Gas Flow – How to Improve It to Enhance ESP, Boiler, FGD, SCR, SNCR Performance

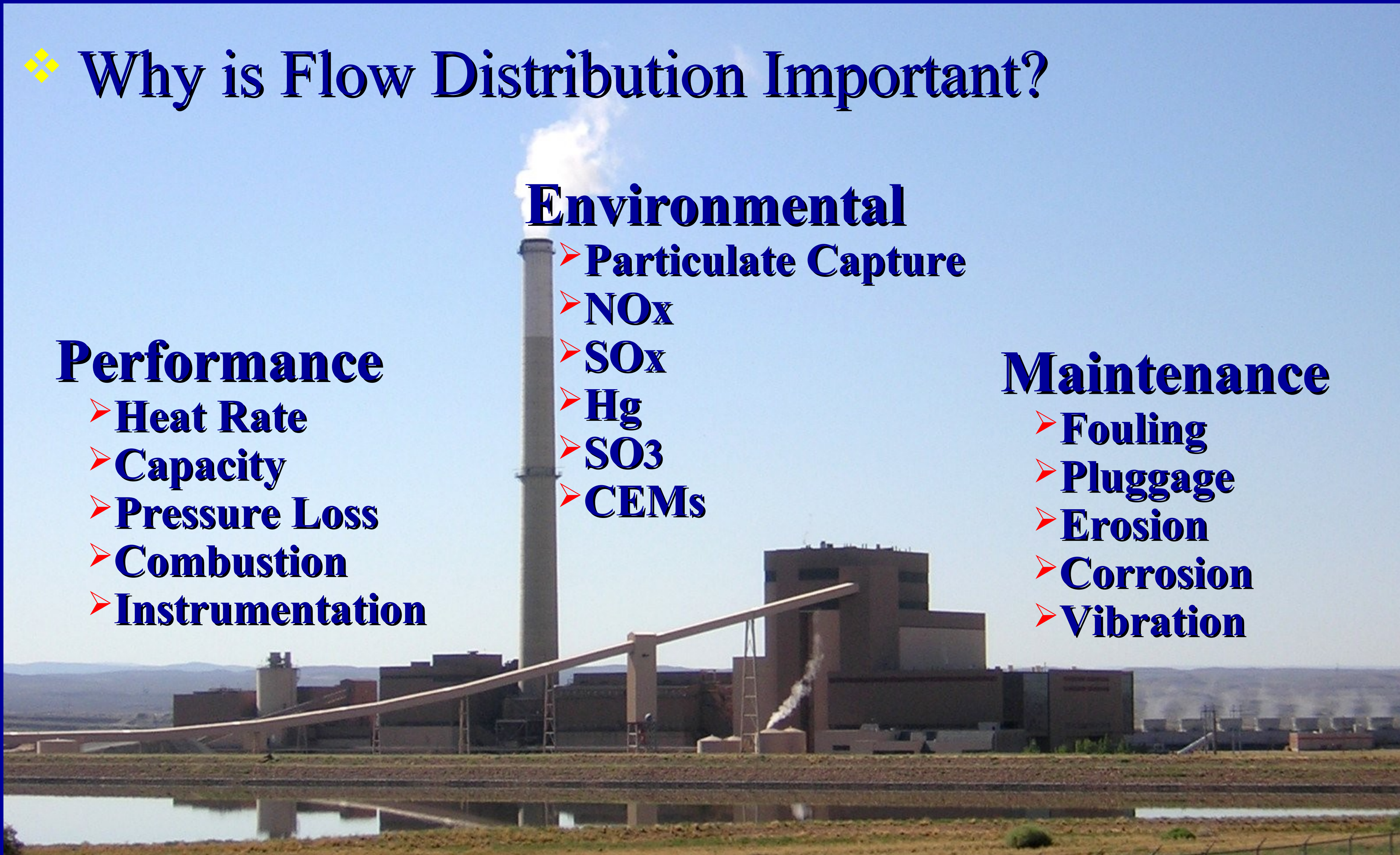
WPCA Seminar – Duke Energy
September 3, 2008

Robert Mudry, P.E.
Vice President – Engineering
Airflow Sciences Corporation
rmudry@airflowsciences.com

Outline

- Introduction
- Flow Distribution Analysis Techniques
- Application to Boilers
- Application to Air Pollution Control Equipment
- Other Applications
- Conclusions
- Questions

Introduction



- Why is Flow Distribution Important?

Performance
- Heat Rate
- Capacity
- Pressure Loss
- Combustion
- Instrumentation

Environmental
- Particulate Capture
- NOx
- SOx
- Hg
- SO3
- CEMs

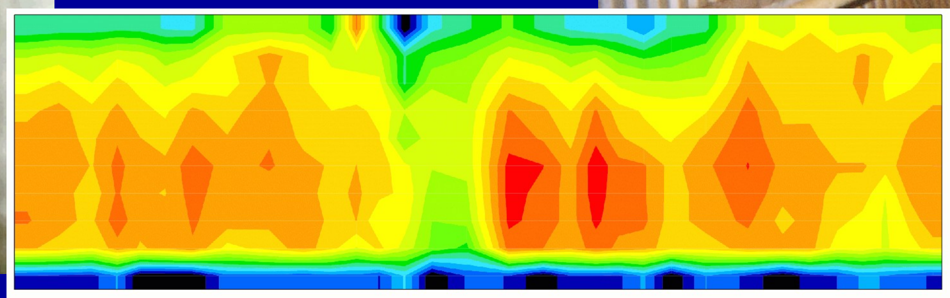
Maintenance
- Fouling
- Pluggage
- Erosion
- Corrosion
- Vibration

Outline

- Introduction
- Flow Distribution Analysis Techniques
  - Field Testing
  - Computational Fluid Dynamics (CFD)
  - Physical Flow Modeling
- Application to Boilers
- Application to APC Equipment
- Other Applications
- Conclusions
- Questions

Field Testing

- Velocity
- Temperature
- Pressure
- Particulate
- Chemical species

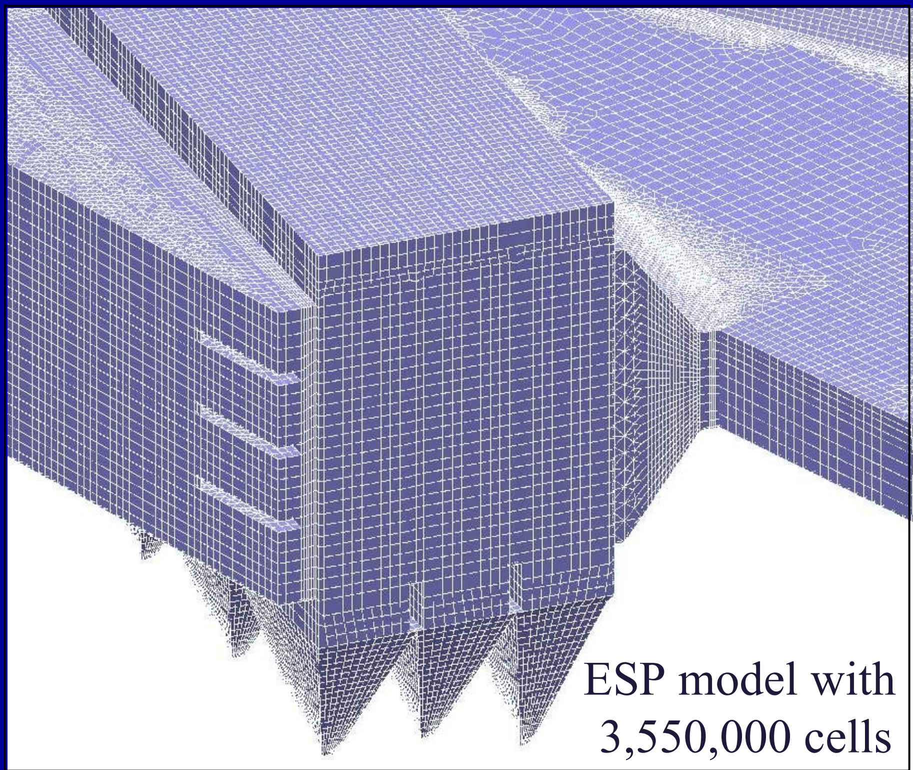


Computational Fluid Dynamics (CFD)

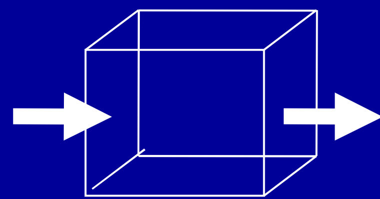
- Numerical simulation of flow
- Utilize high speed computers and sophisticated software
- Calculate flow properties
  - Velocity
  - Pressure
  - Temperature
  - Ammonia
  - Particle streamlines

Computational Fluid Dynamics (CFD)

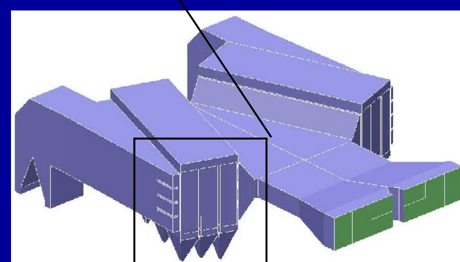
- Control Volume Approach
  - Divide the flow domain into distinct control volumes
  - Solve the Navier-Stokes equations (Conservation of Mass, Momentum, Energy) in each control volume



ESP model with 3,550,000 cells



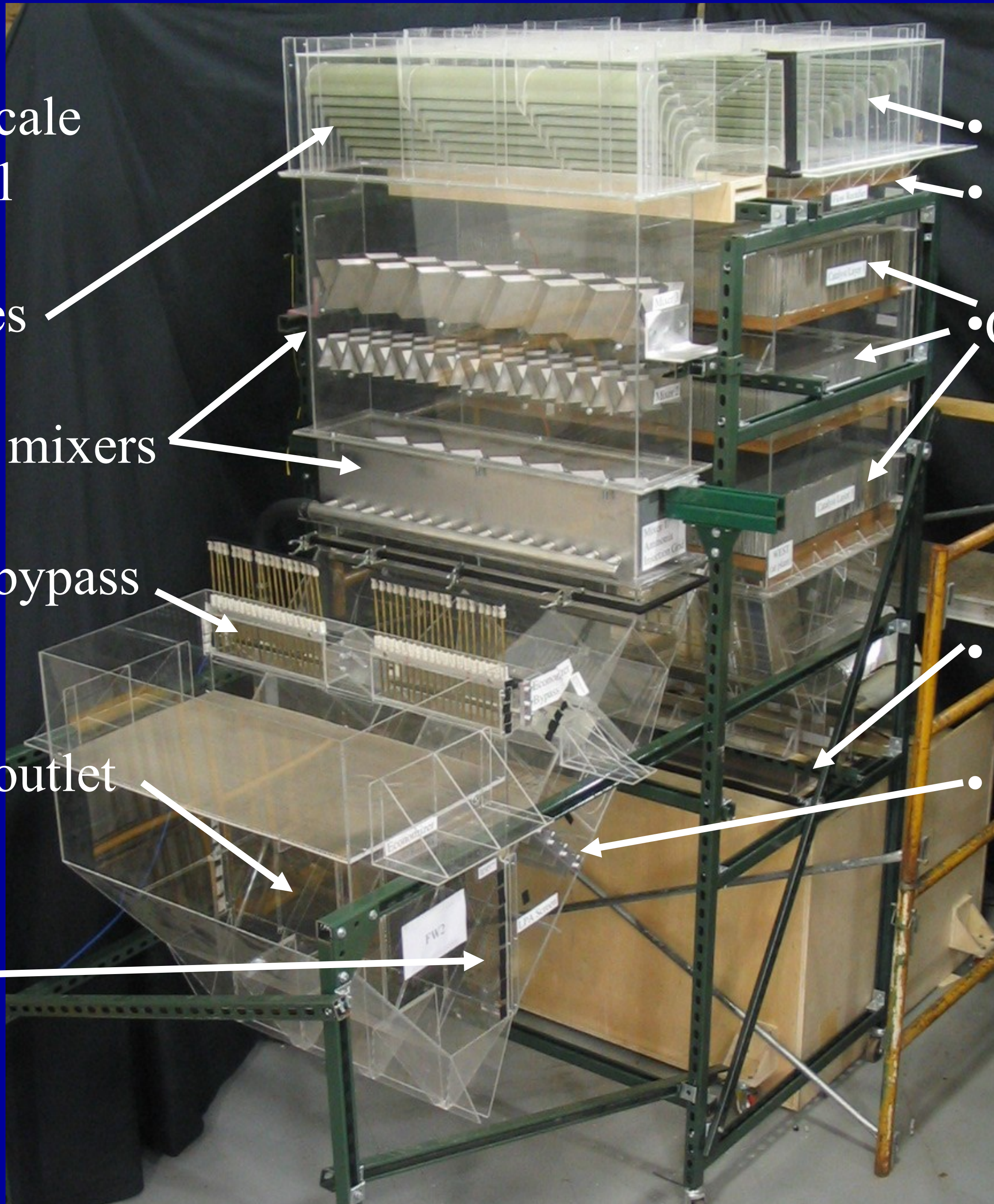
Control Volume or “Cell”



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
  - Tracer gas

Typical 1/12 scale physical model



- Turning vanes
- AIG w/static mixers
- Economizer bypass
- Economizer outlet
- LPA screen

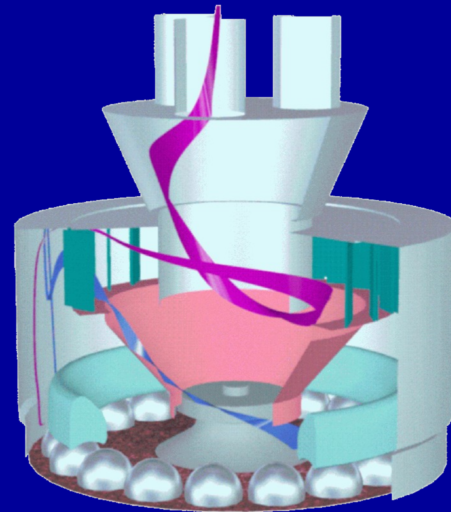
- Vanes
- Rectifier
- Catalyst layers
- Air heater
- Dampers

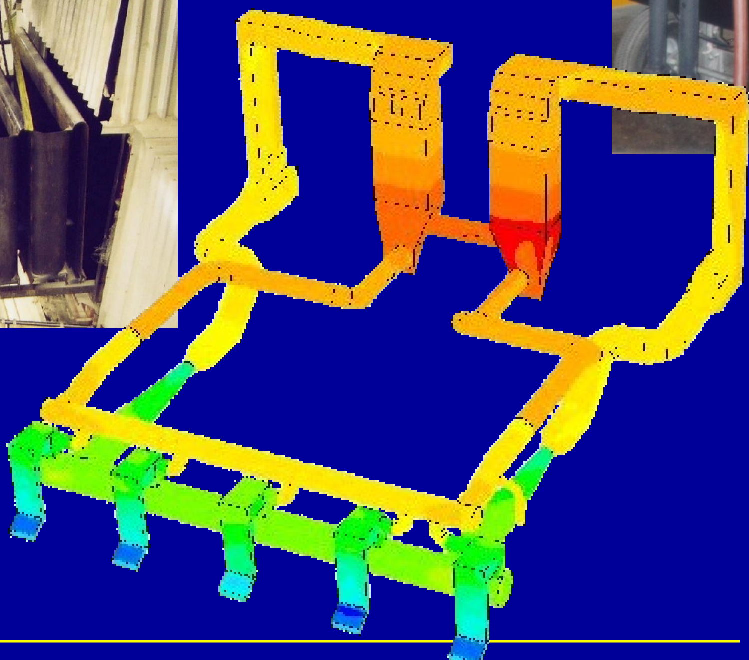
Outline

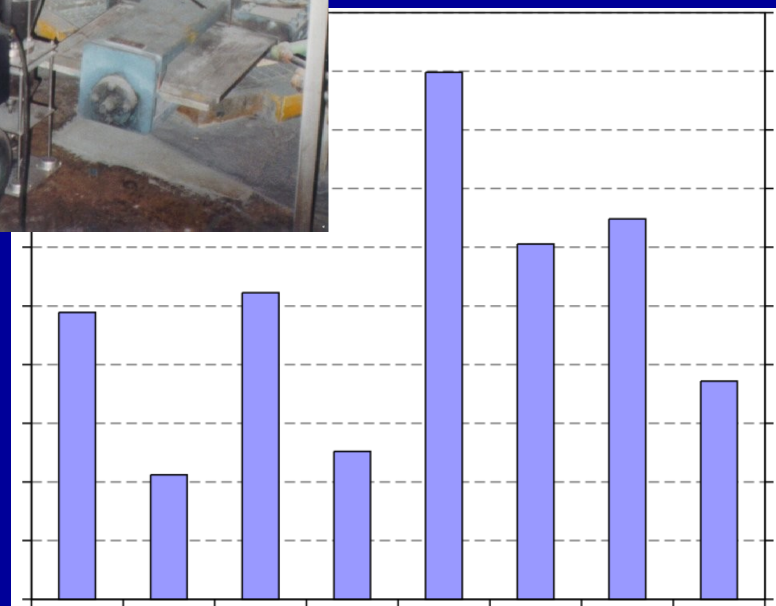
- Introduction
- Flow Distribution Analysis Techniques
- Application to Boilers
  - Primary / Secondary Air Systems
  - Furnace
  - SNCR
- Application to APC Equipment
- Other Applications
- Conclusions
- Questions

Primary Air / Coal Flow Balancing

- Optimize combustion
  - Balance PA flows
  - Equal coal flow per burner
  - Adequate fineness
- Modeling and testing

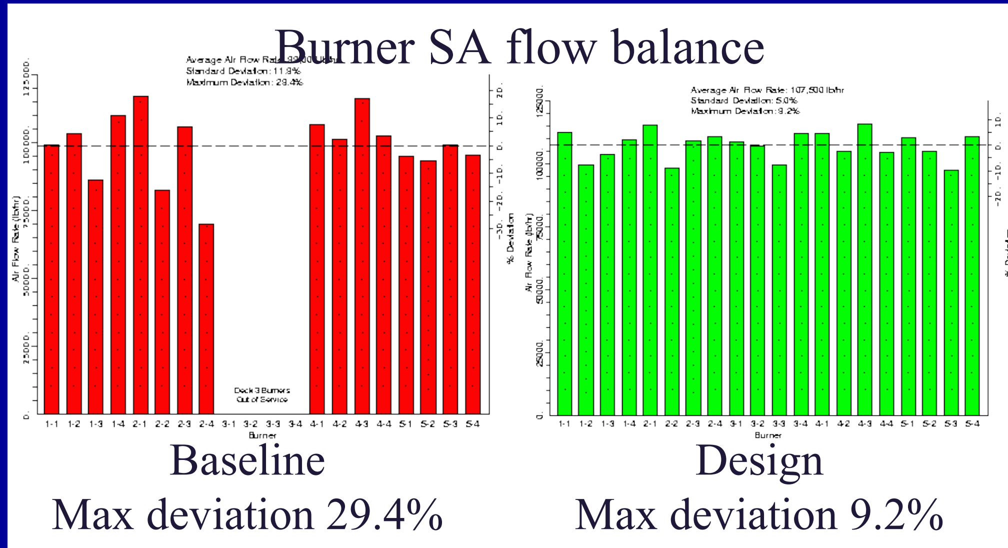


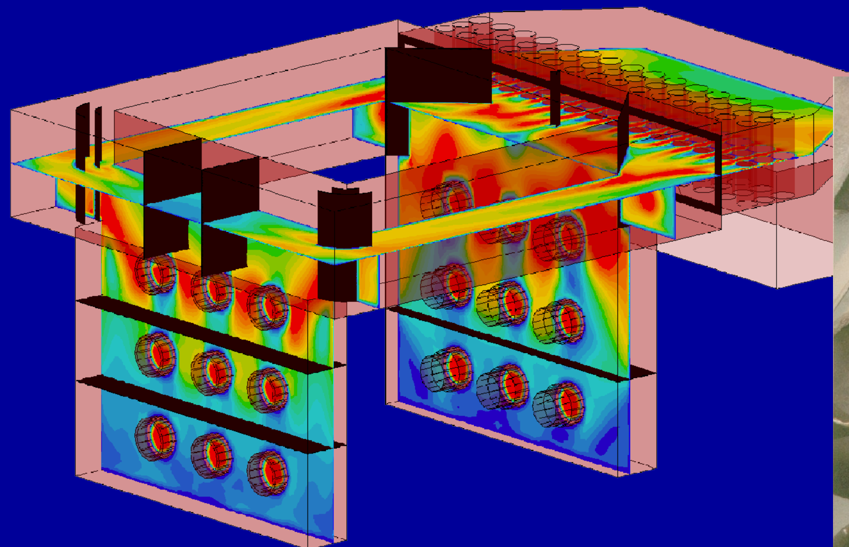




Windbox Flow Balancing

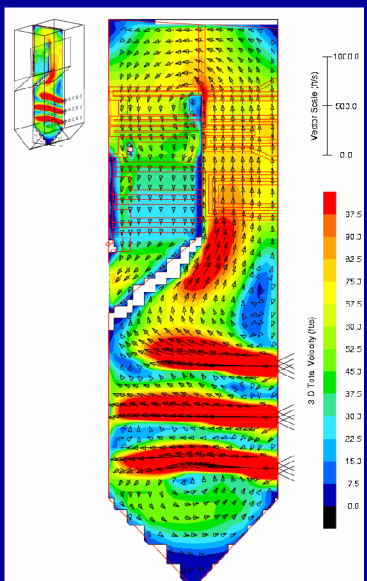
- Optimize combustion
  - Balance secondary air
  - Control flow entering burner (ram air effect)
- Modeling and testing

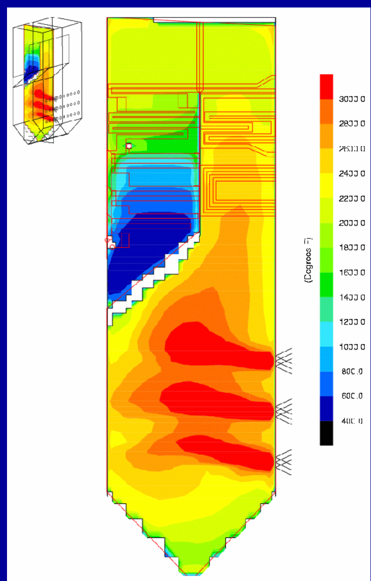


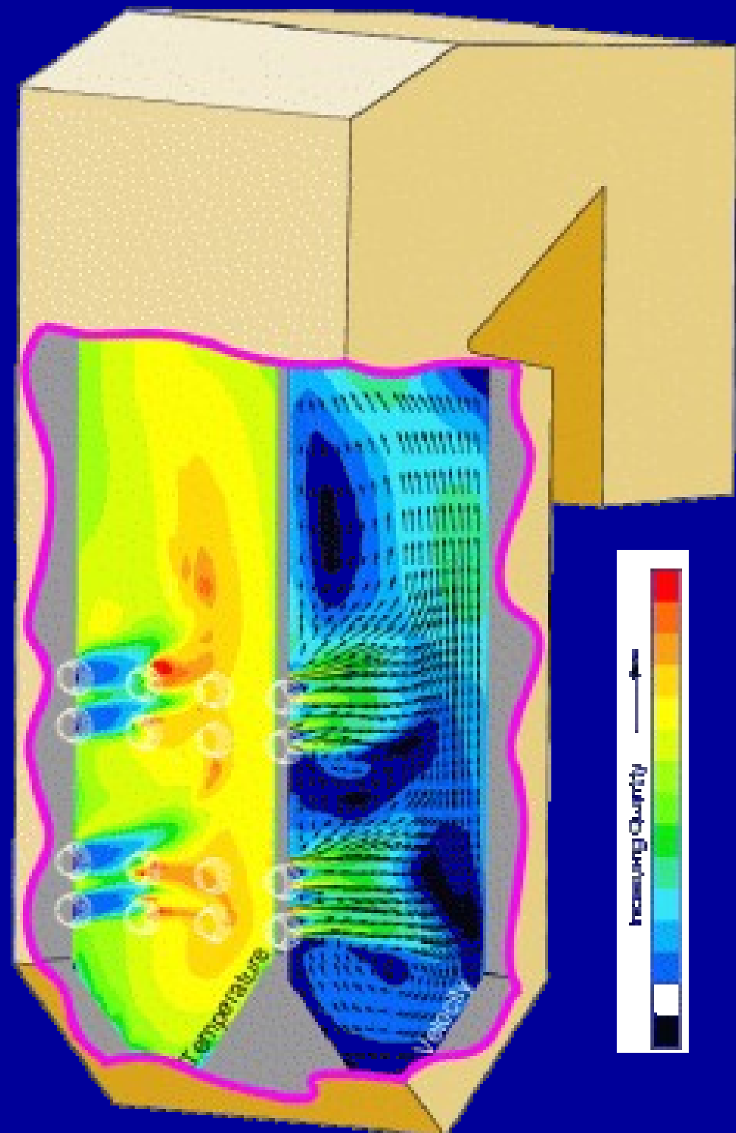


Furnace Combustion Optimization

- Typical goals
  - Reduce NOx
  - Minimize LOI
  - Improve heat transfer
  - Avoid corrosion
  - Decrease slagging

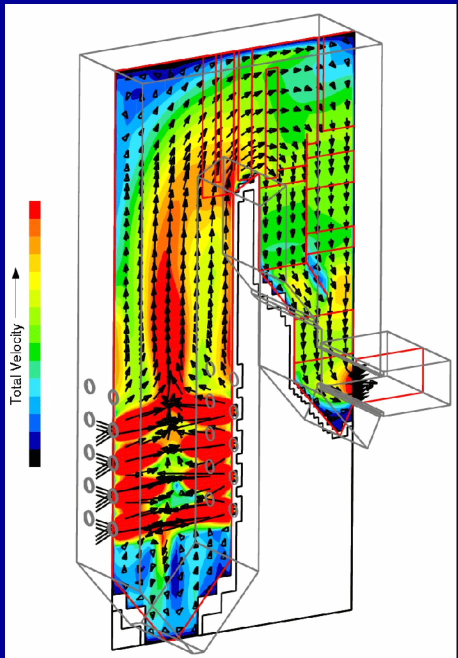


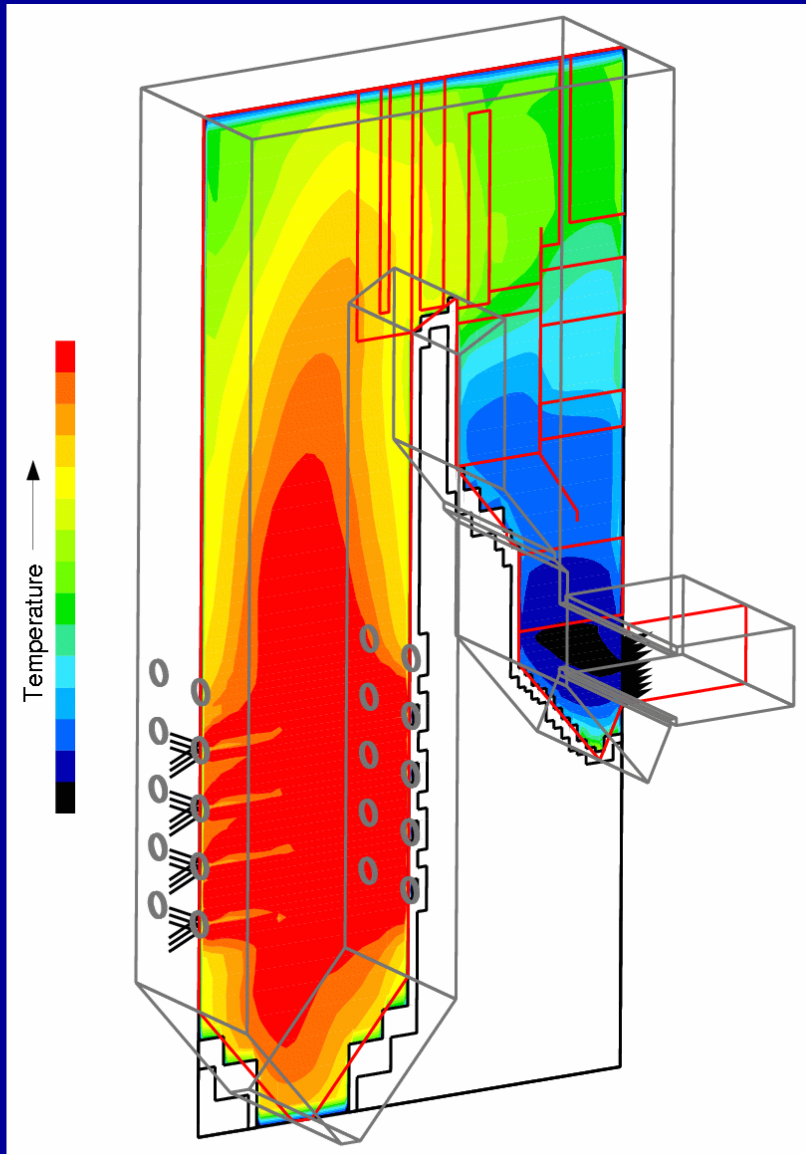




SNCR

- Performance is influenced by
  - Temperature distribution
  - Velocity patterns
- Testing and modeling used to optimize performance



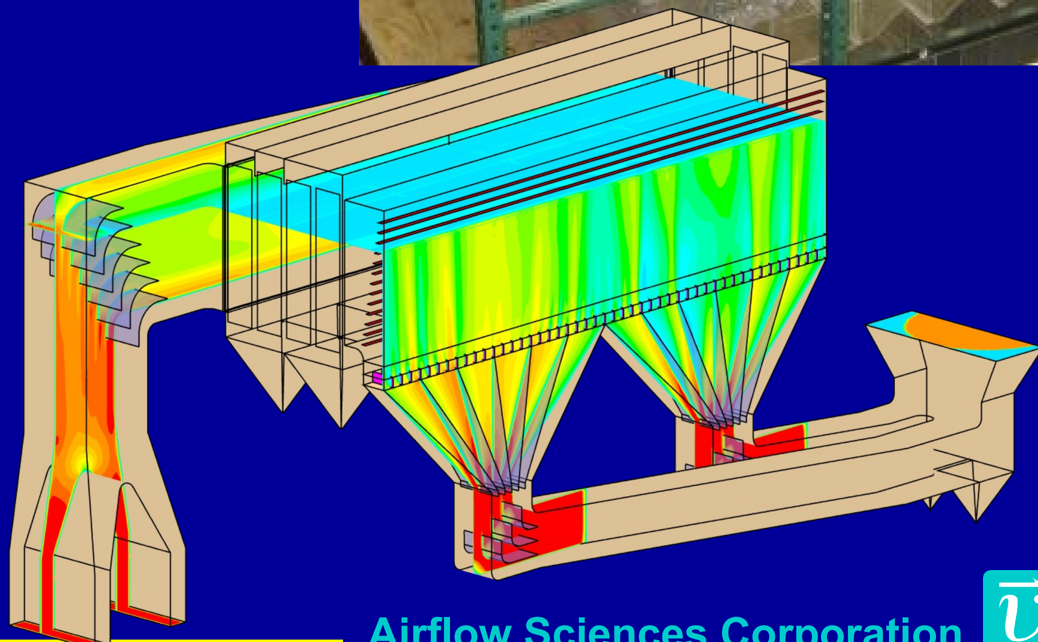


Outline

- Introduction
- Flow Distribution Analysis Techniques
- Application to Boilers
- Application to APC Equipment
  - ESP
  - FF
  - Mercury / SO3
  - SCR
  - FGD
- Other Applications
- Conclusions
- Questions

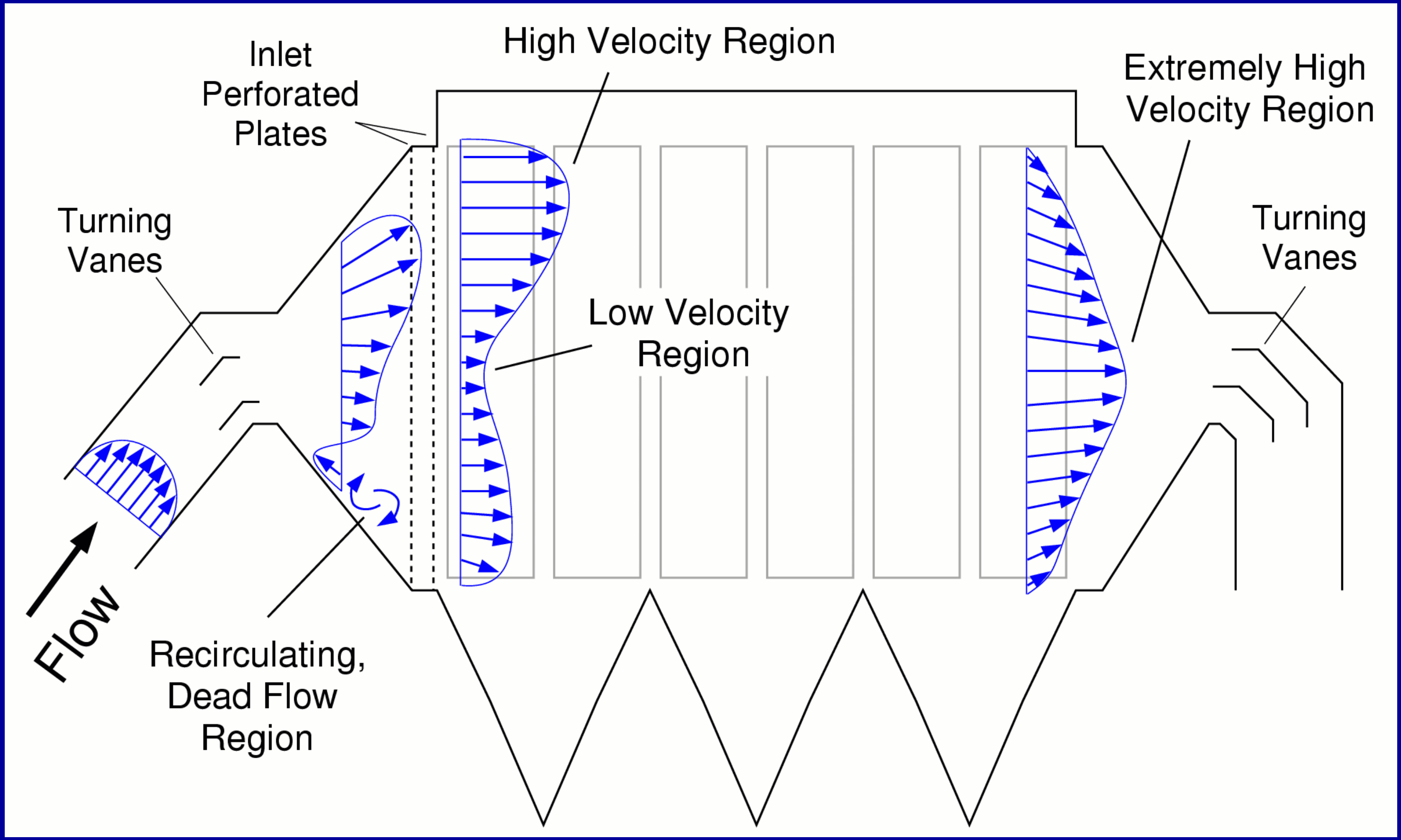
ESP Flow Optimization

- Flow distribution
- Flow balance between cells
- Pressure loss
- Thermal mixing
- Gas conditioning
- Ash deposition



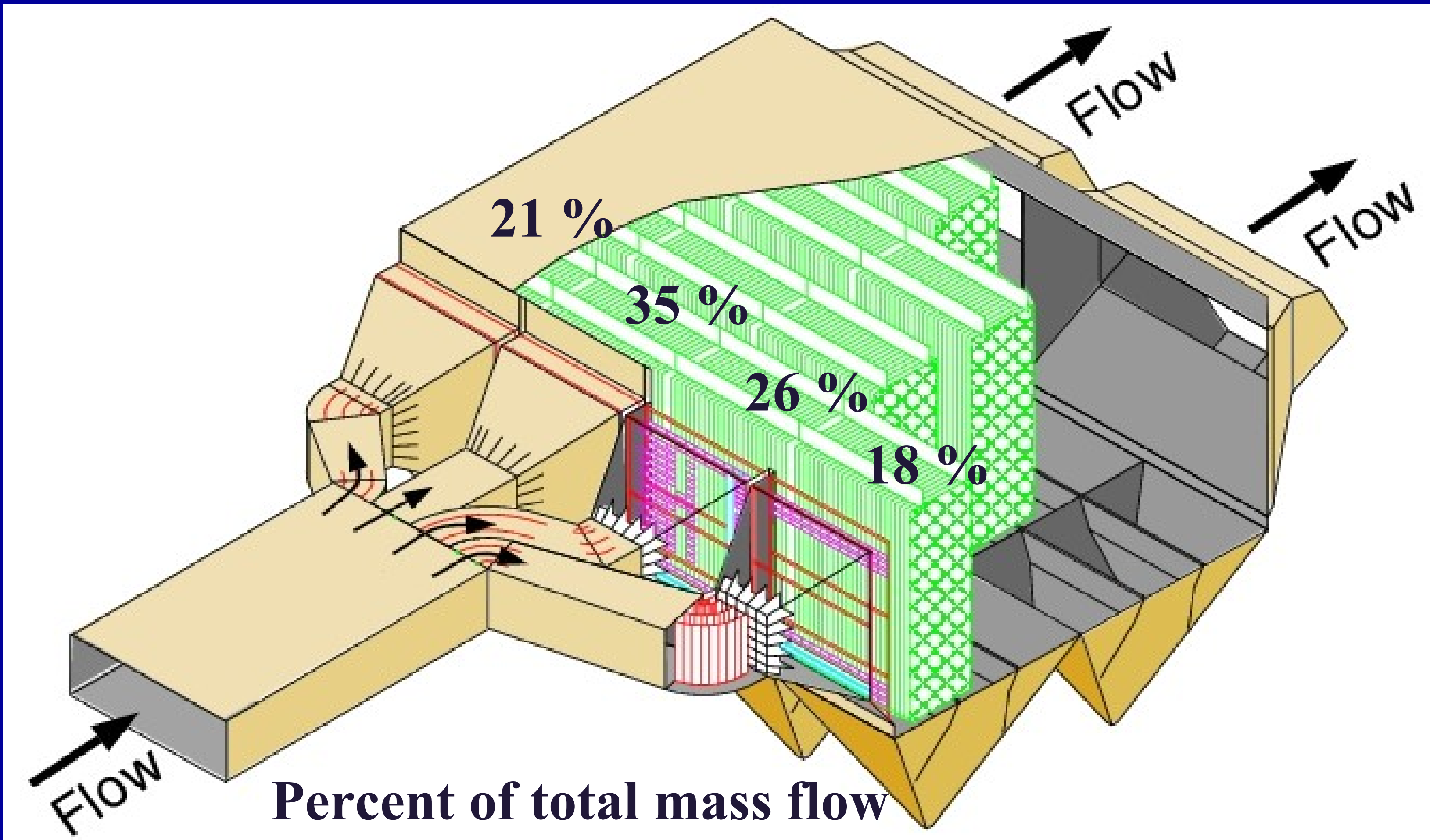
ESP Velocity Distribution

- Uniform velocity within collection region
- Industry standards
  - ICAC
  - % RMS deviation



Gas Flow Balance

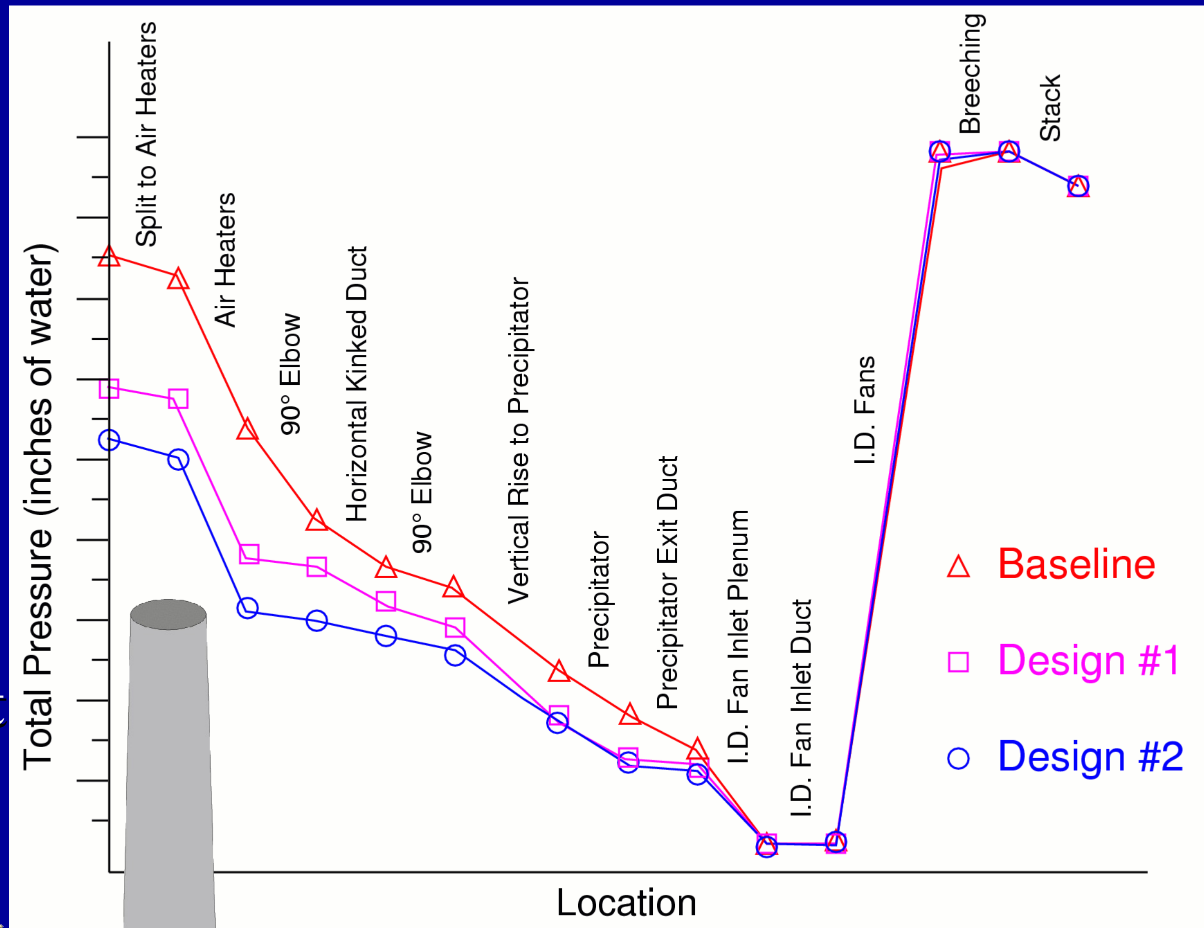
- Industry standard +/- 10% deviation

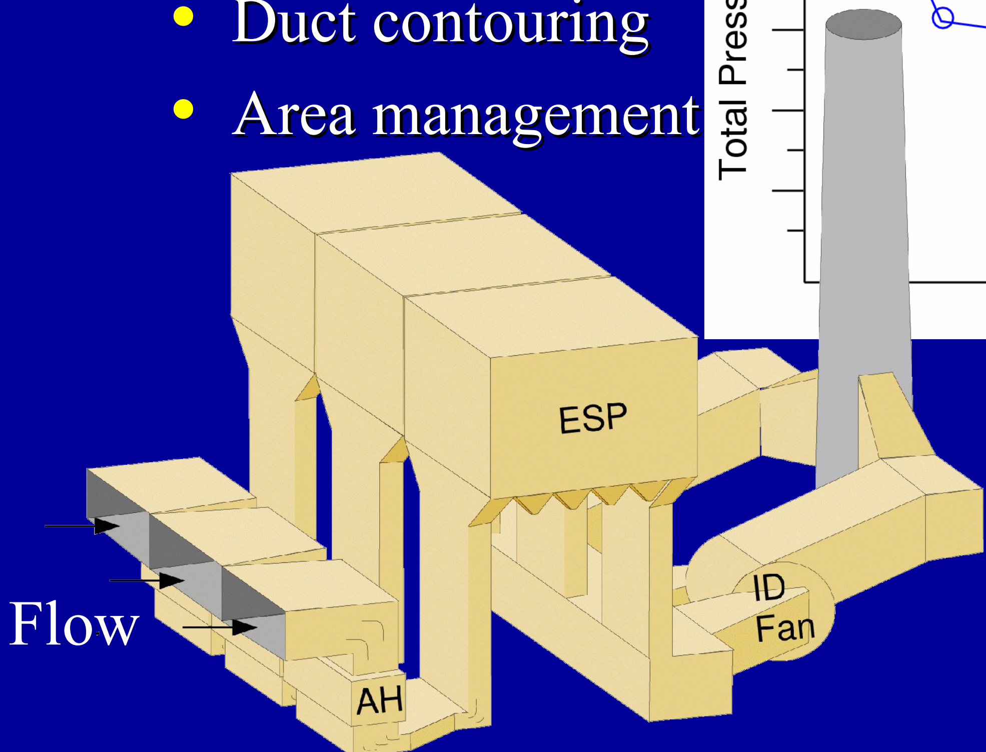


Percent of total mass flow through each chamber

Pressure Drop

- General goal:
  - Minimize DP
- Methods
  - Vanes
  - Duct contouring
  - Area management

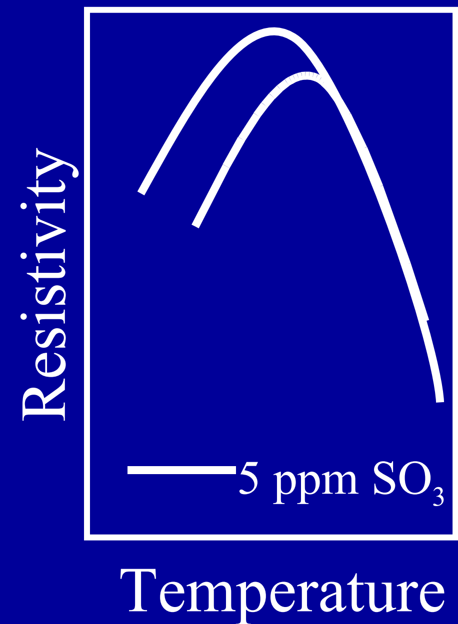




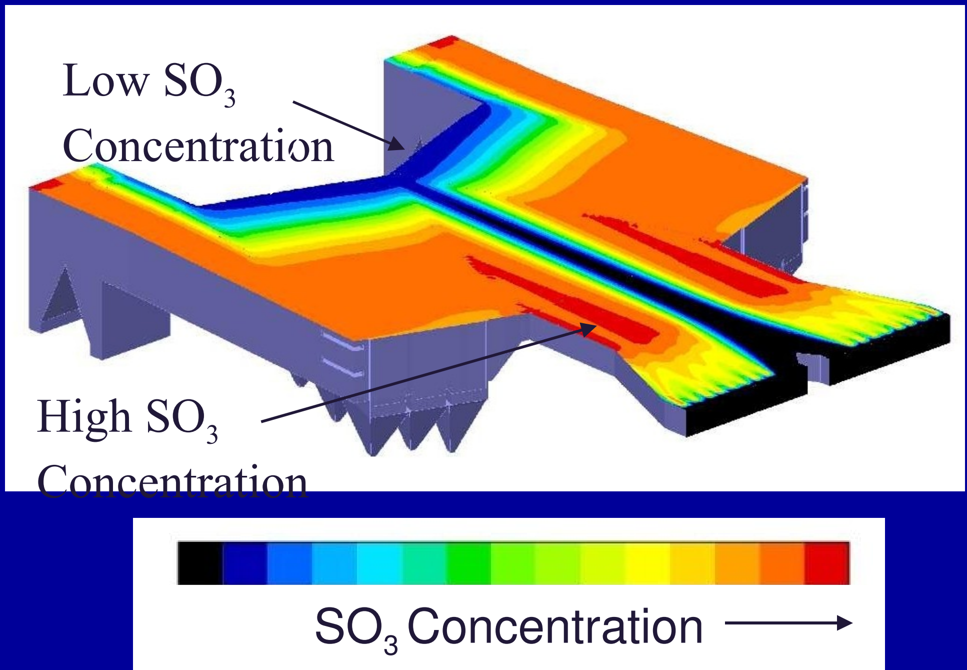
Ductwork redesign saves
2.1 inches H_2O over baseline

ESP Gas Conditioning

- Modify ash resistivity
  - SO_3, ammonia, others
- Alter gas density, viscosity
  - Humidification

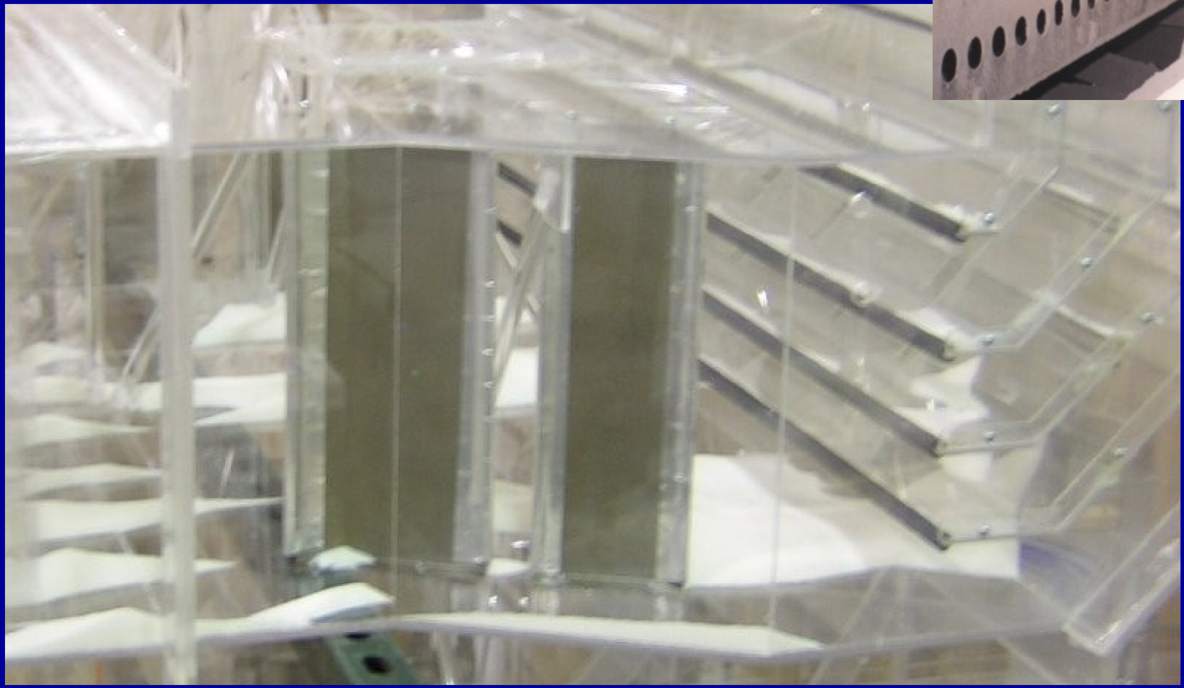


Humidification gone awry



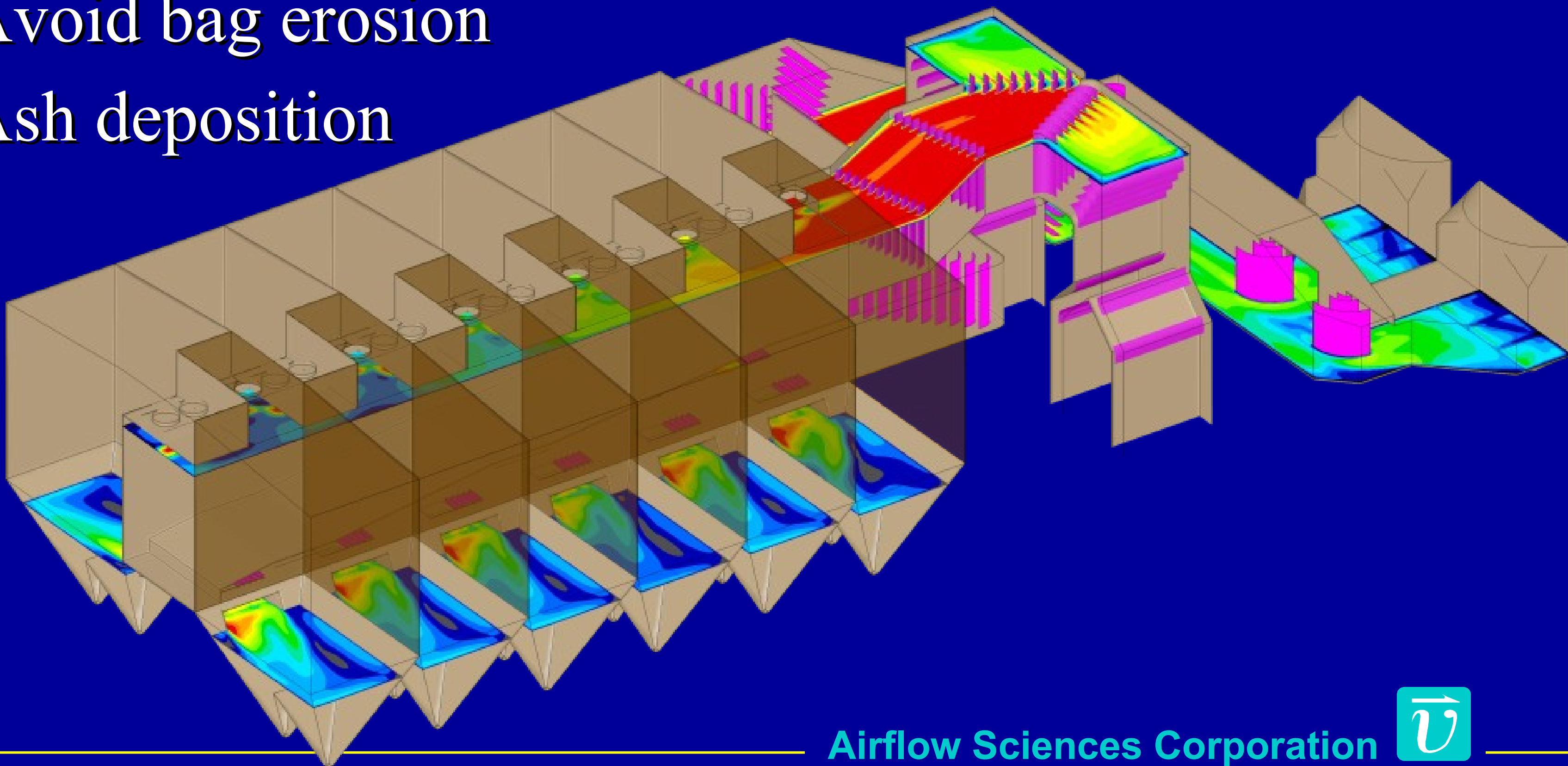
Ash Deposition

- Drop out
- Re-entrainment



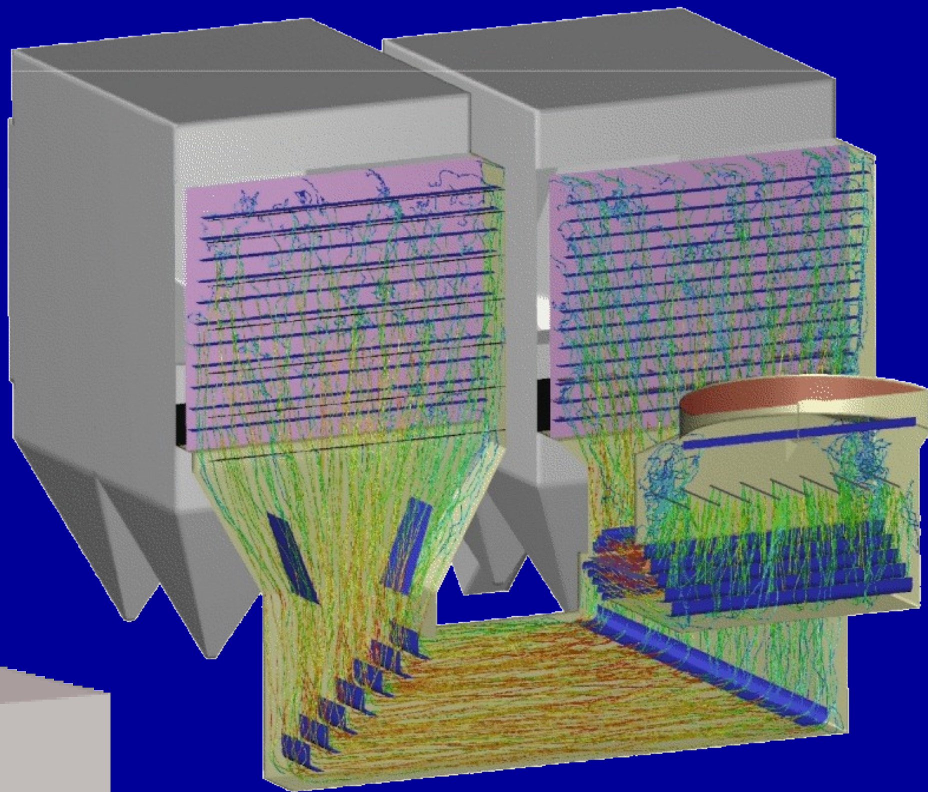
Fabric Filter Flow Modeling

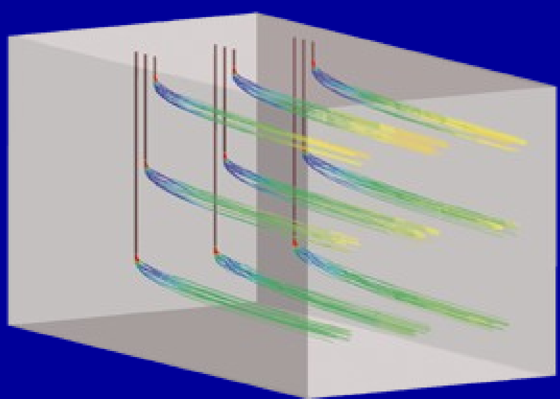
- Uniform velocity distribution and equal balance between compartments
- Pressure loss
- Avoid bag erosion
- Ash deposition

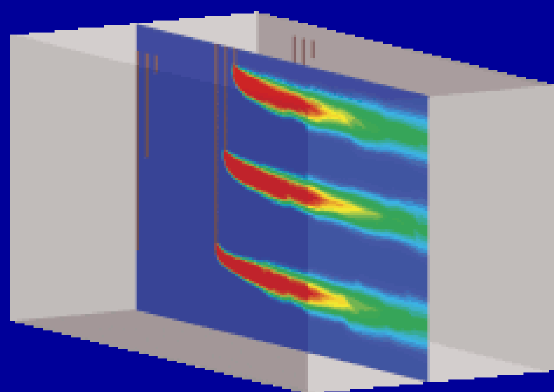


Mercury / SO3 Reduction

- Injection upstream of baghouse or ESP
  - Activated carbon
  - Lime, Trona, SBS, etc.
- Uniform injection
- Maximize residence time





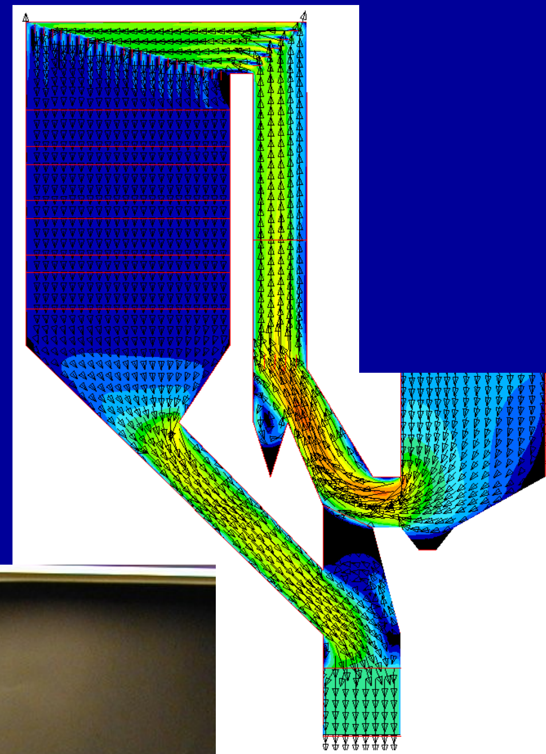


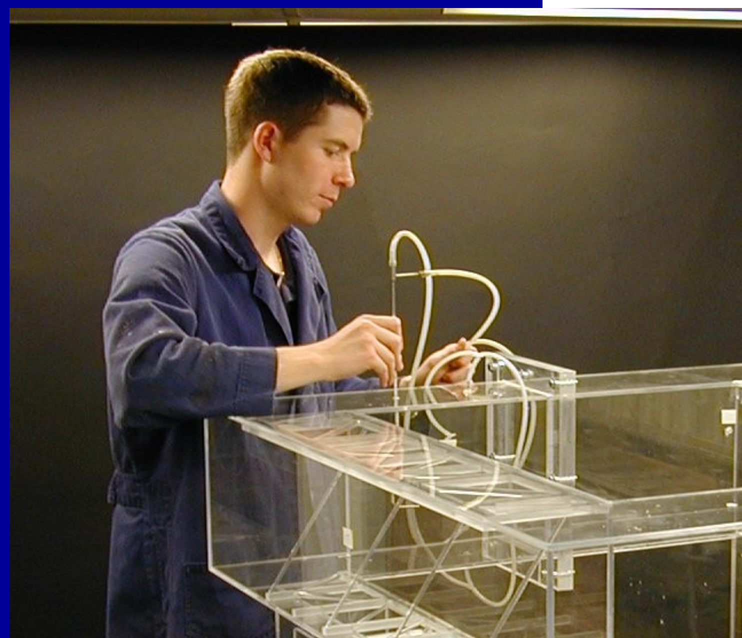
SCR Flow Optimization

- Velocity distribution
- Thermal mixing
- NOx profile / mixing
- Ammonia injection
- Pressure loss
- Large particle ash (LPA) or "popcorn ash" capture
- Ash deposition

SCR Velocity Distribution

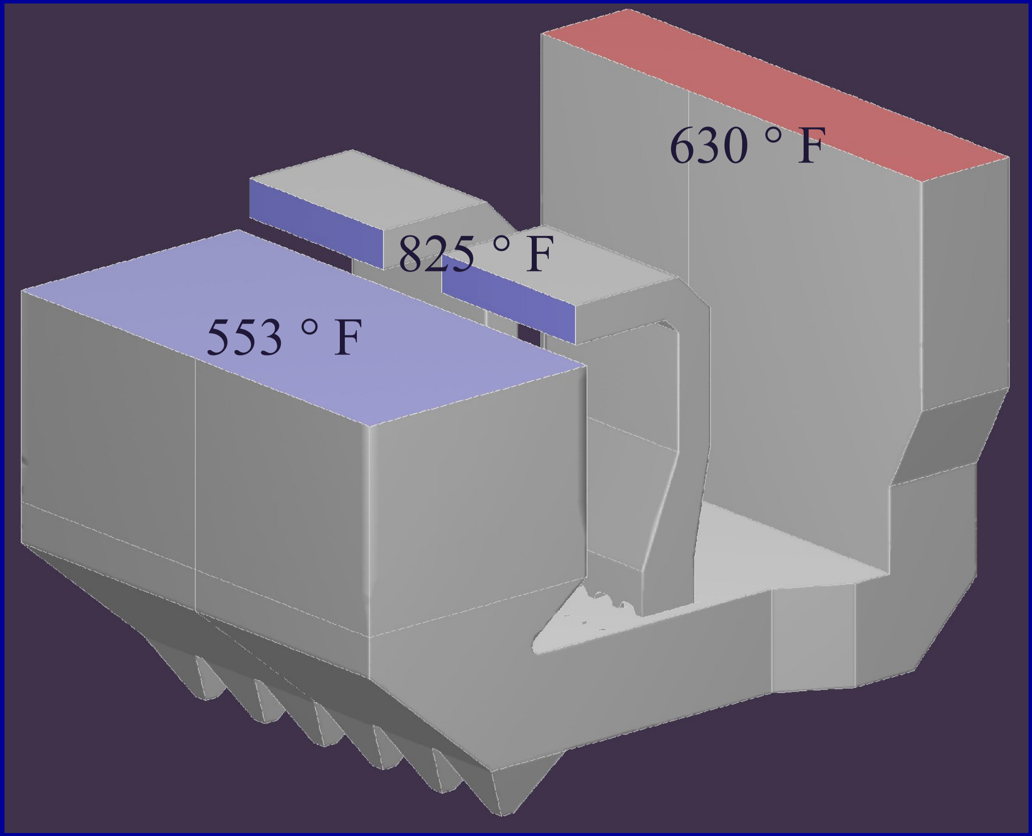
- Uniform velocity profile
  - At ammonia injection grid
  - At catalyst inlet
  - At air heater inlet
- Minimal angularity
  - At catalyst inlet





SCR Thermal Mixing

- SCR low load operation with economizer bypass
- CFD model to design mixer using full scale operating conditions
- Physical model tracer gas tests to confirm design

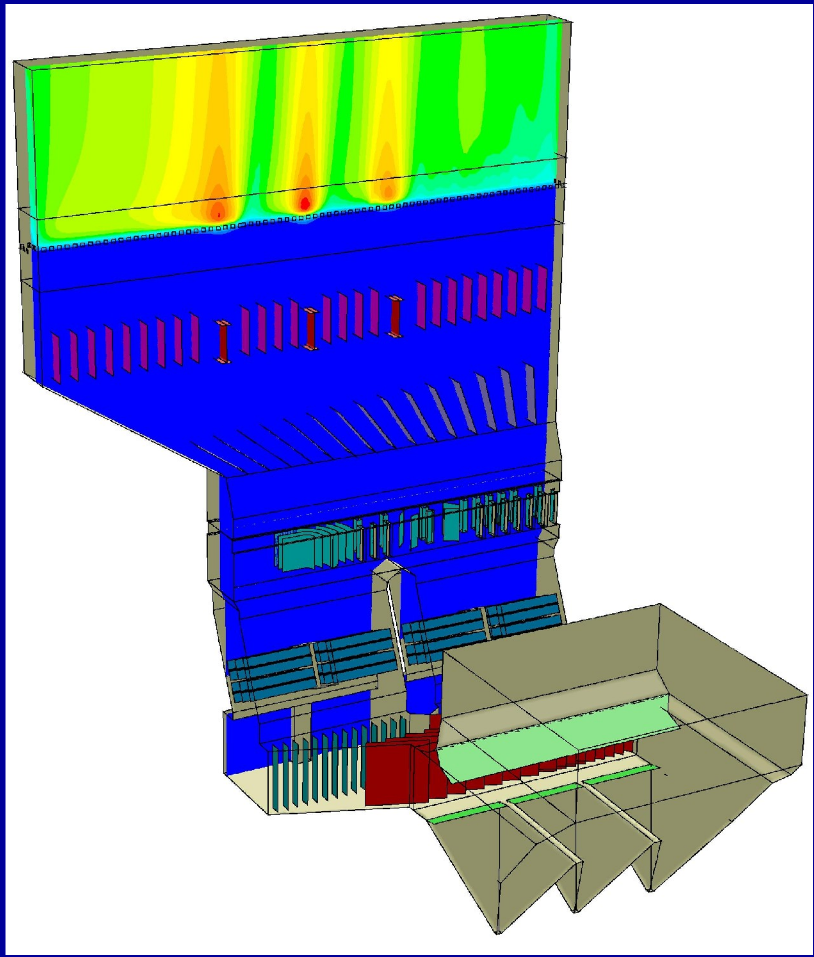


Without mixer, ΔT = ±83 °F

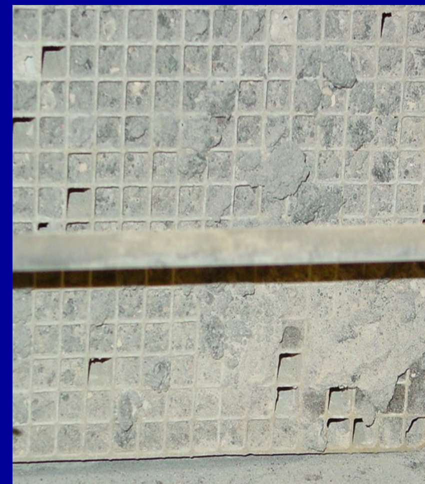
With mixer, ΔT = ±15 °F

SCR Ammonia Injection

- Desire uniform NH3-to-NOx ratio at catalyst
- Tracer gas used to represent flows in physical model
- Track gas species in CFD



SCR Large Particle Ash Capture



- Catalyst openings for coal-fired plants are smaller than LPA particles
- Once LPA becomes “wedged” into a cell, fine ash builds up as well
  - Hard to clean
  - Get dunes of ash on top layer catalyst

LPA System Design – Key Points

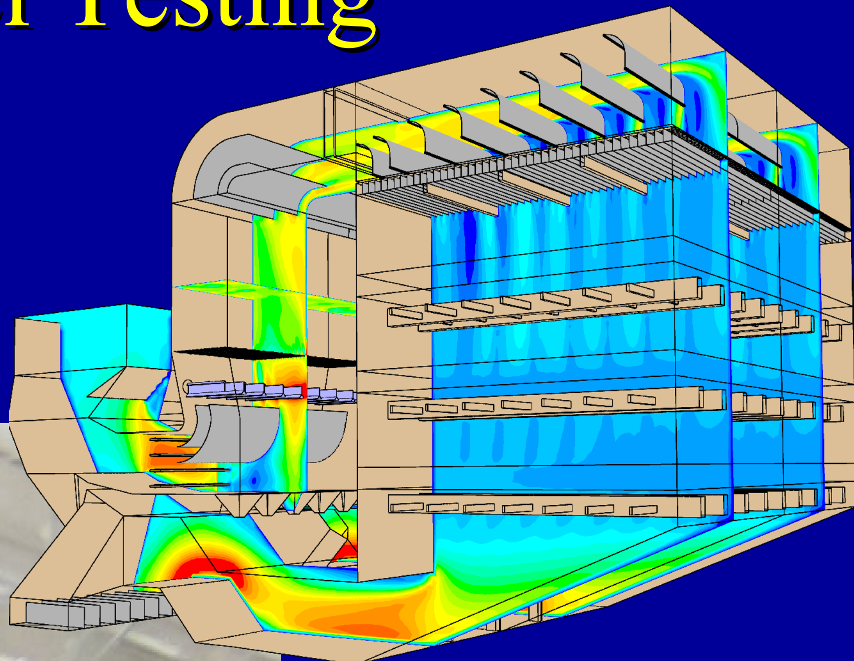
- Capture LPA in hoppers of adequate size
- LPA screens have become standard practice
- Ash deflection baffles also useful
- Screen erosion and pluggage remain issues

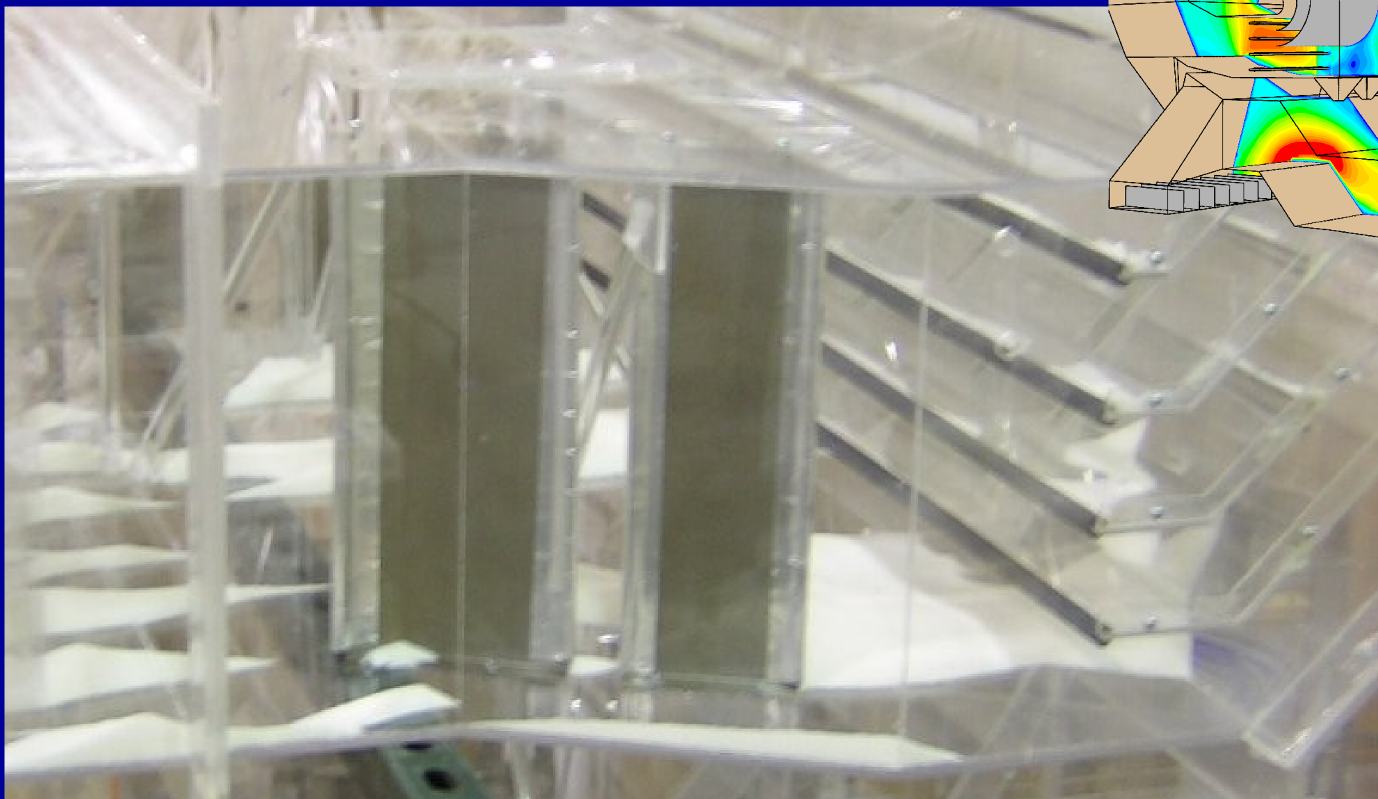
Ash Deposition

- Duct floors
- Turning vanes
- Catalyst

Ash Deposition – Model Testing

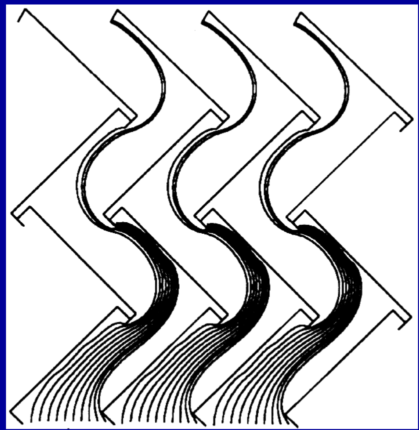
- Drop out
- Re-entrainment

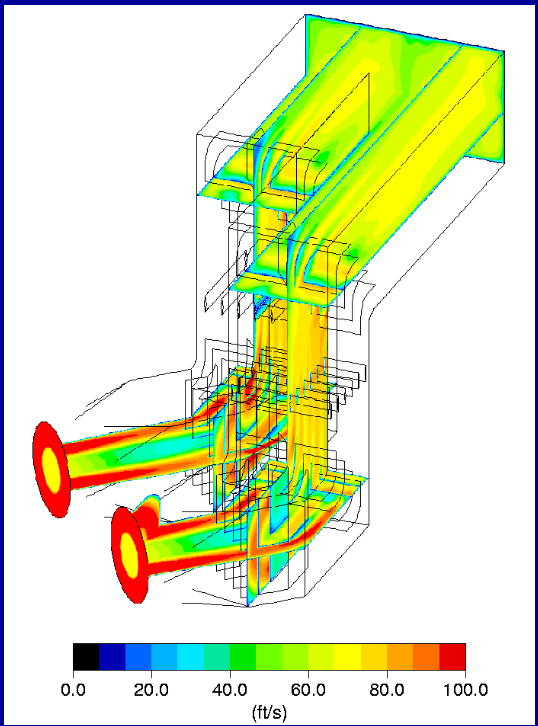


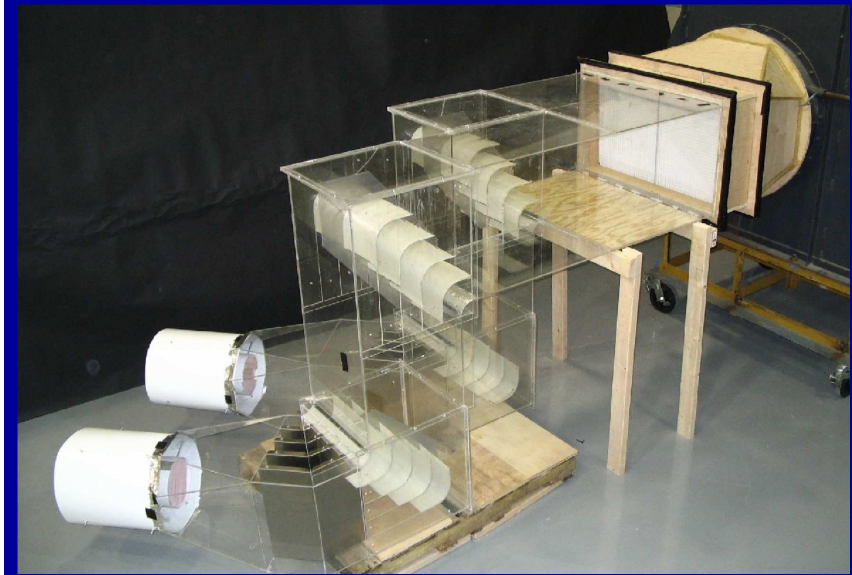


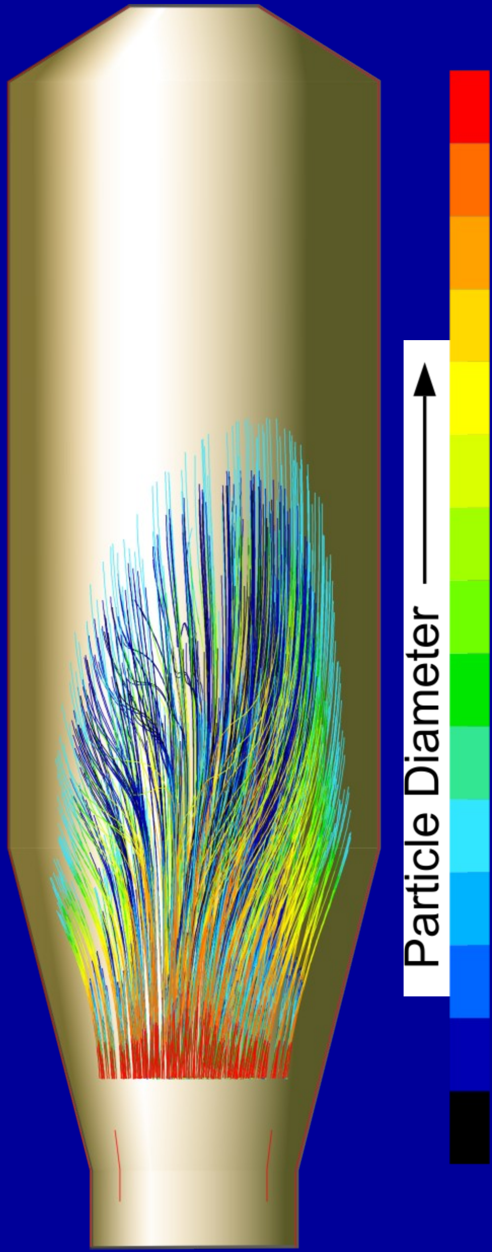
FGD Flow Modeling

- Flow distribution
- Water droplet behavior
- Pressure loss
- Ash deposition

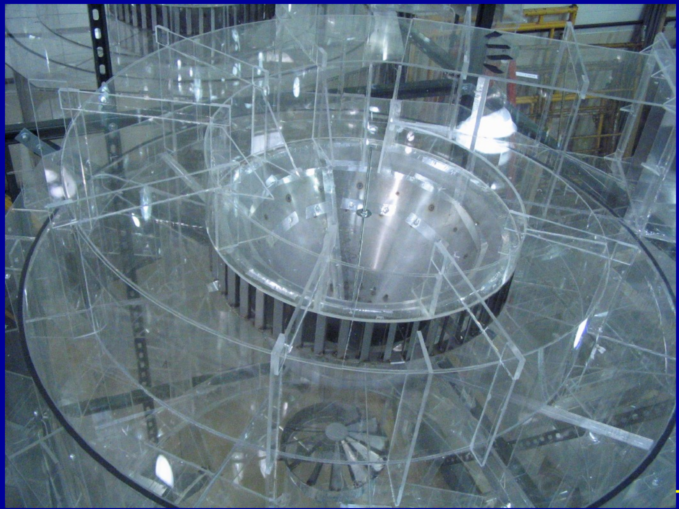








FGD Flow Modeling

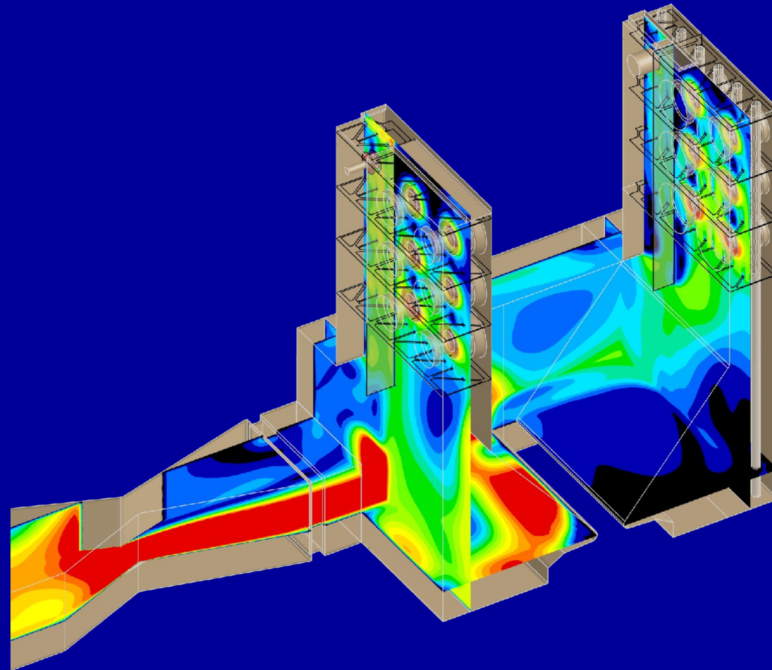


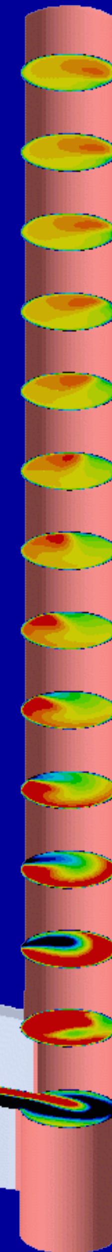
Outline

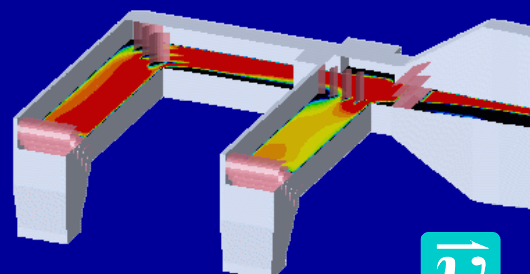
- Introduction
- Flow Modeling Methods
- Application to Boilers
- Application to APC Equipment
- Other Applications
- Conclusions
- Questions

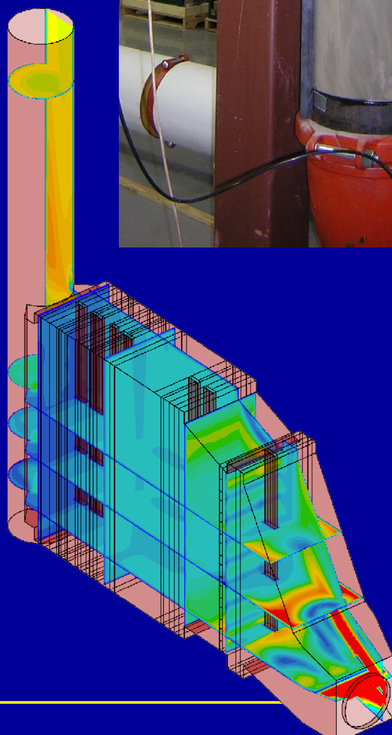
Power Industry

- Fans
- Ducts
- Pulverizers
- Windboxes
- Furnaces
- Air Heaters
- Stacks
- Turbines
- Condensers
- HRSGs
- …









Conclusions

- Gas flow patterns have significant impact on the performance of power plant equipment
- Analysis and design tools include field testing and flow modeling
- CFD and physical modeling are applied to a wide range of equipment "from the fan to the stack"