ESP Gas Flow Fundamentals

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

ESP/FF Round Table & Exposition

August 12, 2002

Outline

- Introduction
- ESP Fluid Flow Basics
- Assessing Flow Characteristics
- ESP Flow Modeling
- Case Studies
- Questions

Introduction

- Why Worry About Fluid Dynamics?
  - Strong influence on performance of pollution control equipment (ESP, FF, SCR, LNB, Scrubber, etc.)
  - Relatively low cost performance enhancements are possible
- Example Cases
- About Your Speaker

Example Cases

- How important is flow distribution?

Plant	Baseline Performance	After Flow Improvements
Mississippi Power Watson Unit 5	Full load opacity 25%	Full load opacity less than 5%
Southern California Edison Mohave Units 1&2	High opacity causes 240 MW derate per unit	23% reduction in particulate emissions allows load increase of 150 MW per unit
Essroc Materials Nazareth Unit 1	High opacity (14%) and high pressure loss cause high operating costs	Improved dust capture reduces opacity to 7%; system pressure loss reduced by 5 inches H_2O

About Your Speaker

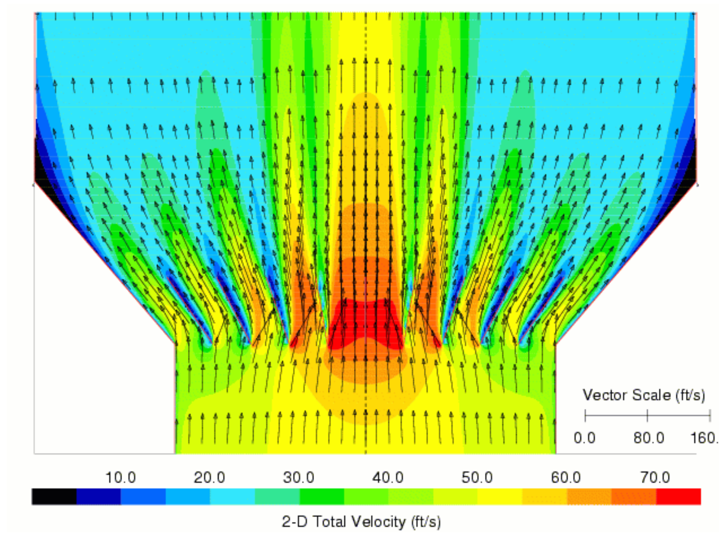
- BSE, MSE Aerospace Engineering – University of Michigan
- 13 years as fluid dynamics consultant to industry
- Involved in 300+ testing/modeling projects
- Institute of Clean Air Companies (ICAC) member
- Author of 6 power industry technical papers
- Registered Professional Engineer – MI, NC, VA

Outline

- Introduction
- ESP Fluid Flow Basics
  - Gas Velocity Distribution
    - Ductwork
    - Collection Region
  - Gas Flow Balance
  - Pressure Drop
  - Gas Temperature
  - Gas Conditioning
- Assessing Flow Characteristics
- ESP Flow Modeling
- Case Studies
- Questions

Gas Velocity Distribution – Ductwork

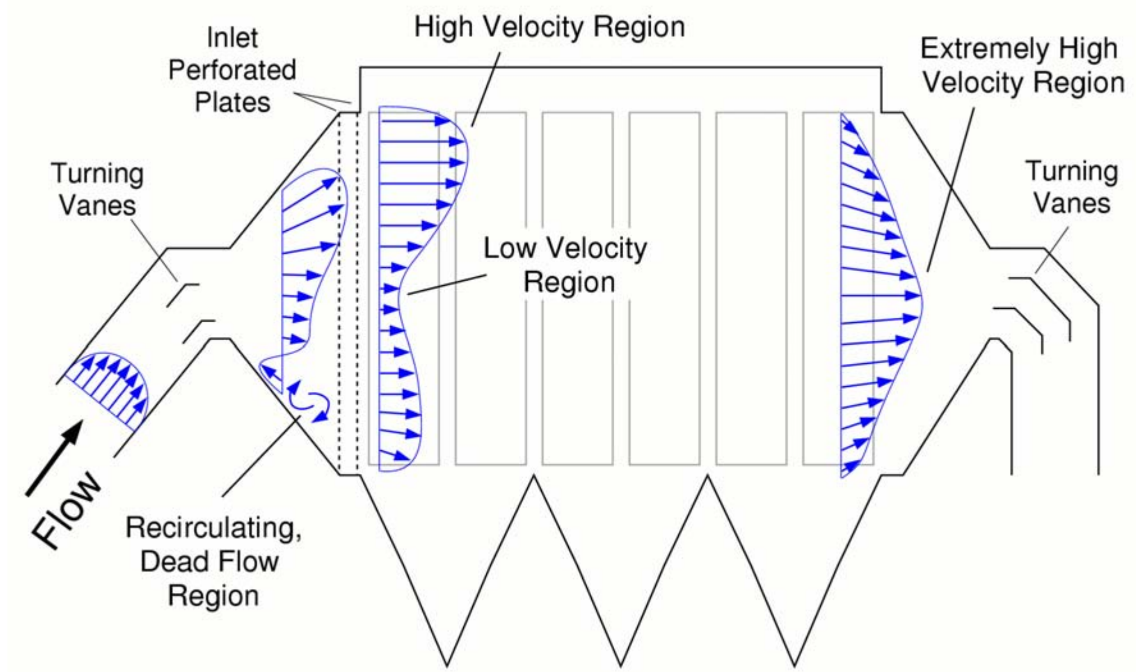
- Ductwork Design Criteria
  - Maintain minimum velocity requirements to avoid particle dropout
  - Provide good flow characteristics to ESP



- Considerations
  - Horizontal surfaces
  - Cross sectional area
  - Bends
  - Structure

Gas Velocity Distribution – Collection Region

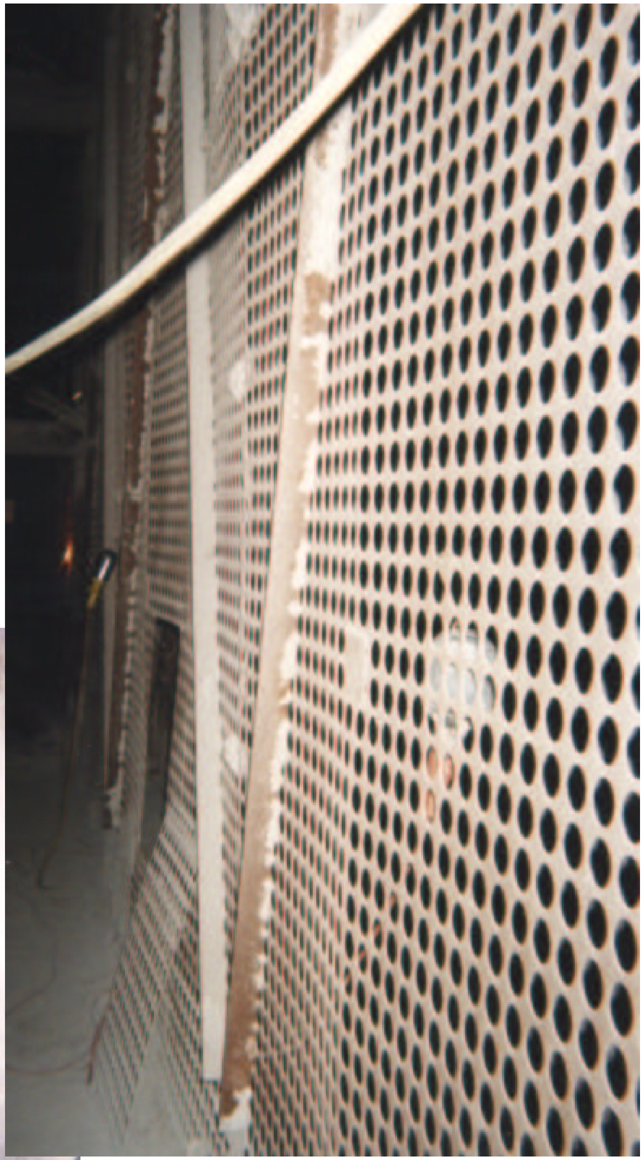
- Uniform Flow Concept
  - ESP inlet & outlet planes
- Industry Standards
  - ICAC
  - % RMS Deviation
- "Skewed" Flow Concepts



ICAC: 85% of velocities $\leq 1.15 * V_{avg}$
99% of velocities $\leq 1.40 * V_{avg}$
Other: % RMS Deviation $\leq$ 15% of V_{avg}

Gas Velocity Distribution – Collection Region

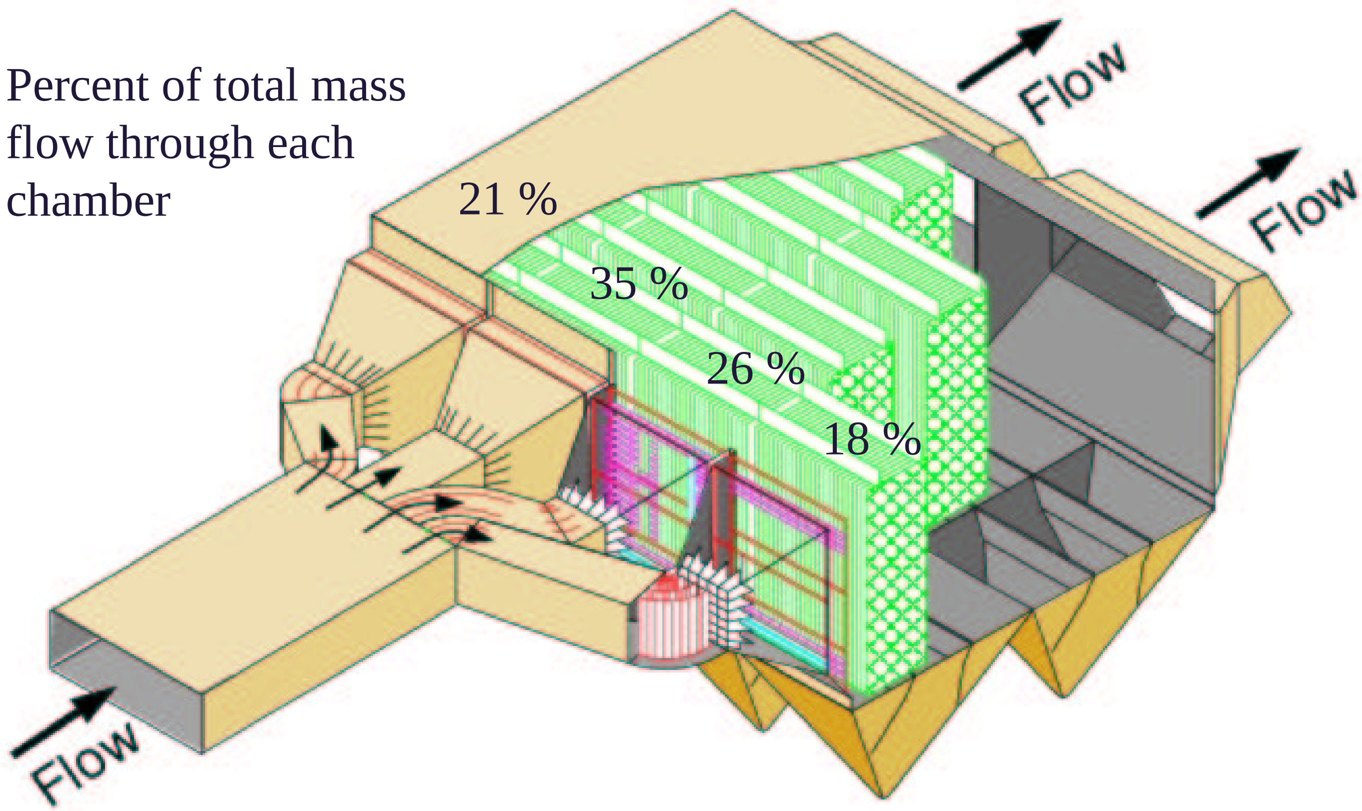
- Flow Control Methods
  - Vanes, baffles
  - Flow straighteners
  - Perforated plates



Gas Flow Balance

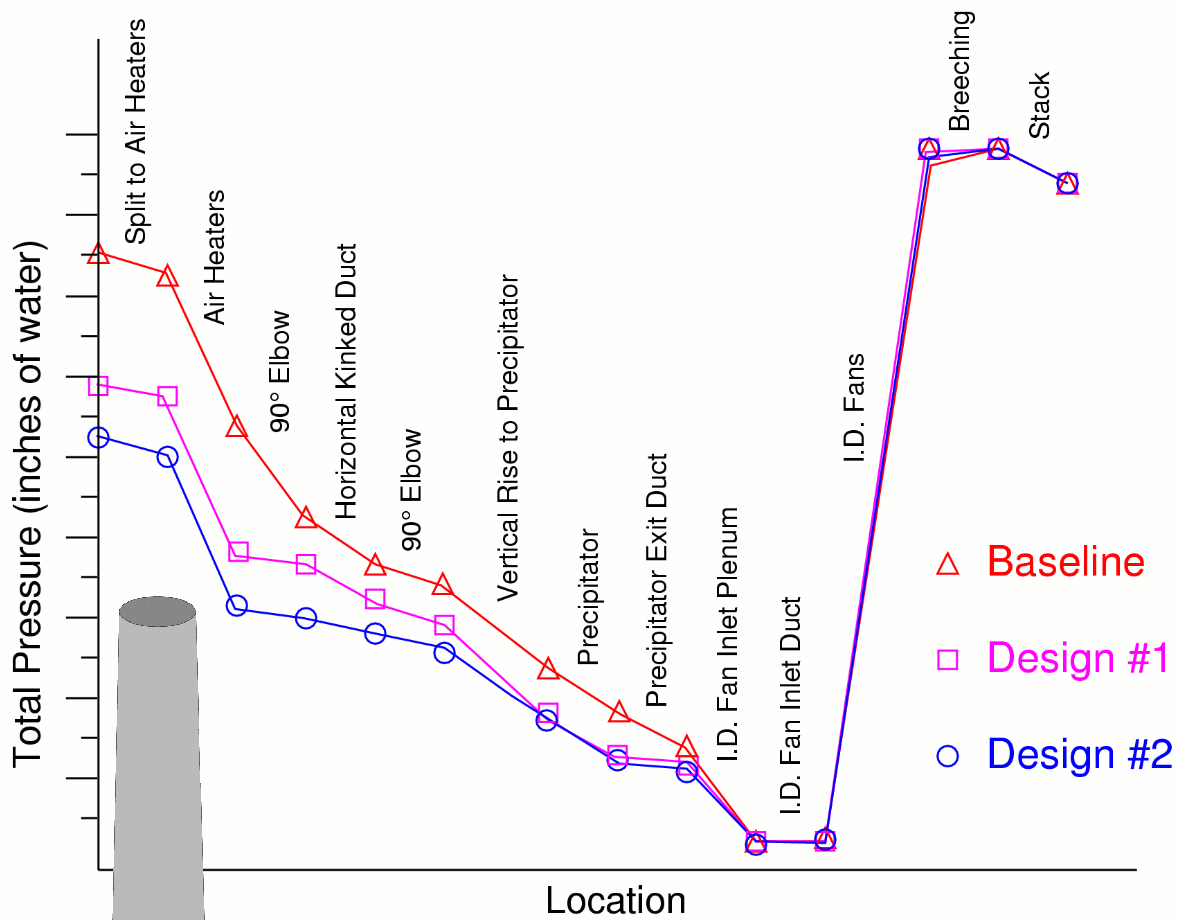
- Industry Standards
- Control Methods

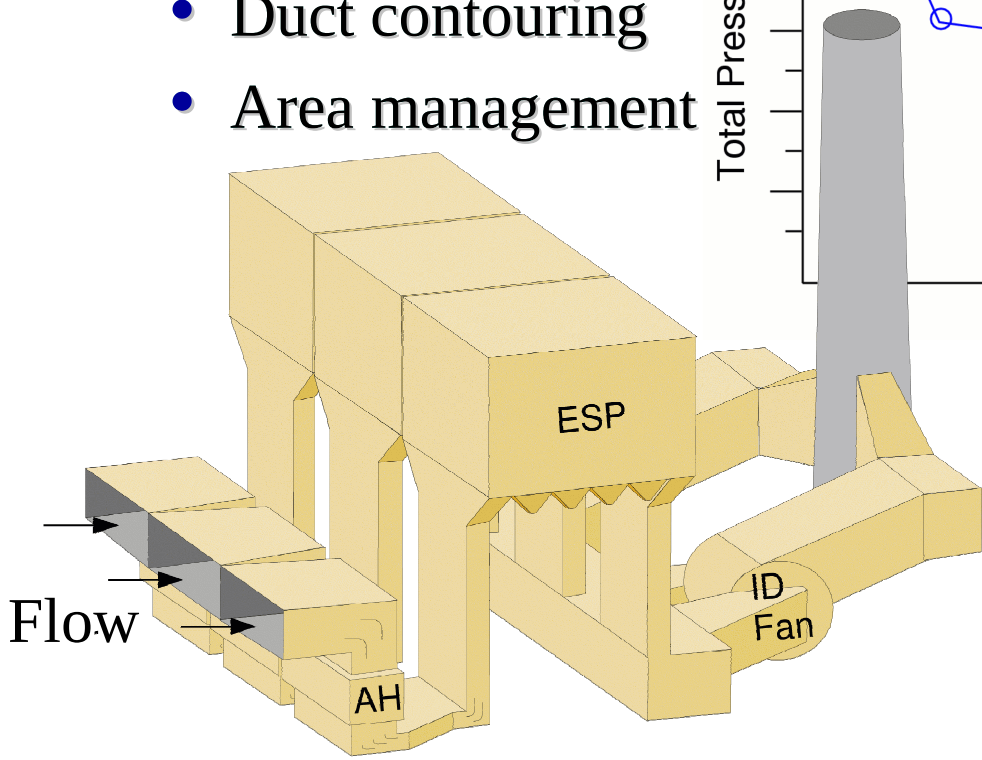
ICAC: Flow within each chamber to be within ±10% of its theoretical share



Pressure Drop

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

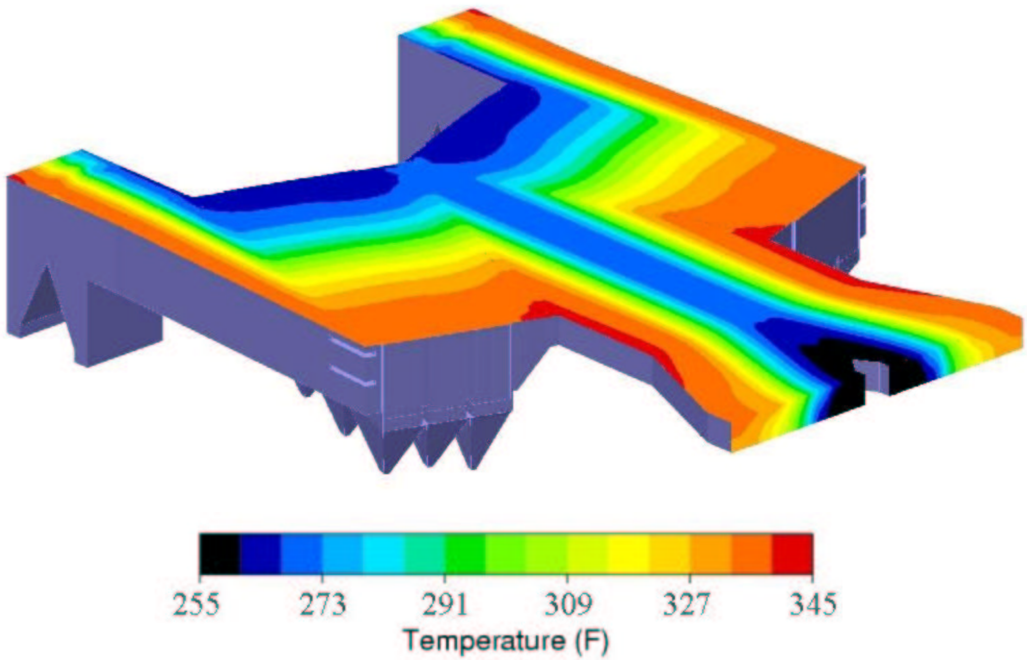


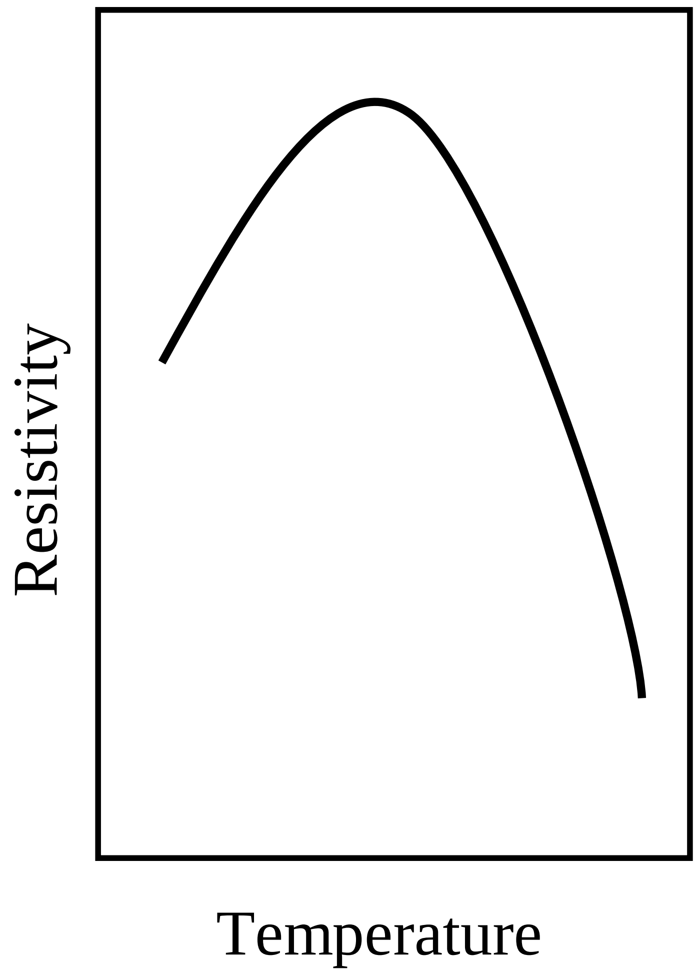


Ductwork redesign saves 2.1 inches H_2O over baseline

Gas Temperature

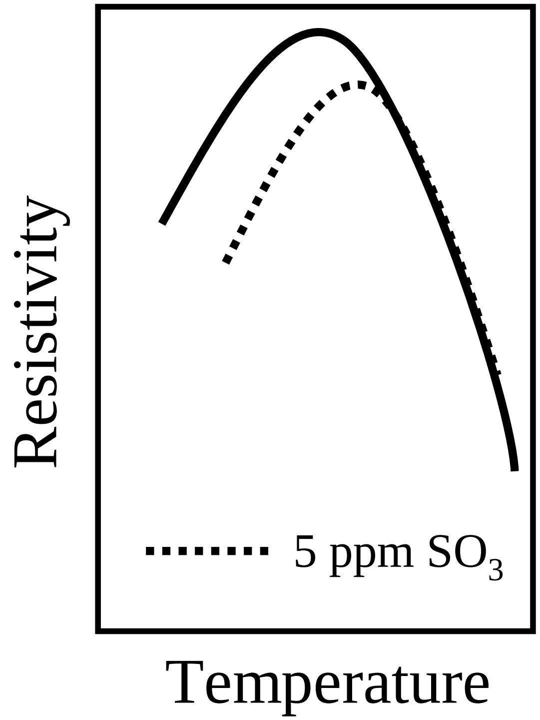
- Average temperature
- Temperature stratification
- Inleakage

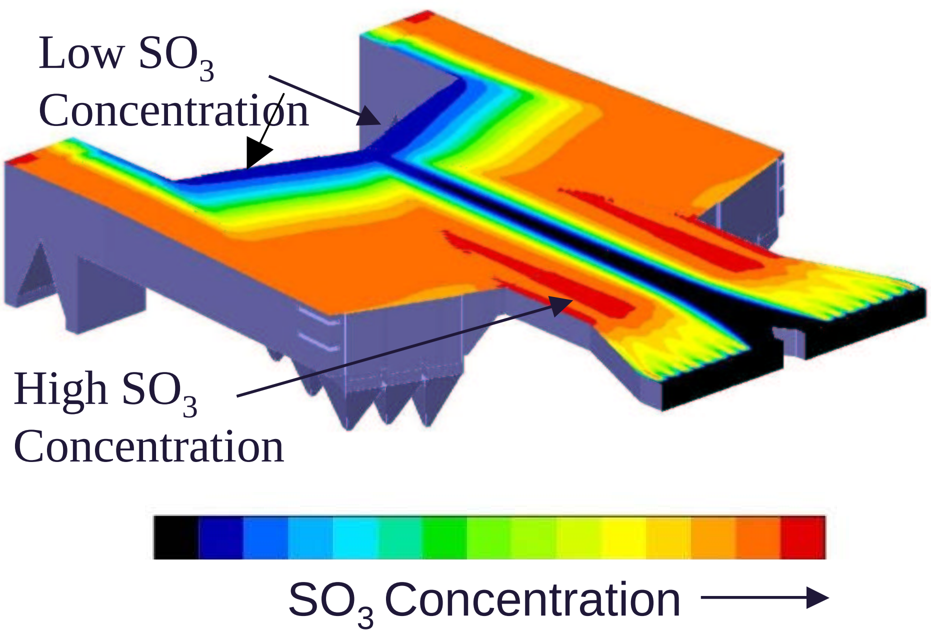




Gas Conditioning

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





Humidification principle:

$\dot{m} = \rho * v * A$

$\dot{m}$, A = constant

$\rho = f(T)$

If T is reduced, ρ increases

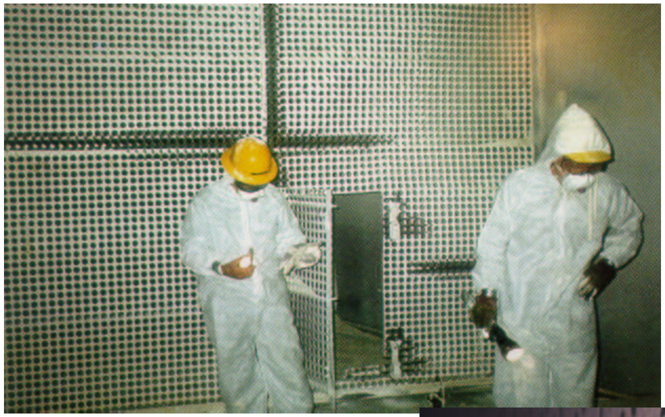
Thus v decreases when water is added

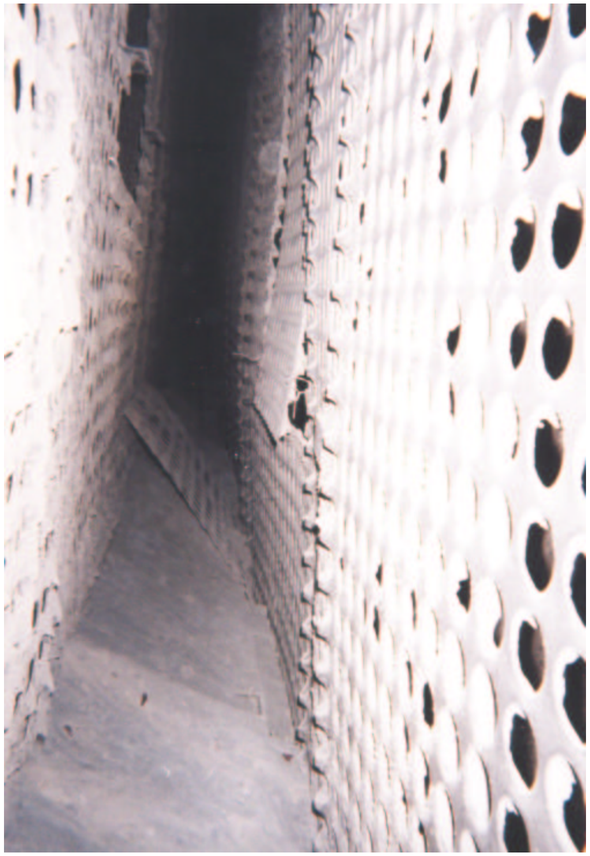
Outline

- Introduction
- ESP Fluid Flow Basics
- Assessing Flow Characteristics
  - Inspections
  - Field Testing
    - Ductwork
    - Collection Region
- ESP Flow Modeling
- Case Studies
- Questions

Inspections

- Ash Patterns
- Geometry Influence on Fluid Dynamics
- Irregularities



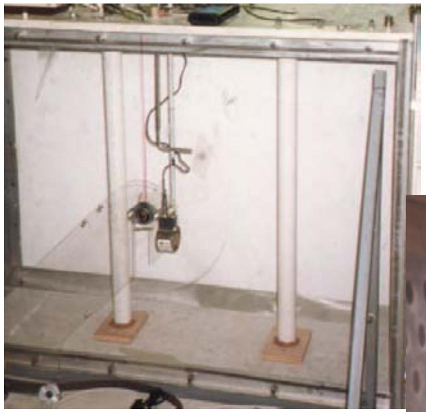


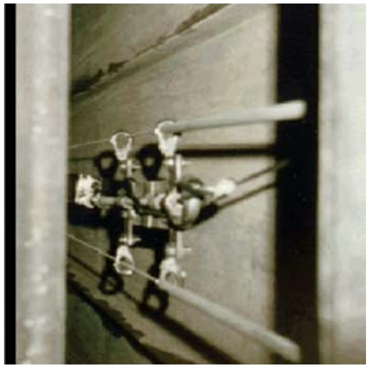
Field Testing – Ductwork

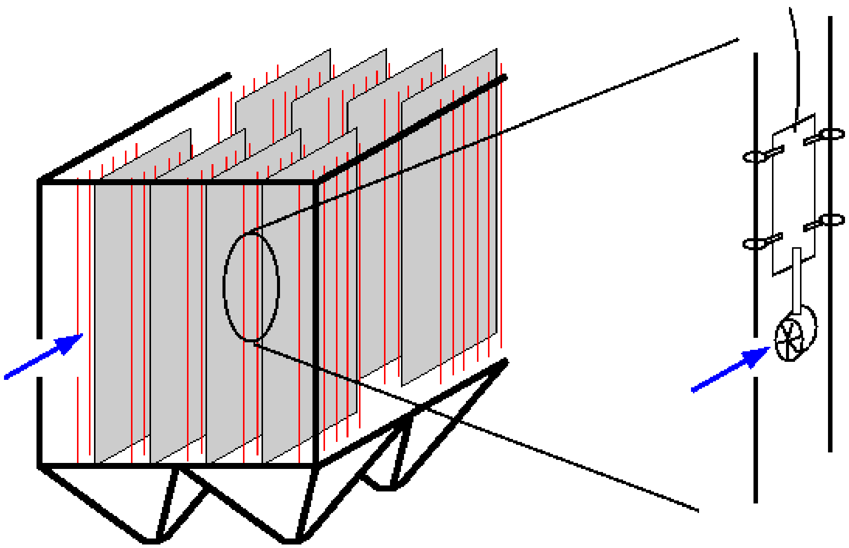
- Velocity
- Temperature
- Pressure
- Particulate
- Resistivity
- Chemical Species

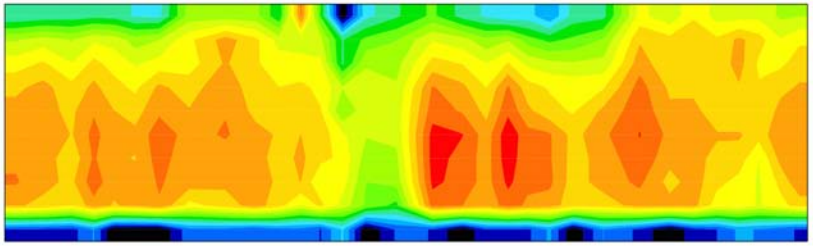
Field Testing – Collection Region

- Velocity Distribution
  - Cold flow conditions
  - Vane anemometer
    - Accuracy 1% in 3-10 ft/sec range
    - Lightweight, portable
    - Sensitive to flow angularity, turbulence, dust









Outline

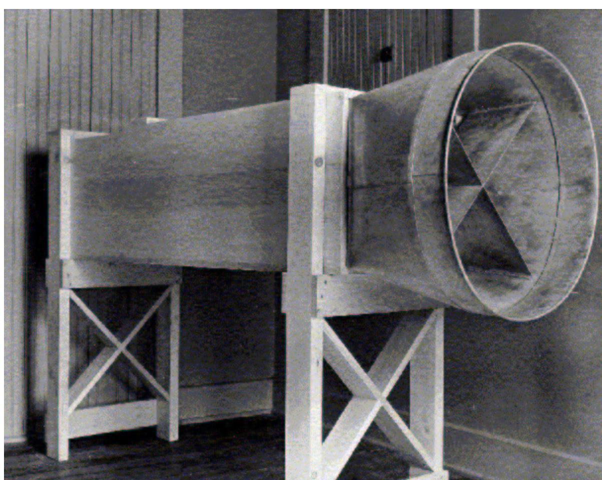
- Introduction
- ESP Fluid Flow Basics
- Assessing Flow Characteristics
- ESP Flow Modeling
  - Physical Models
  - Computational Fluid Dynamics (CFD) Models
- Case Studies
- Questions

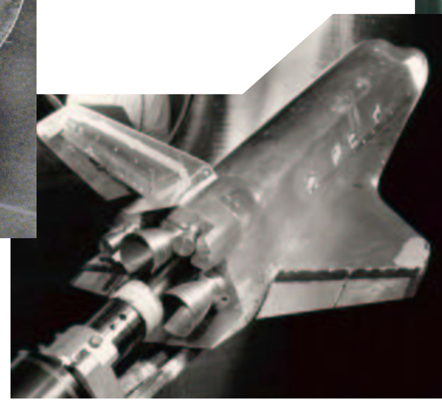
ESP Modeling – Physical Models

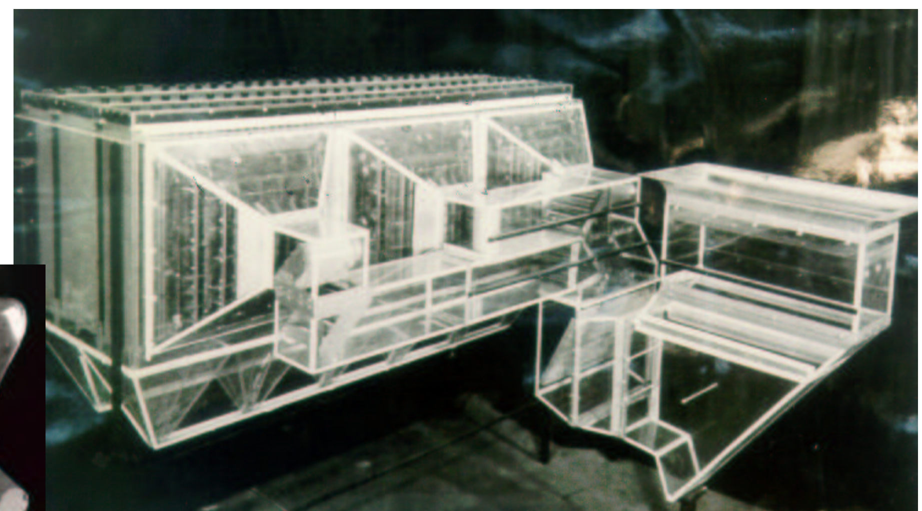
- Background
- Theory
- Simulation Parameters (how the model is set up)
- Results Analysis (what you get from the model)

Physical Models – Background

- Utilized for fluid flow analysis for a century … or more?
- Applied to ESPs for decades
- Underlying principle is to reproduce fluid flow behavior in a controlled, laboratory environment







Physical Models – Theory

- Key criteria is to generate “Similarity” between the scale model and the real-world object
  - Geometric similarity
    - Accurate scale representation of geometry
    - Inclusion of all influencing geometry elements (typically those >4”)
    - Selection of scale can be important
  - Fluid dynamic similarity
    - Precise Reynolds Number (Re) matching is not feasible
    - General practice is to match full scale velocity but ensure that Re remains in the turbulent range throughout the model

$$Re = \frac{\rho \, v \, D_h}{\mu}$$

Physical Models – Simulation Parameters

- ESP geometry
  - 1/8th to 1/16th scale representation
  - Include features >4" in size
- Flow conditions
  - Scaled <u>air</u> flow rate (ambient temperature)
  - Reproduce velocity profile at model inlet
  - Simulated chemical injection
  - Simulated particle tracking

Physical Models – Results Analysis

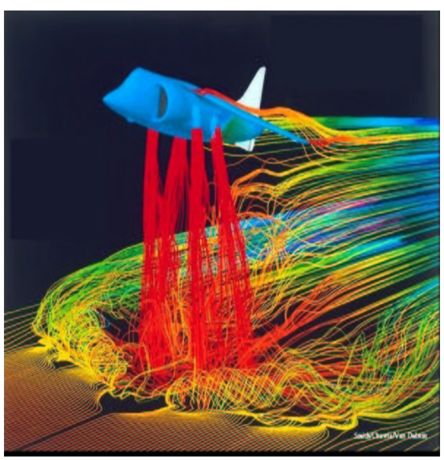
- Quantitative data available at discrete measurement points
  - Velocity magnitude, directionality
  - Pressure (corrected to full scale)
  - Chemical species concentrations
- Integrated/reduced data
  - Mass balance between ESP chambers
  - Comparison to ICAC conditions or target velocity profiles
  - Correlation to test data
- Qualitative data
  - Flow directionality (smoke, tufts)
  - Particle behavior, drop-out

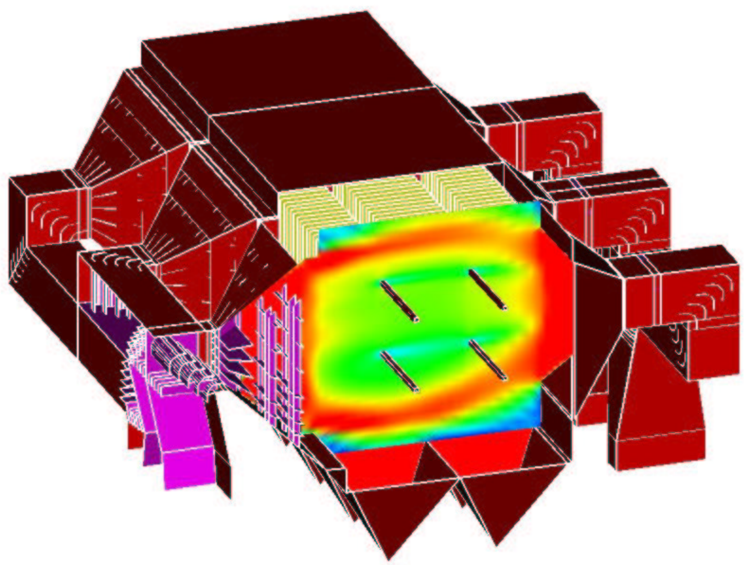
Flow Modeling – Computational Fluid Dynamics (CFD)

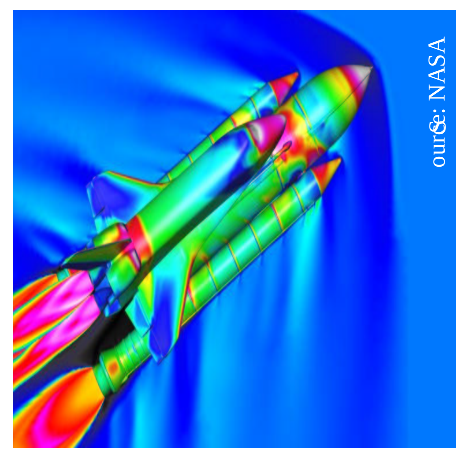
- Background
- Theory
- Simulation Parameters (how the model is set up)
- Results Analysis (what you get from the model)

CFD – Background

- Developed in the aerospace industry c.1970 (with the advent of “high speed” computers)
- Applied to ESPs for 15+ years
- Underlying principle is to solve the first-principles equations governing fluid flow behavior using a computer

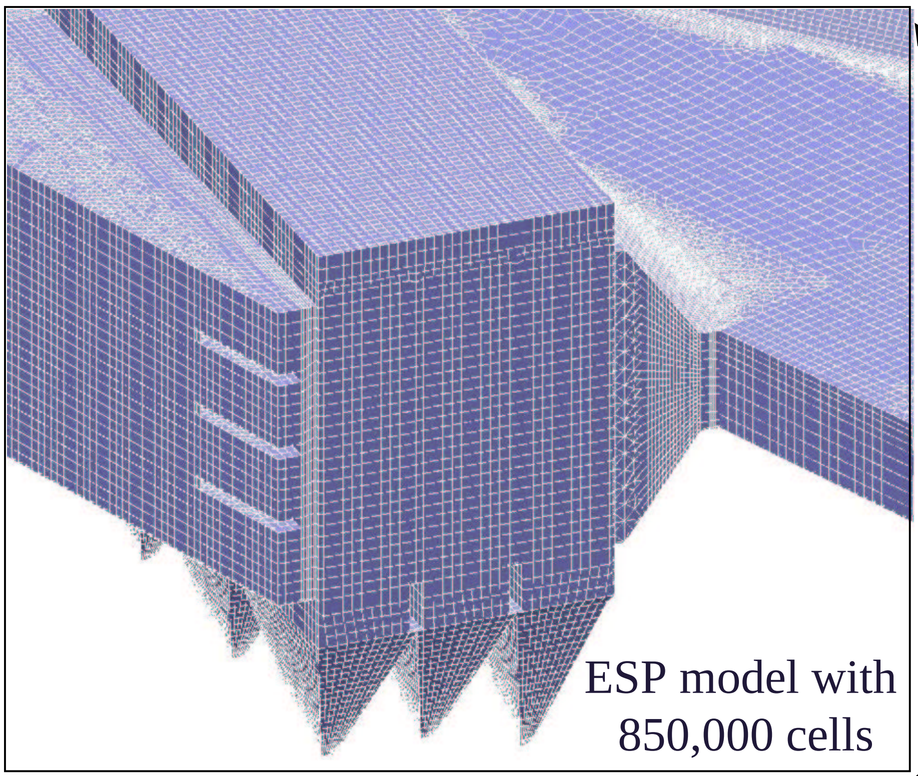


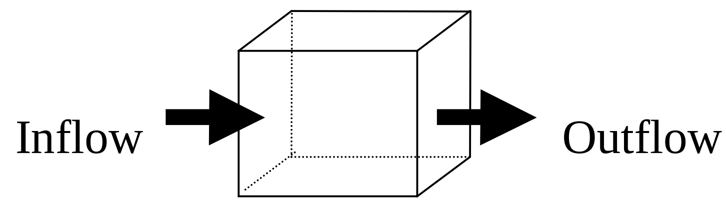




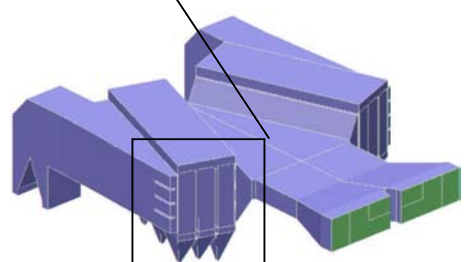
CFD – Theory

- 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



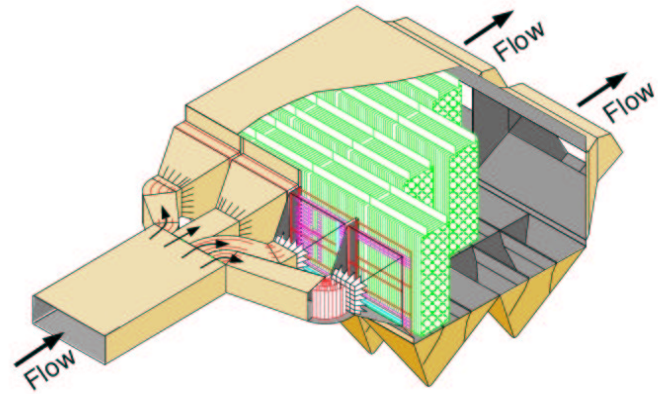


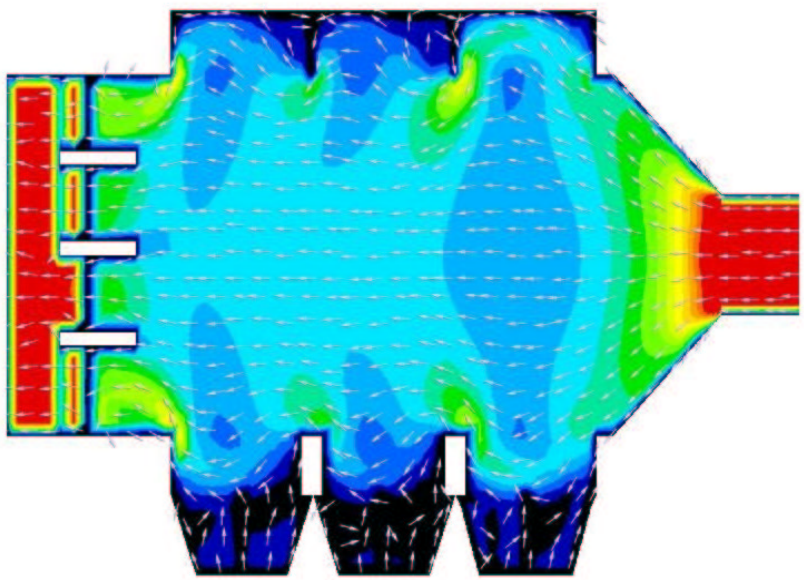
Control Volume
or “Cell”



CFD – Simulation Parameters

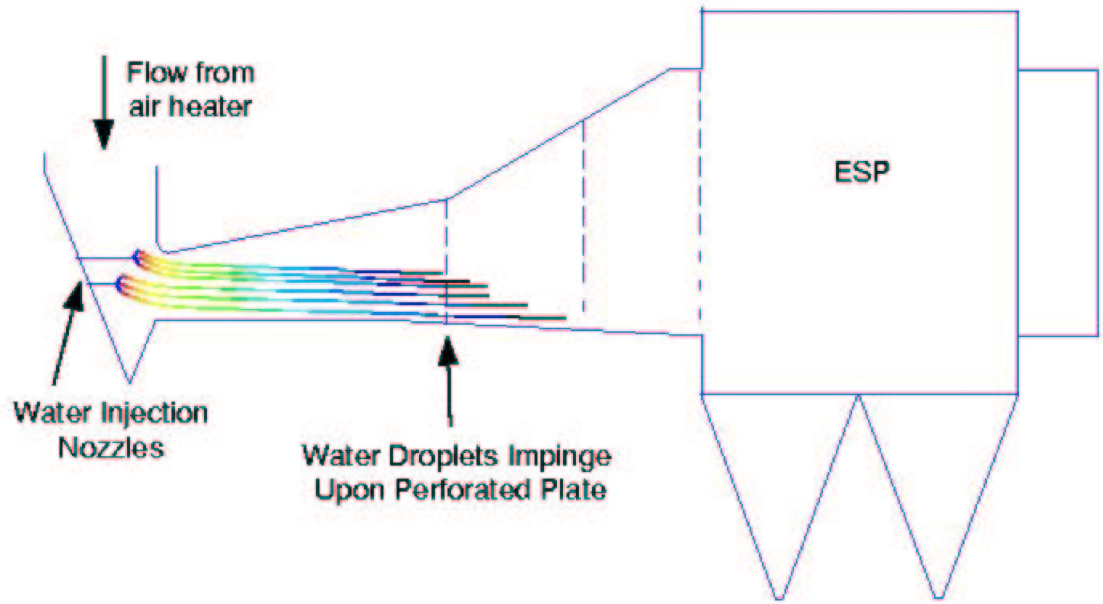
- ESP geometry
  - Full scale representation
  - Include features >4” in size, more detail if possible
- Flow conditions
  - Full scale gas flow rate
  - Reproduce velocity profile at model inlet
  - Reproduce temperature profile at model inlet
  - Simulated chemical injection
  - Simulated particle tracking





CFD – Results Analysis

- Quantitative data available at all control volumes
  - Velocity magnitude, directionality
  - Temperature
  - Pressure
  - Turbulence
  - Chemical species concentrations
  - Particle trajectories

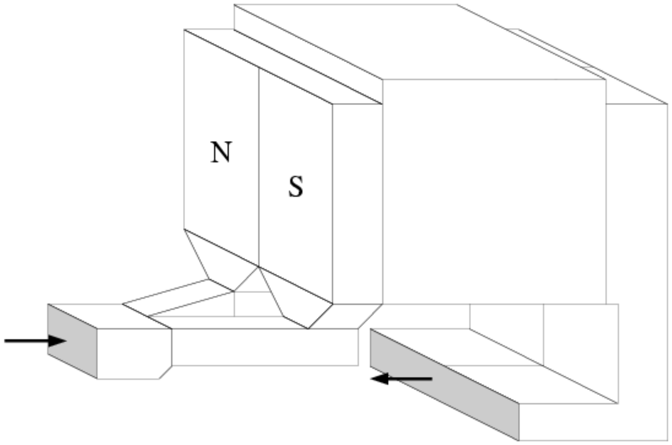


- Integrated/reduced data
  - Mass balance between ESP chambers
  - Comparison to ICAC conditions or target velocity profiles
  - Correlation to test data

Outline

- Introduction
- ESP Fluid Flow Basics
- Assessing Flow Characteristics
- ESP Flow Modeling
- Case Studies
  - Reducing Forced Outages for Hot Side ESP Cleaning
  - Improving Capture Efficiency to Avoid MW Derates
  - Gas Conditioning System Design
- Questions

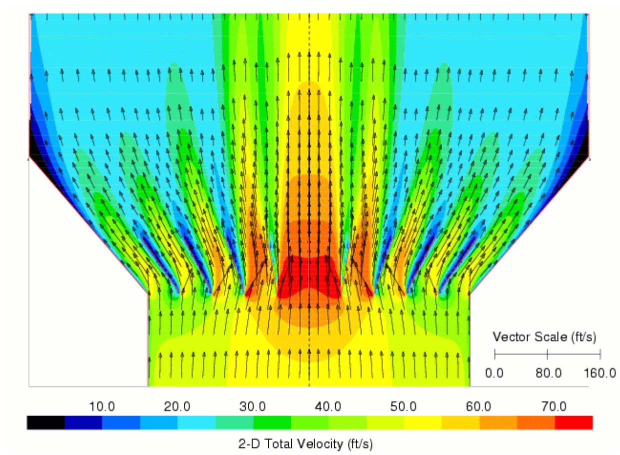
Reducing Forced Outages for ESP Cleaning



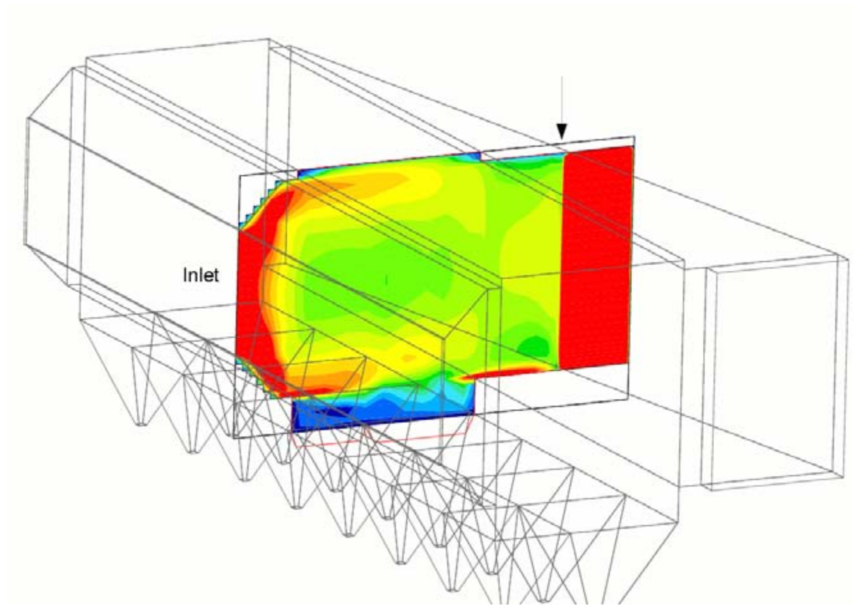
- Hot side ESP
- Southeast U.S.
- 185 MW unit
- ESP cleaning required every 2-3 months to operate within opacity limits
- Unit derate and eventual forced outage as ESP capture performance degrades

Reducing Forced Outages for ESP Cleaning

- Known problem: Poor side-to-side gas velocity distribution within collection region
- Solution: Expand flow more efficiently in the ESP inlet ductwork
- Result: ESP operates for 12 months without cleaning; no derates due to opacity



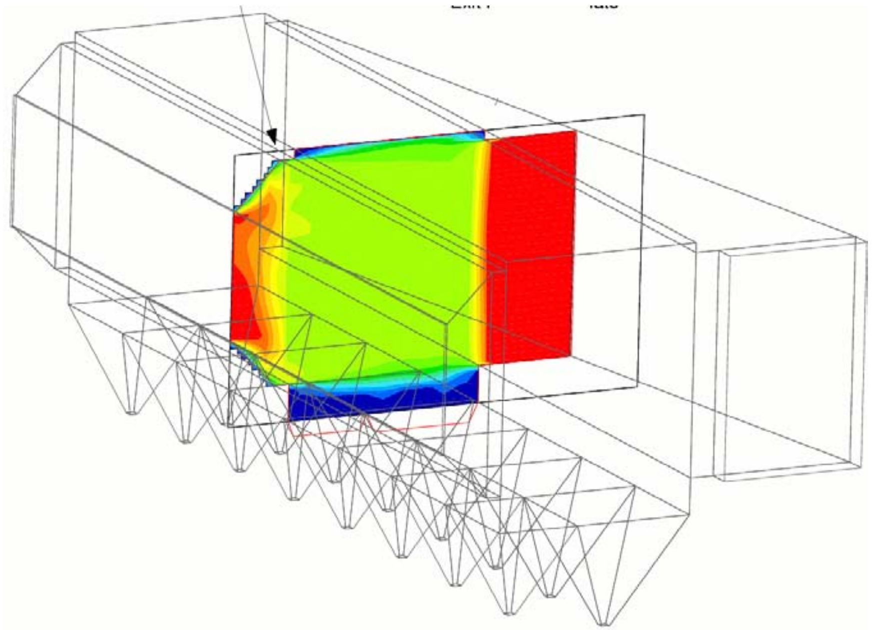
Avoiding MW Derates



- Cold side ESP
- Western U.S.
- Two 790 MW units
- Undersized ESPs
- Both units regularly derated by 240 MW to operate within opacity limits

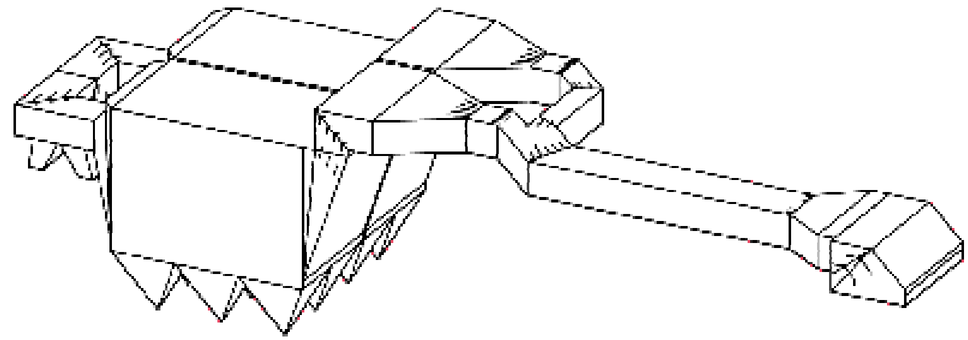
Avoiding MW Derates

- Baseline CFD modeling indicates poor gas velocity distribution within collection region
- Solution: Redesign flow control devices (turning vanes, perforated plates)
- Results
  - 23% reduction in particulate emissions
  - Output increased by 150 MW per unit

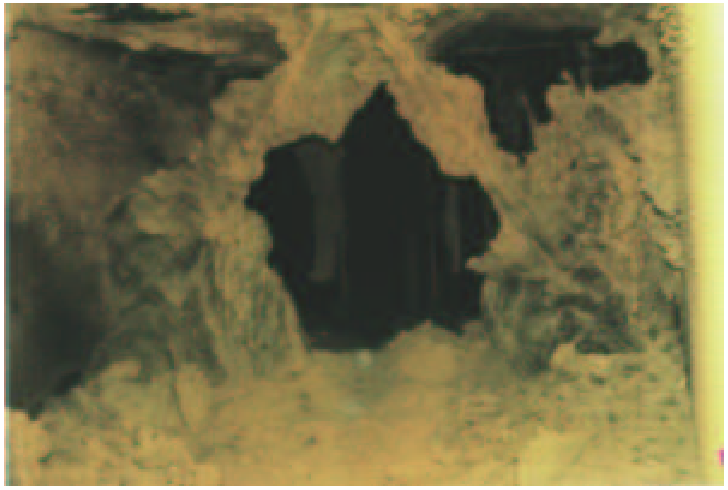


Gas Conditioning System Design

- Cold side ESP
- Midwest U.S.
- 422 MW unit

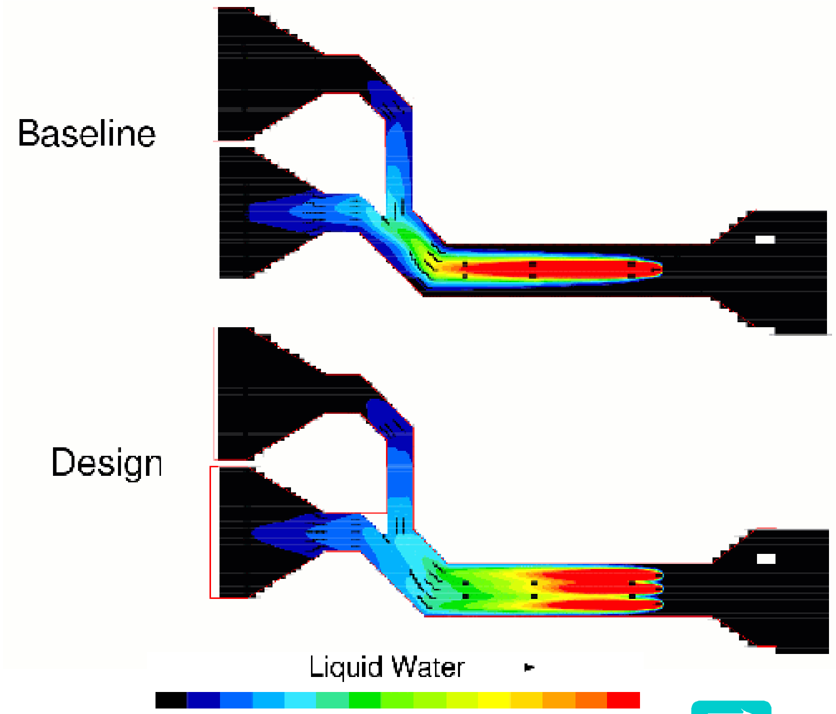


- Humidification system injects water into ESP inlet ductwork
- Severe buildup on internal structure causes forced outages and high maintenance costs



Gas Conditioning System Design

- Baseline CFD modeling indicates water droplets do not evaporate completely before impacting structure
- Solution: Redesign spray nozzles and internal structure
- Results: Minimal material buildup, elimination of forced outages



Questions?

If you would like an electronic copy of this presentation, please contact Rob Mudry as follows:
rmudry@airflowsciences.com
Tel. 734-464-8900