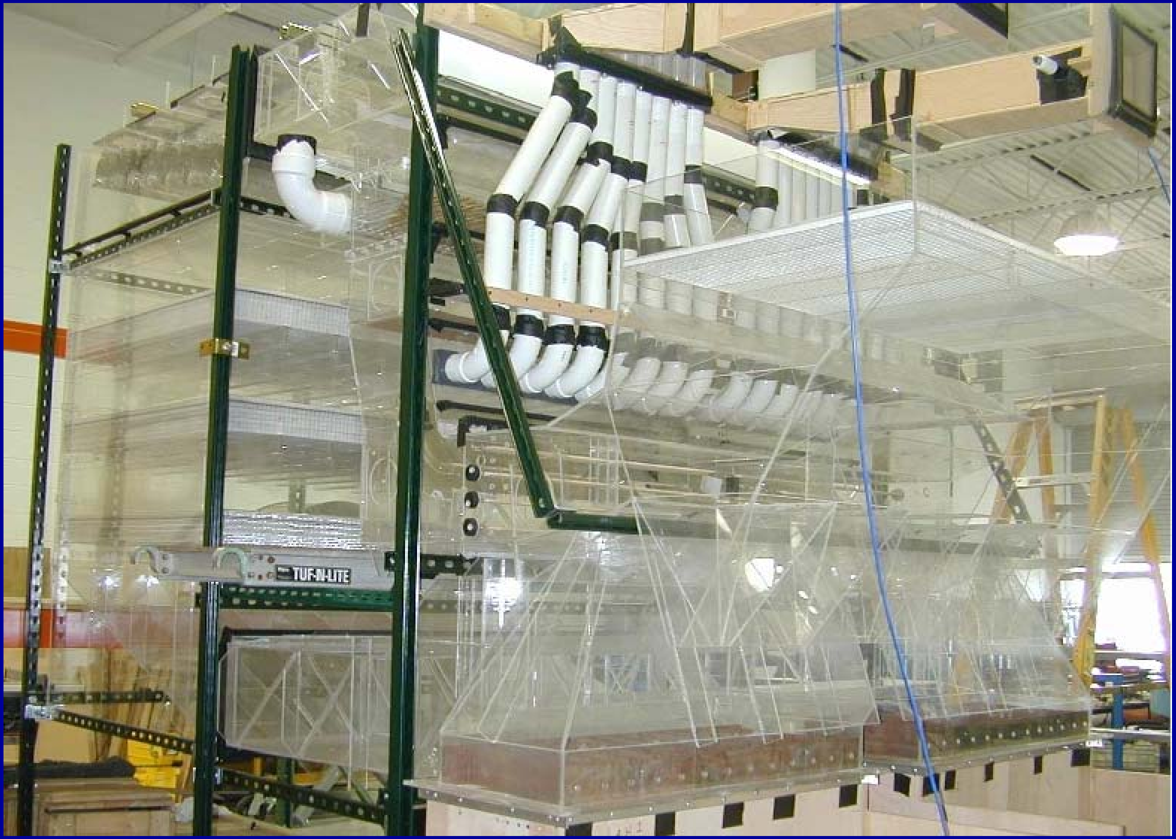
SCR Case Study – IPL Harding Street Unit 7

- 470 MW
- Single reactor
- Dense grid AIG
- Economizer bypass



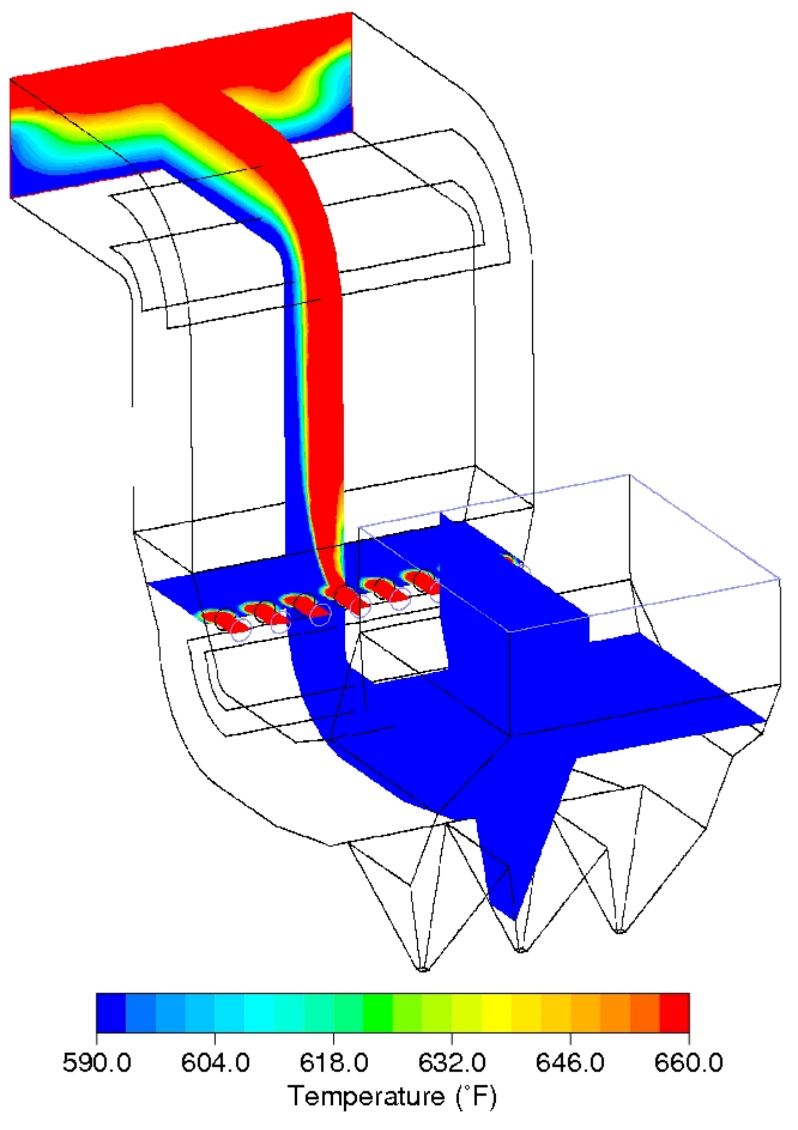
Harding Street 7 Economizer Bypass

- Catalyst design temperature 630 °F
- Economizer bypass required for low and mid load operation
- Mixing goal: ΔT at catalyst ±20 °F
- Initial design of economizer bypass ductwork
  - Two 5’x5’ takeoffs in backpass
  - Split to sixteen 18” pipes



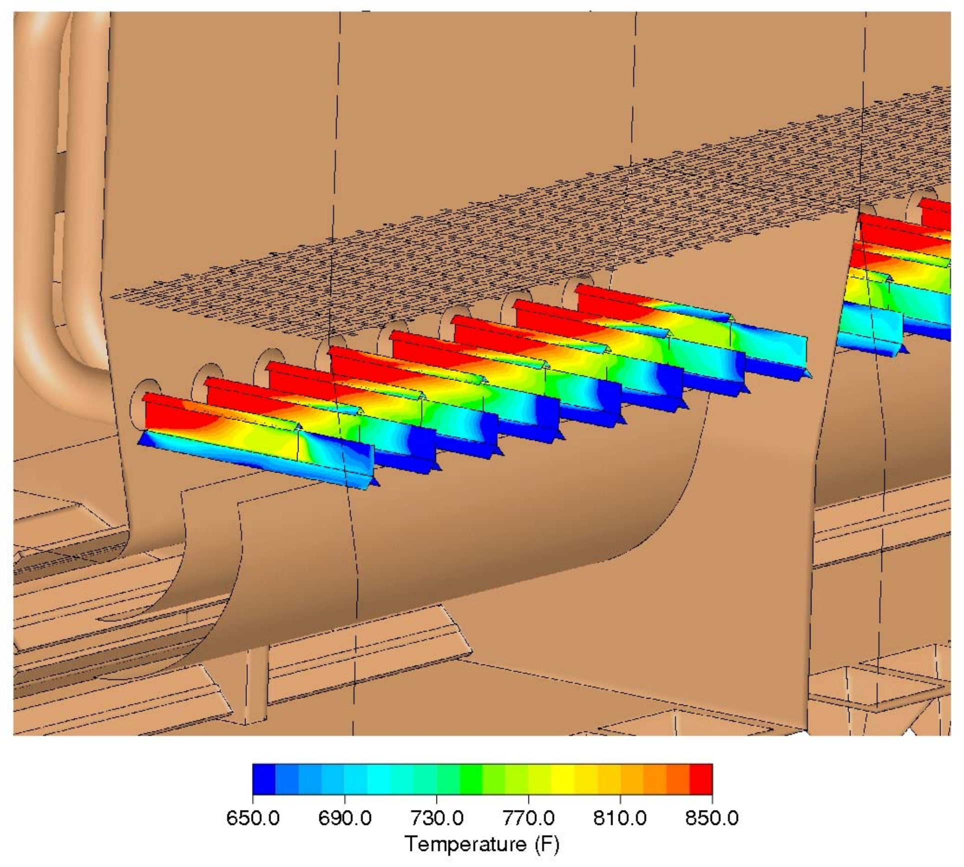
Harding Street 7 Economizer Bypass

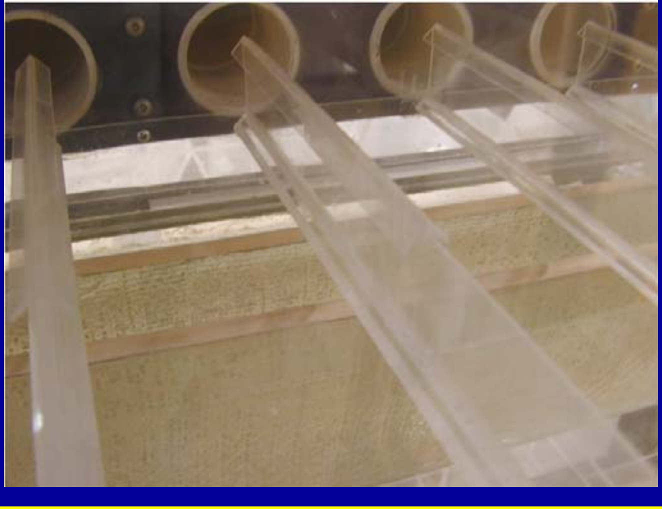
- Baseline CFD runs indicate bypass flow is well distributed East-West, but not North-South
- Low Load ΔT at catalyst ±120 °F
- Bulk static mixer not desired
- Mixer designed at hot gas injection point to reduce North-South gradient



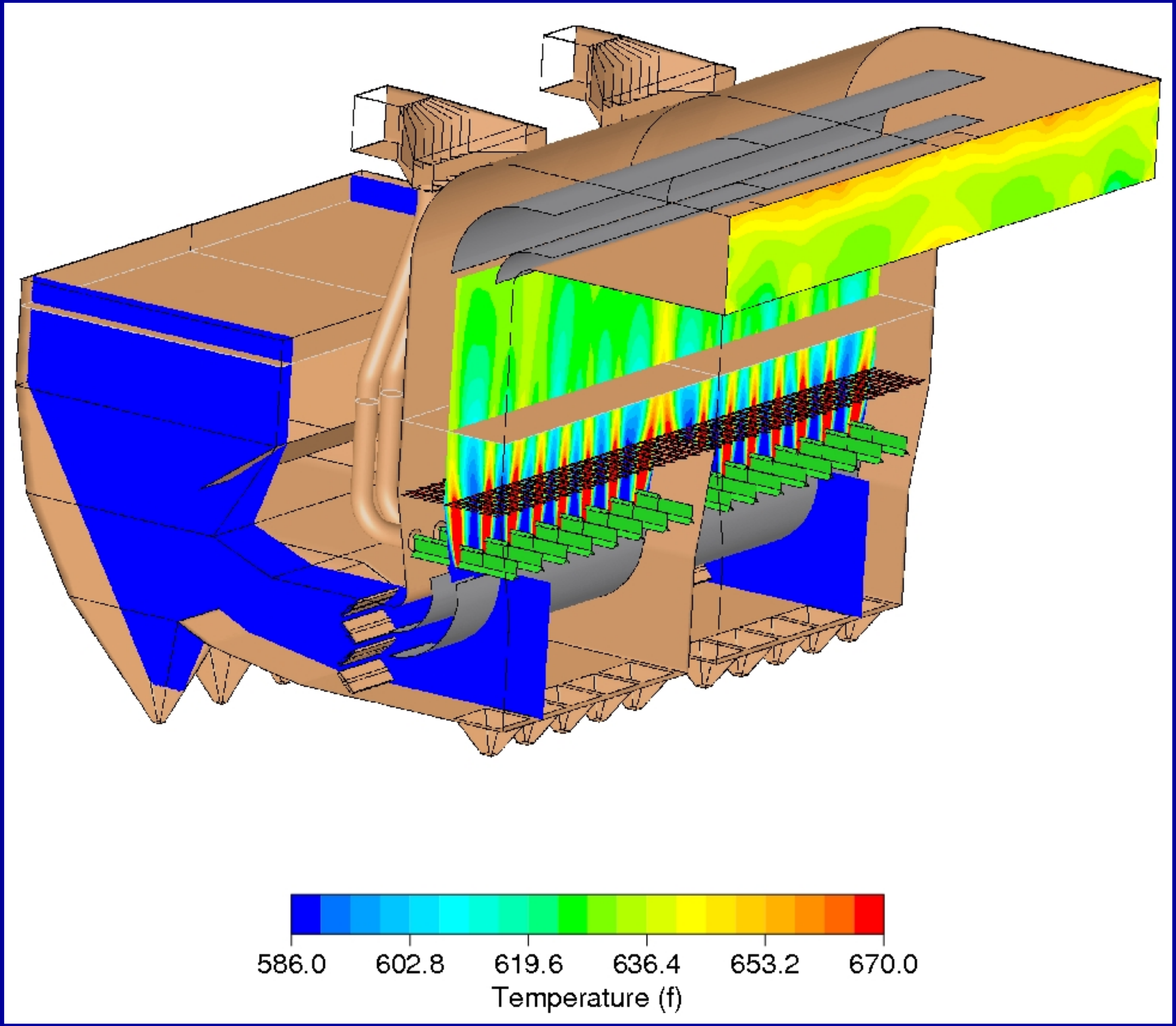
Harding Street 7 Economizer Bypass

- Mixer elements based on patented design
- CFD runs performed to optimize thermal mixing with minimum full load pressure loss
- ΔT at catalyst ±20 °F





Harding Street 7 Economizer Bypass



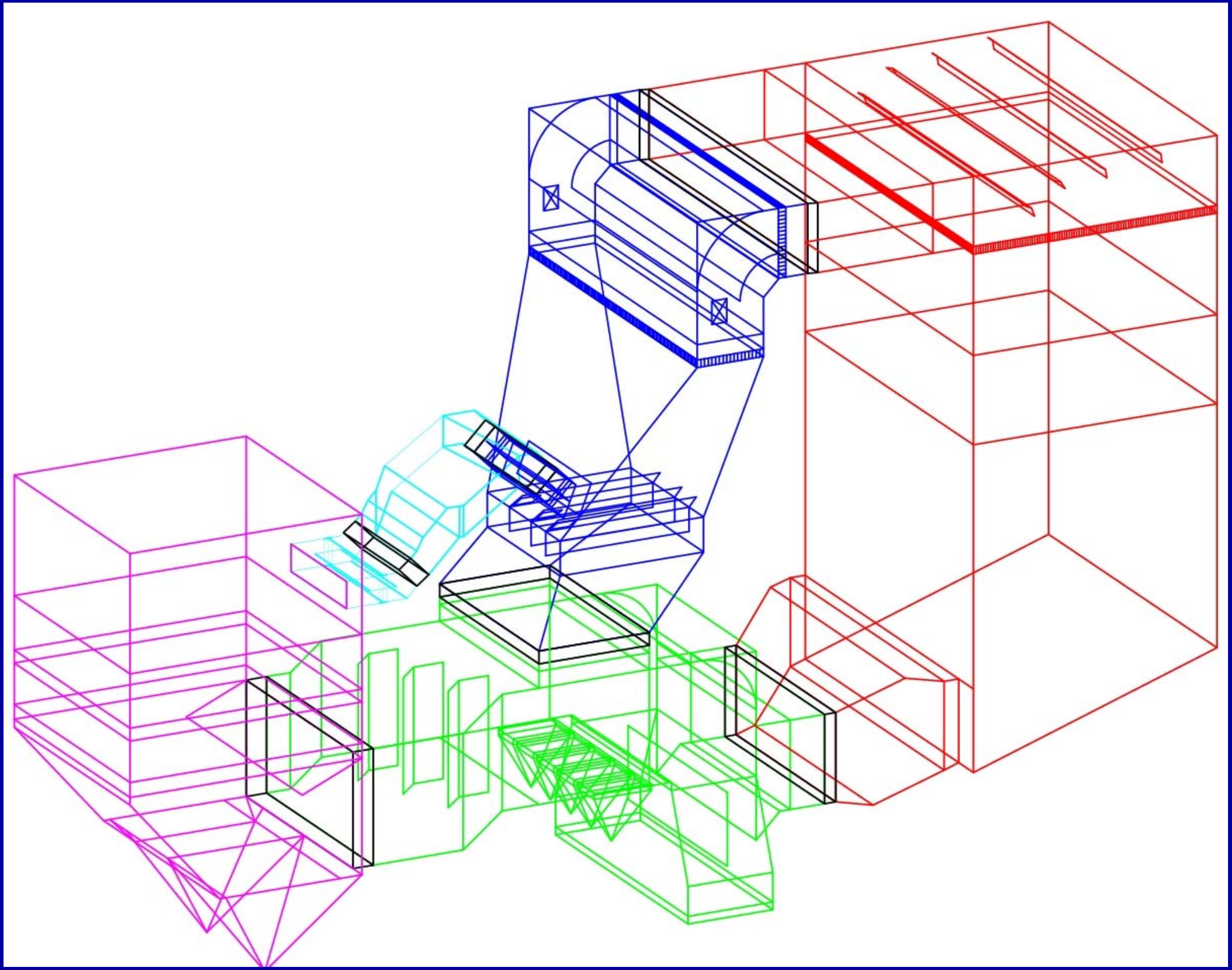
Harding Street 7 Economizer Bypass

- Low Load
  - ΔT at catalyst ±20 °F
- Mid Load
  - ΔT at catalyst ±22 °F
- Operating experience since start up May 2005
  - No problems achieving low load turndown
  - NOx reduction guarantees met

Case Study – Existing Midwest SCR

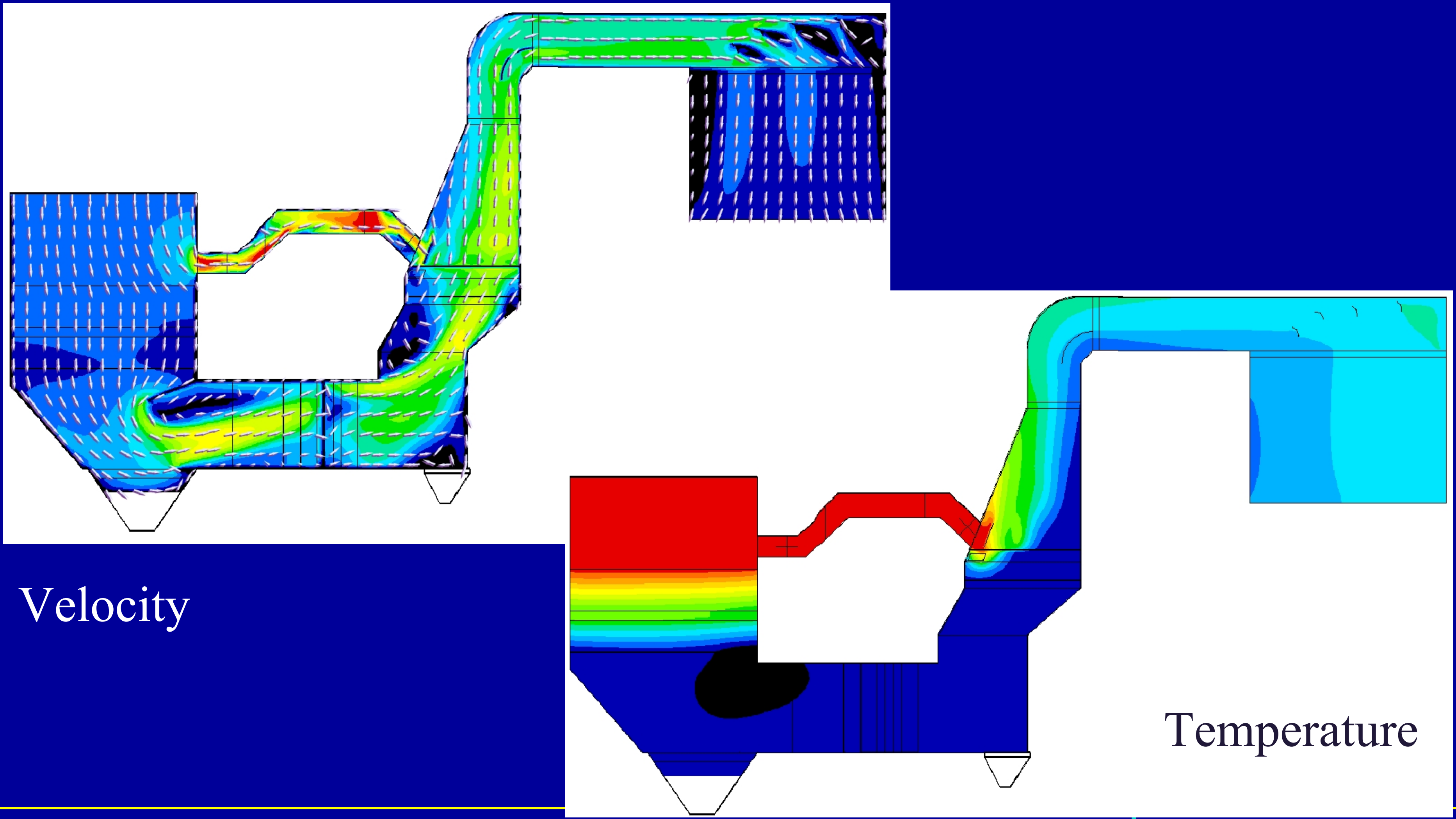
- 600 MW Unit
- Turndown to 250 MW desired with SCR in operation
- Sub-optimal thermal mixing of economizer bypass flow only allows turndown to ~380 MW
  - Thermocouple grid at SCR inlet detects local temperatures below the minimum NH3 injection temperature
  - Field testing at catalyst inlet shows local temperatures as low as 540 °F
- Rapid-pace CFD effort was performed to meet outage schedule for modification installation

Case Study – Existing Midwest SCR



Case Study – Existing Midwest SCR

- Baseline CFD model indicates ΔT at catalyst ±75 °F



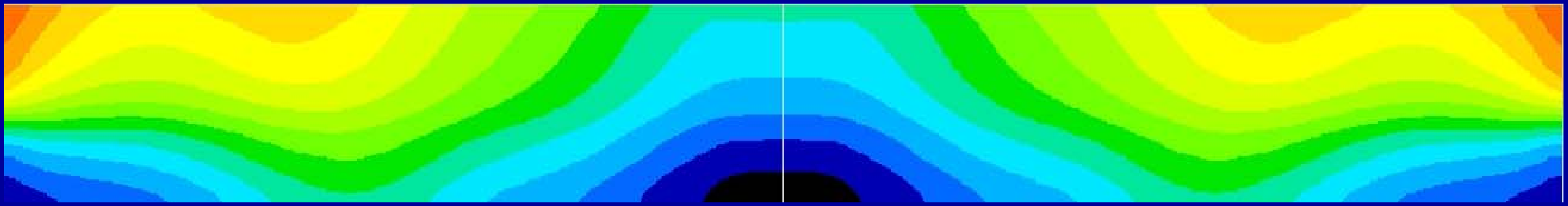
Velocity

Temperature

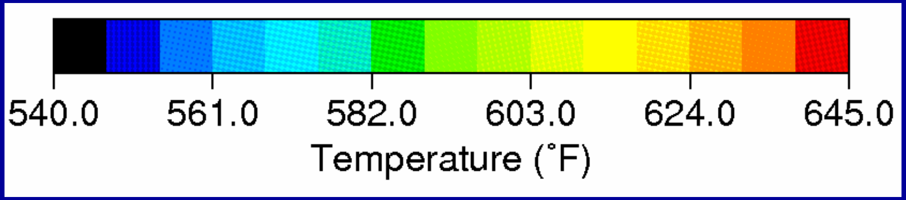
Case Study – Existing Midwest SCR

- CFD model correlation with low load field data

Measured temperatures, horizontal duct at reactor inlet

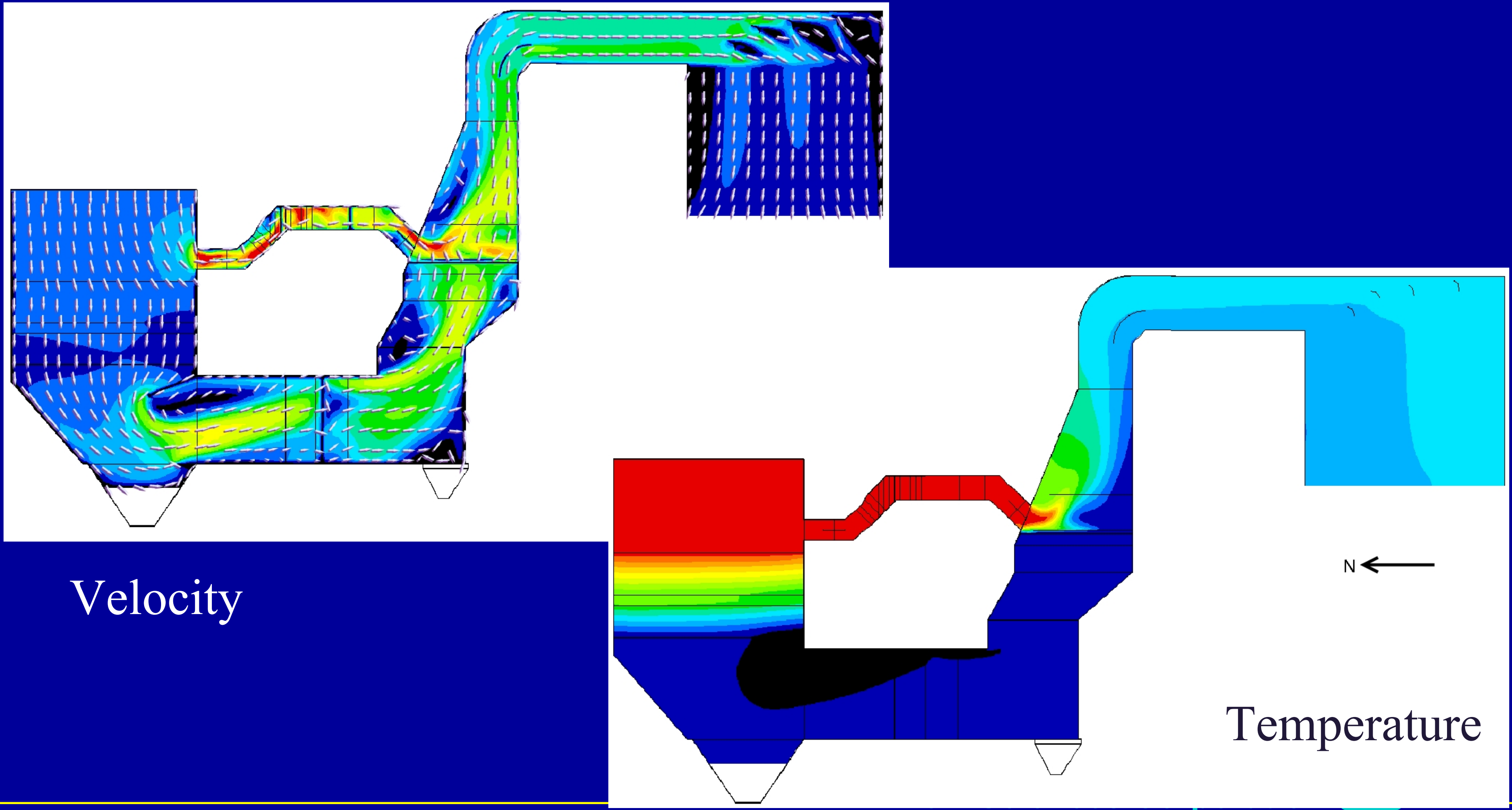


CFD temperature prediction



Case Study – Existing Midwest SCR

- Final CFD design ΔT at catalyst ±18 °F

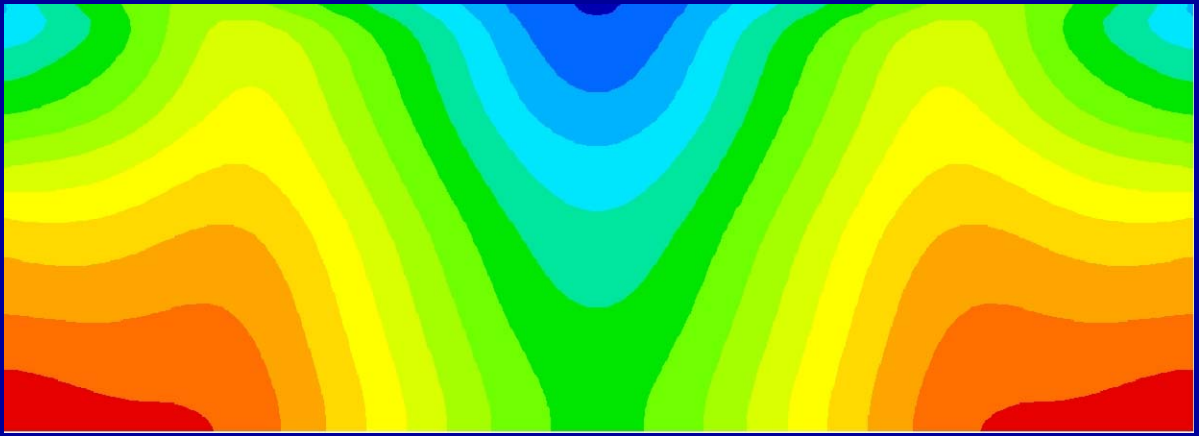


Velocity

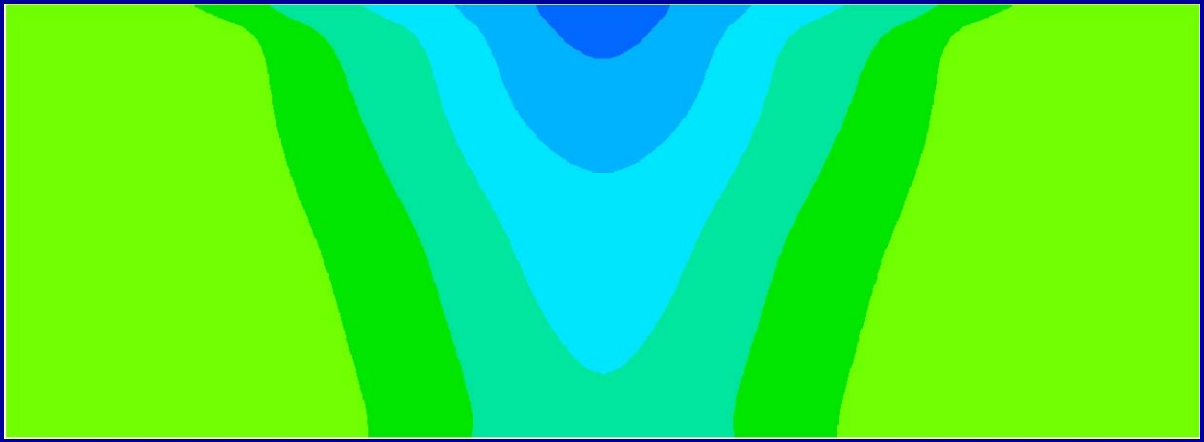
Temperature

Case Study – Existing Midwest SCR

- CFD temperature profile at catalyst inlet plane



Baseline



Design

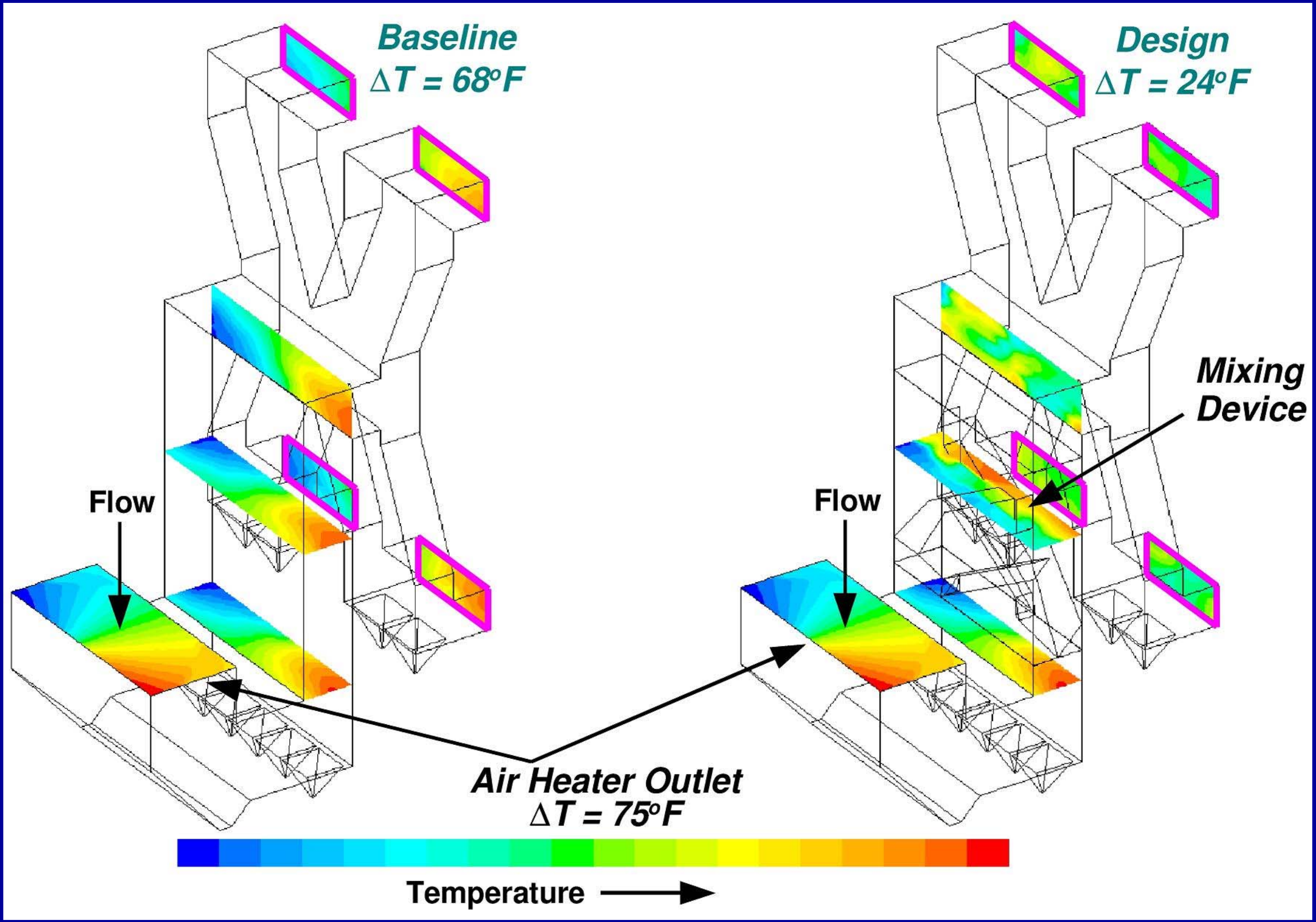
Case Study – Existing Midwest SCR

- Modifications installed Fall 2004
- Temperature uniformity at SCR inlet improved
- Unit turndown to ~300 MW with SCR operational
- Additional pressure loss of 0.5 inches H2O

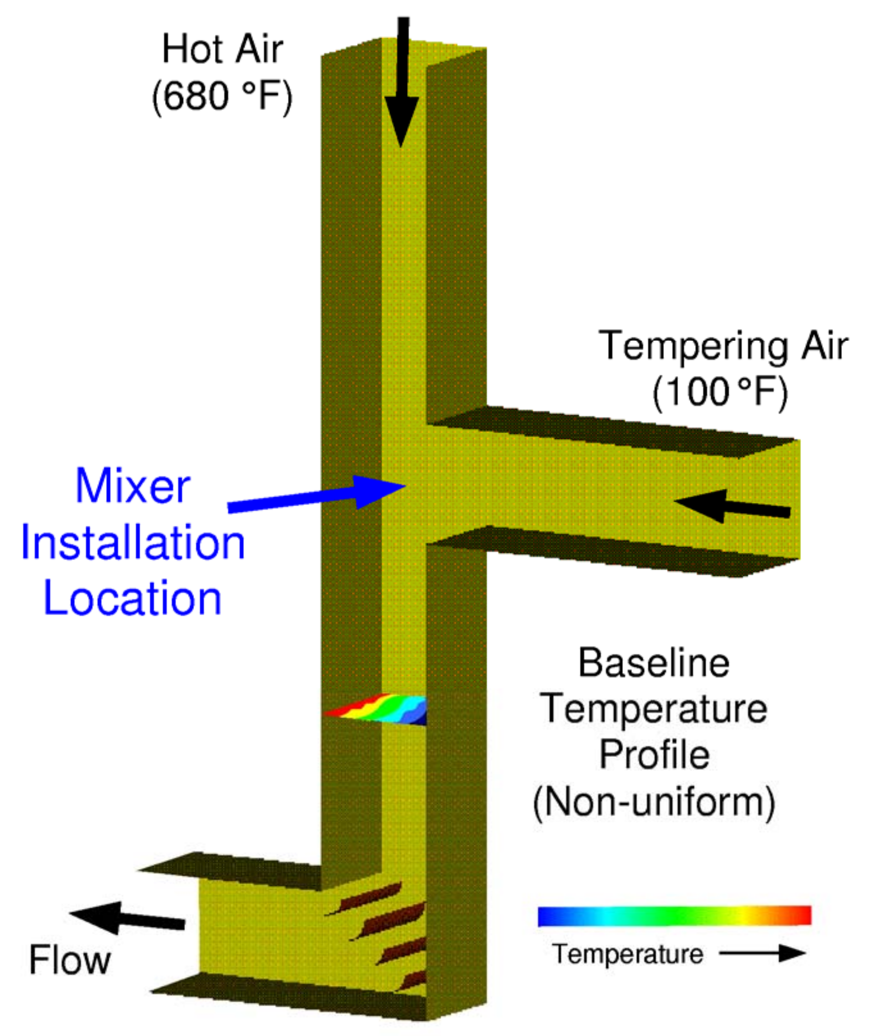
Outline

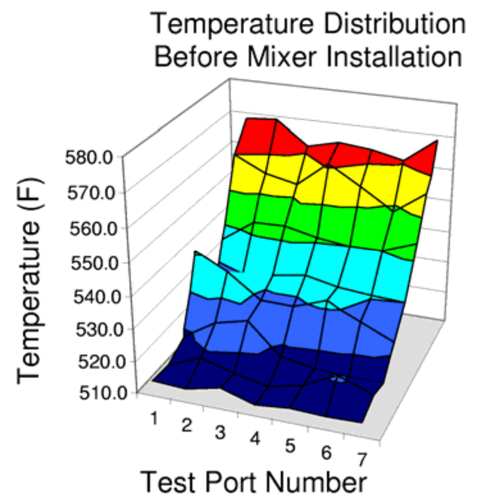
- Introduction
- Mixing and SCR Performance
- SCR Case Studies
- Other Power Plant Mixing Issues
  - Air Heaters / ESPs / FF
  - Injection Systems (SO3, carbon, SBS, …)
  - Pulverizers
  - Combustion optimization
- Summary

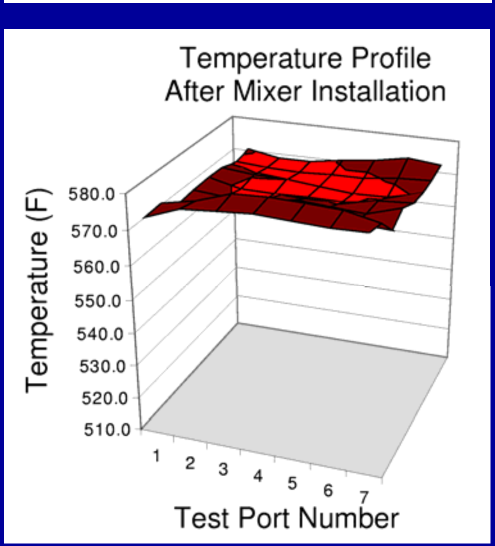
ESP Temperature Mixing



Pulverizer Temperature Mixing




Temperature Distribution Before Mixer Installation


Temperature Profile After Mixer Installation

Pulverizer Temperature Mixing

Summary

- Many power plant systems require adequate mixing of flow streams to perform optimally
- For SCRs: NH3, NOx, and temperature are key players
- For other APC equipment: chemical species and temperature are important
- For combustion: air and coal balancing are key
- Mixer design involves many competing criteria which must be understood and optimized

Flow Modeling Videos