Pulverized Coal Extractive Testing Methods
Evaluation at the EPRI Coal Flow Loop

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Why Measure Primary Air and Coal?

- **Quantify Pipe to Pipe Balance**
  - Burner Performance
    - Unburned Carbon
    - NOx Emissions
  - Overall Boiler Efficiency
  - Diagnose Burner Line Issues

- **Assess Mill Performance**
  - Fineness
Coal Pipe Flow Measurement Methods

- Online, continuous measurement
  - Real-time coal balance information
  - Data over the load range

- Extractive measurement
  - Pipe to pipe air and coal flow balance
  - Data at select operating conditions
  - Pulverized coal samples
EPRI Coal Flow Loop Project

Objectives

- Develop a Research Facility with Controlled and Known Conditions
  - Operate in full scale with coal
  - Precise control over air and coal flow rates

- Evaluate Online Coal Flow Instrumentation
  - Accuracy
  - Sensitivity to piping layout, flow rates, temperature, …

- Assess Extractive Testing Methods
  - Accuracy
  - Sensitivity to piping layout, flow rates, temperature, …
EPRI Coal Flow Loop
EPRI Coal Flow Loop

- Built in Livonia, Michigan
- Construction Completed 2003
- 12” Schedule 40 Steel Pipe
- Victaulic couplings
- Reconfigurable pipe sections
EPRI Coal Flow Loop (cont.)

- Precise Control & Measurement of Air and Coal
  - < 0.5% air flow measurement
  - < 1.0% coal flow measurement

- 10-120 ft/sec in-pipe Velocity
  - 1400-5600 CFM

- 1 to 4 Air/Coal Ratio
  - 2,000-20,000 lbm/hr coal flow

- Ambient to 180 °F Air/Coal Temperature
Particulate Flow After Double Bend
Extractive Sampling Methods Evaluated

- Dirty Air Velocity Probe
- ASME PTC 4.2 (“The ASME Method”)
- ISO 9931 (“The Rotorprobe™ Method”)
Extractive Sampling Methodology

- Primary Air Flow
  - Mill Inlet or Coal Pipe
  - Flow Rate
  - Velocity
  - Temperature

- “Clean Air” Testing

- “Dirty Air” Testing

Coal pipe testing with Advanced Coal Flow Measurement (ACFM) device.
Extractive Sampling Methodology

- **Coal Flow**
  - Isokinetic sampling based on primary air velocity
  - Integrate coal flow rate based on sample weight and extraction time
  - Dry vs. wet coal comparison to feeder
Extractive Test Matrix

- Examine effect of various parameters on accuracy
  - Probe / Method Type
  - Measurement Location
  - Air / Coal Ratio Conditions
  - Extraction Rate Sensitivity
  - Number of Test Ports Required
  - Number of Traverse Points Required
Clean Air Velocity Measurement

- The Dirty Air Velocity Probe traverse initially read ~6% high compared to the true pipe velocity profile measured with a pitot probe.

- The deviation was found to be caused by probe blockage of the pipe cross section and incomplete measurement at the far wall due to probe geometry.

- With corrections for these two probe geometry influences, the Dirty Air Probe traverse correlated to within 0.5% of the true pipe velocity profile.
Comparison of Velocity Profile
Pitot Tube And Dirty Air Probe

DA Probe integrates flow rate ~6% high compared to pitot
Pipe Blockage Correction Factor

- **Point 1**: 8.68% of pipe area blocked by probe blockage. 
  Blockage CF = 1 - 0.0868 = 0.9132

- **Point 8**: 3.99% of pipe area blocked by probe blockage. 
  Blockage CF = 1 - 0.0399 = 0.9601

- **Point 15**: 0.61% of pipe area blocked by probe blockage. 
  Blockage CF = 1 - 0.0061 = 0.9939

Note: The larger the pipe diameter, the less impact the probe blockage has on the velocity measurement.
Comparison of Velocity Profile
Pitot Tube And Dirty Air Probe

Indicated Air Velocity (ft/s)

-6.00 -4.00 -2.00 0.00 2.00 4.00 6.00
Distance From Pipe Centerline (inches)

Location 1V15
80 ft/sec
Clean Air

Pitot Tube
Uncorrected DA Probe
Blockage Corrected DA Probe
Far Wall Correction Factor
DA Probe correlates to within 0.5% of pitot after both corrections
Dirty Air Velocity Measurement

- Dirty Air Velocity Probe has now been calibrated in clean air flow.
- How accurately does it measure air velocity in the presence of coal?
- Test matrix:

<table>
<thead>
<tr>
<th>Air Velocity (ft/sec)</th>
<th>Air/Coal Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td>75</td>
<td>X</td>
</tr>
<tr>
<td>95</td>
<td>X</td>
</tr>
<tr>
<td>110</td>
<td></td>
</tr>
</tbody>
</table>
Dirty Air Velocity Measurement

- Results indicate that the velocity reading is, in fact, influenced by the amount of coal flowing in the pipe.

- It is hypothesized that the coal affects the pressure reading on each side of the probe’s disc.

- This causes the Dirty Air Probe to read high compared to the true air flow rate.

- A correction factor can be developed based on the coal mass flow rate to restore accuracy to within 2%.

- This creates a bit of a dilemma in setting the extraction rate for isokinetic coal sampling, but corrections can be made post-test.
Effect of Air/Coal Ratio On Dirty Air Probe Accuracy

DA Probe Measurement Error (%) vs Coal/Air Ratio

- Green diamond: 75 Ft/s
- Blue square: 95 Ft/s
- Red triangle: 110 Ft/s
Effect of Air/Coal Ratio on Dirty Air Probe Accuracy

\[ y = 0.2071x - 0.0018 \]

\[ R^2 = 0.9773 \]
Coal Flow Rate Measurement
Coal Flow Rate Measurement

- For the ASME method, the accuracy (random error) of the coal flow measurement can be influenced by the proximity to the upstream elbow:
  - Accuracy ±9% at 15 diameters, 2 test ports
  - Accuracy ±35% at 3 diameters, 2 test ports
  - Accuracy ±13% at 3 diameters, 4 test ports

- ISO 9931 method accuracy (random error) is fairly consistent at all test locations:
  - Accuracy ±8%, 2 test ports
Isokinetic Extraction Rate Sensitivity

- Accuracy of the coal flow measurement is degraded for both methods if the isokinetic extraction rate is incorrect.

- The ASME method is more sensitive to extraction rate:
  - For every 10% change in the extraction rate, coal flow measurement changes by ~7%.

- The ISO 9931 method is less sensitive to extraction rate:
  - For every 10% change in the extraction rate, coal flow measurement changes by ~2.5%.
Number of Test Ports and Traverse Points

Equivalent Port Location: up to 12 Traverses were performed spaced 15 degrees apart.

15 Points were sampled in each traverse.
Rotating Test Port for Extractive Testing

- 180° Swivel
- String Potentiometer for Angle Alignment
- 180 Point Grid
  - 15 ° intervals = 12 traverses
- Linear Probe Actuator
  - 15 sampling points/traverse
Effect of Number of Test Ports on Air Flow Measurement
Standard Dirty Air Probe - Location 1V15

Change Relative to 12 Port Measurement

- 75 ft/s, Air/Coal=3
- 95 ft/s, Air/Coal=2.25
- 115 ft/s, Air/Coal=3
- 115 ft/s, Air/Coal=1.5
- Average
Effect of Number of Test Ports on Coal Flow Measurement
ASC Coal Sampling Probe - Location 1V15

Change Relative to 12 Port Measurement

- 75 ft/s, Air/Coal=3
- 115 ft/s, Air/Coal=3
- 115 ft/s, Air/Coal=1.5
- Average
Effect of Number of Test Ports on Air Flow Measurement
Standard Dirty Air Probe - Location 1V3

Change Relative to 12 Port Measurement

- 75 ft/s, air/coal=3
- 75 ft/s, air/coal=1.5
- 95 ft/s, air/coal=2.25
- 115 ft/s, air/coal=3
- No Data
- Average
Effect of Number of Test Ports on Coal Flow Measurement
ASC Coal Sampling Probe - Location 1V3

Change Relative to 12 Port Measurement

- 75 ft/s, air/coal=3
- 75 ft/s, air/coal=1.5
- 95 ft/s, air/coal=2.25
- 115 ft/s, air/coal=3
- No Data
- Average
Effect of Number of Traverse Points on Air Flow Measurement
Standard Dirty Air Probe - Location 1V15

Change Relative to 15 Point Traverse

- 75 ft/s, air/coal=3
- 95 ft/s, air/coal=2.25
- 115 ft/s, air/coal=3
- 115 ft/s, air/coal=1.5
- Average

Number of Traverse Points

0% 1% 2% 3% 4% 5% 6% 7% 8% 9% 10% 11% 12% 13% 14% 15%
Effect of Number of Traverse Points on Coal Flow Measurement
ASC Coal Sampling Probe - Location 1V15

Number of Traverse Points vs. Change Relative to 15 Point Traverse

- 75 ft/s, air/coal=3
- 115 ft/s, air/coal=3
- 115 ft/s, air/coal=1.5
- Average

Change Relative to 15 Point Traverse:
-16%
-14%
-12%
-10%
-8%
-6%
-4%
-2%
0%
2%
Number of Test Ports and Traverse Points

- Results to date have been summarized
- Additional testing is still planned
- For acceptable accuracy (within 2% on air, 5% on coal):

<table>
<thead>
<tr>
<th>Location</th>
<th>Number of Test Ports Required</th>
<th>Number of Traverse Points Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>1V15</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>1V11</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>1V7</td>
<td>3-4</td>
<td>9</td>
</tr>
<tr>
<td>1V3</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>3V3</td>
<td>6</td>
<td>15</td>
</tr>
</tbody>
</table>
In Summary, Results to Date Suggest...

- Dirty Air Probe can achieve dirty air flow measurement accuracy to within 2%
  - Proper correction factors are required
  - Velocity reading is dependent on air-to-coal ratio, complicating calculation of isokinetic extraction rate

- For a single upstream bend
  - ASME method can achieve coal measurement accuracy within 10-13%
  - More test ports are required as test plane moves closer to an elbow
  - ISO 9931 method can achieve coal measurement accuracy to within 8%

- Accuracy of both methods is influenced by geometry of upstream elbows (degree of roping)

- Rotorprobe is less sensitive to extraction rate than ASME method

- Need to perform additional testing to complete the data analysis and create generalized correction factors
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- TXU – Mark Smith

EPRI Program 71 Members
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