Worldwide Pollution Control Association

Ameren Seminar
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Understanding Gas Flow to Improve ESP Performance

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WPCA / Ameren Seminar
August 19-20, 2008
Outline

- Introduction
- ESP Fluid Flow Basics
- Assessing Flow Characteristics
- ESP Flow Modeling
- Movies and Animations
- Questions
Introduction

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

Example Cases

About Your Speaker
# Example Cases

## How important is flow distribution?

<table>
<thead>
<tr>
<th>Plant</th>
<th>Baseline Performance</th>
<th>After Flow Improvements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mississippi Power Watson Unit 5</td>
<td>Full load opacity 25%</td>
<td>Full load opacity less than 5%</td>
</tr>
<tr>
<td>Dominion Generation Bremo Unit 4</td>
<td>Hot side ESP requires outage and wash every 2-3 months</td>
<td>Opacity reduced and duration between washes extended to annual outage</td>
</tr>
<tr>
<td>Essroc Materials Nazareth Unit 1</td>
<td>High opacity (14%) and high pressure loss cause high operating costs</td>
<td>Improved dust capture reduces opacity to 7%; system pressure loss reduced by 5 inches H₂O</td>
</tr>
</tbody>
</table>
About Your Speaker

- BSE, MSE Aerospace Engineering – University of Michigan
- 19 years as fluid dynamics consultant to industry
- Involved in 500+ testing/modeling projects
- Institute of Clean Air Companies (ICAC) member
- WPCA Director and Treasurer
- Author of 10 power industry technical papers
- Registered Professional Engineer in four states
Outline

- Introduction
- ESP Fluid Flow Basics
  - Gas Velocity Distribution
    - Ductwork
    - Collection Region
  - Gas Flow Balance
  - Pressure Drop
  - Gas Temperature
  - Injection Systems
- Assessing Flow Characteristics
- ESP Flow Modeling
- Movies and Animations
- 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

ICAC: 85% of velocities $\leq 1.15 \times V_{avg}$
99% of velocities $\leq 1.40 \times V_{avg}$
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

Percent of total mass flow through each chamber

Flow

21%

35%

26%

18%
Pressure Drop

- General goal:
  - Minimize DP

- Methods
  - Vanes
  - Duct contouring
  - Area management

Ductwork redesign saves 2.1 inches H₂O over baseline
Gas Temperature

- Average temperature
- Temperature stratification
- Inleakage
Injection Systems

- **Gaseous injection**
  - SO$_3$, NH$_3$, others

- **Particulate injection**
  - Activated carbon
  - Trona, SBS, lime, etc.

Activated Carbon Injection – Particle Tracking
Outline

- Introduction
- ESP Fluid Flow Basics
- Assessing Flow Characteristics
  - Inspections
  - Field Testing
    - Ductwork
    - Collection Region
- ESP Flow Modeling
- Movies and Animations
- 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
- Movies and Animations
- 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 air 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 18+ years
- Underlying principle is to solve the first-principles equations governing fluid flow behavior using a computer

Source: NASA
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

ESP model with 1,850,000 cells
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
Movies and Animations

- Physical flow model movies
  - Smoke flow
  - Dust deposition
- CFD model animations
  - Particle tracking
  - Thermal mixing
Questions?

If you would like an electronic copy of this presentation, please contact Rob Mudry as follows:
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