Catalyst Pluggage Reduction for Roxboro U3

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- November 17, 2009

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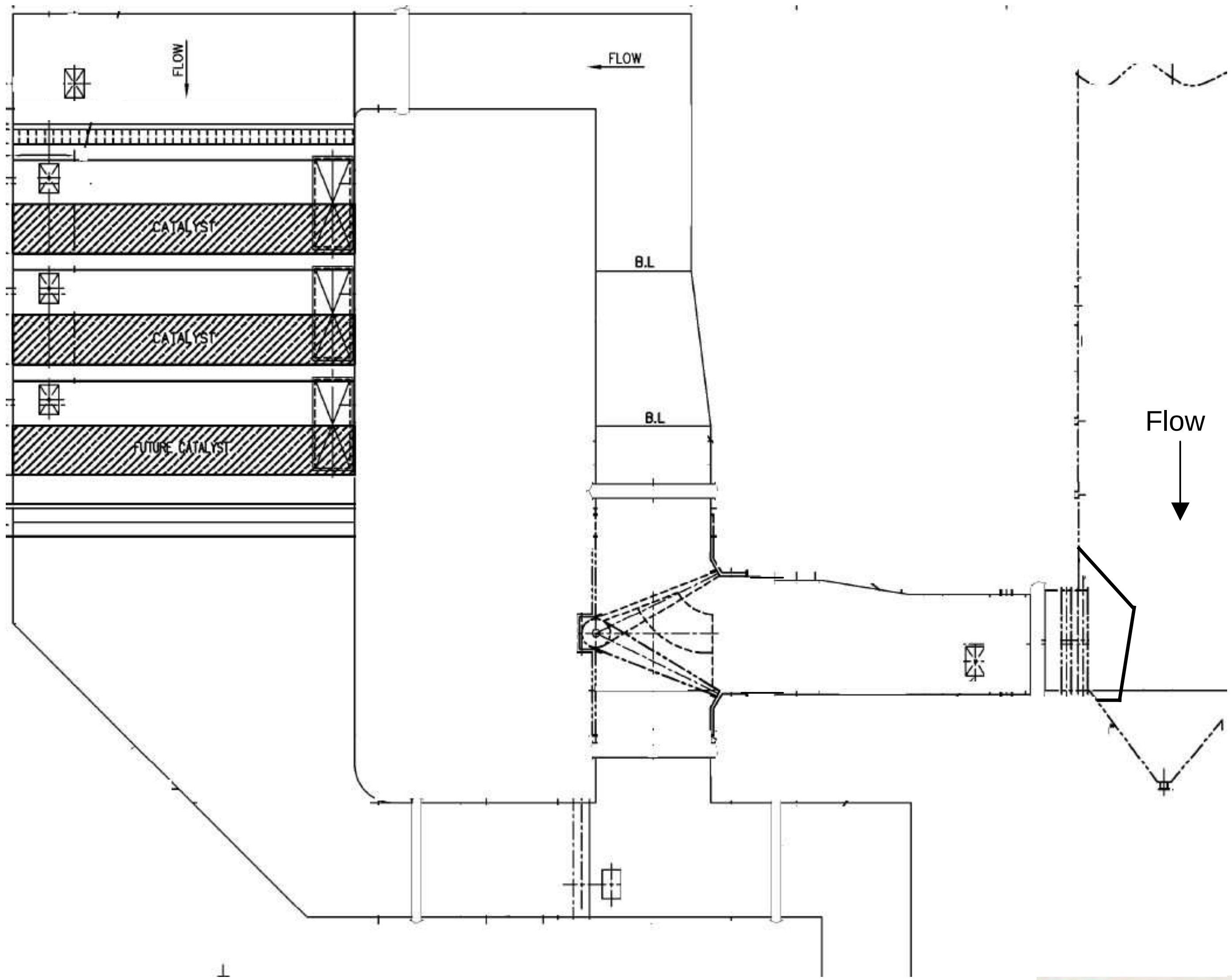
Roxboro Steam Plant

- Four units built 1966-1980
- 2500 MW total
- Eastern bituminous coal
- Unit 3
  - Riley 745 MW twin furnace
  - Rear wall firing w/Atrita mills
  - Two Foster Wheeler SCR reactors (A and B) added in 2003
  - Two layers Cormetech honeycomb catalyst (6.9 mm pitch)
  - One empty layer
  - Two-segment LPA screen installed 2004, updated in 2006

Roxboro 3 SCR



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Problem Description – SCR

- Catalyst plugs with ash over time
- Large dunes (>4’ high) over ~50% of both catalyst layers

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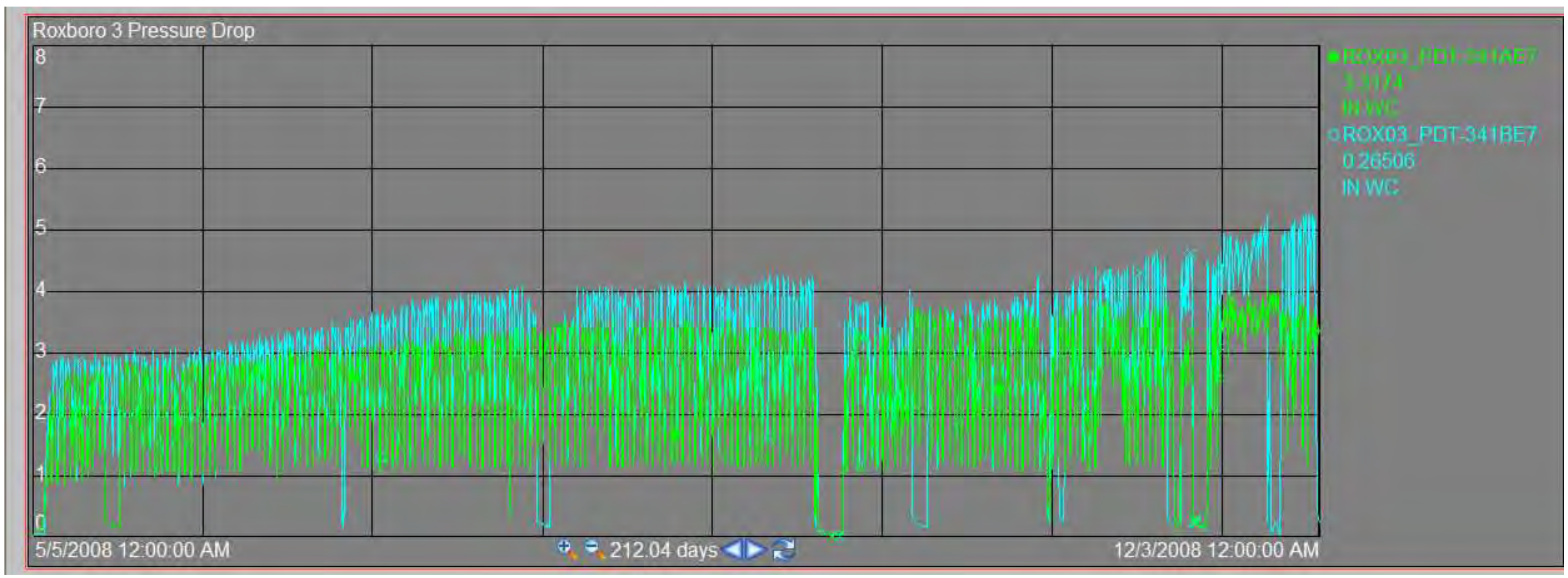
Problem Description – SCR

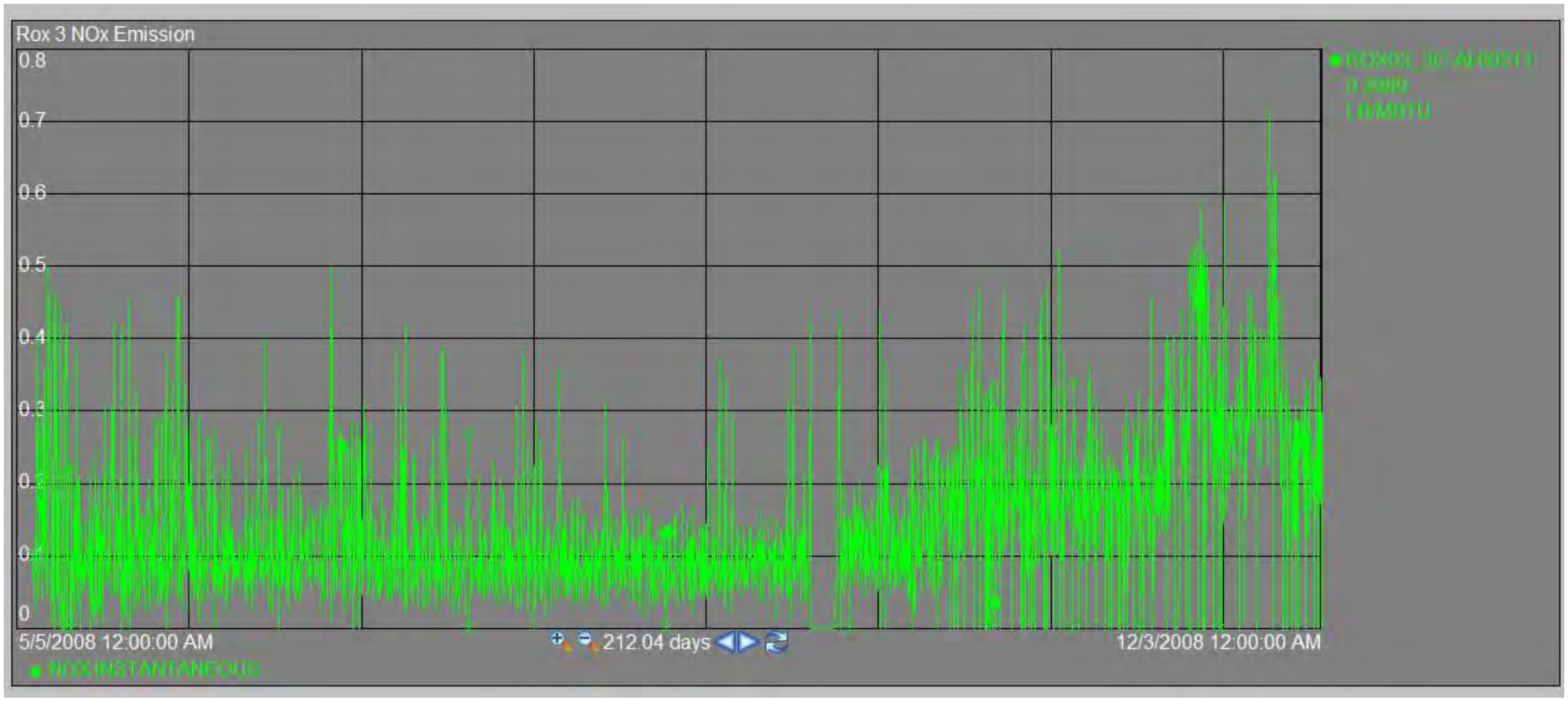
- Reactor pressure drop increases over time
- NH3 usage increases as reactor pluggage advances
- NOx reduction limited when NH3 slip hits maximum



Reactor B DP: May 2008 (3 IWC) to December 2008 (5 IWC)

Problem Description – SCR

Nox emissions over time



NOx emissions: May 2008 to December 2008

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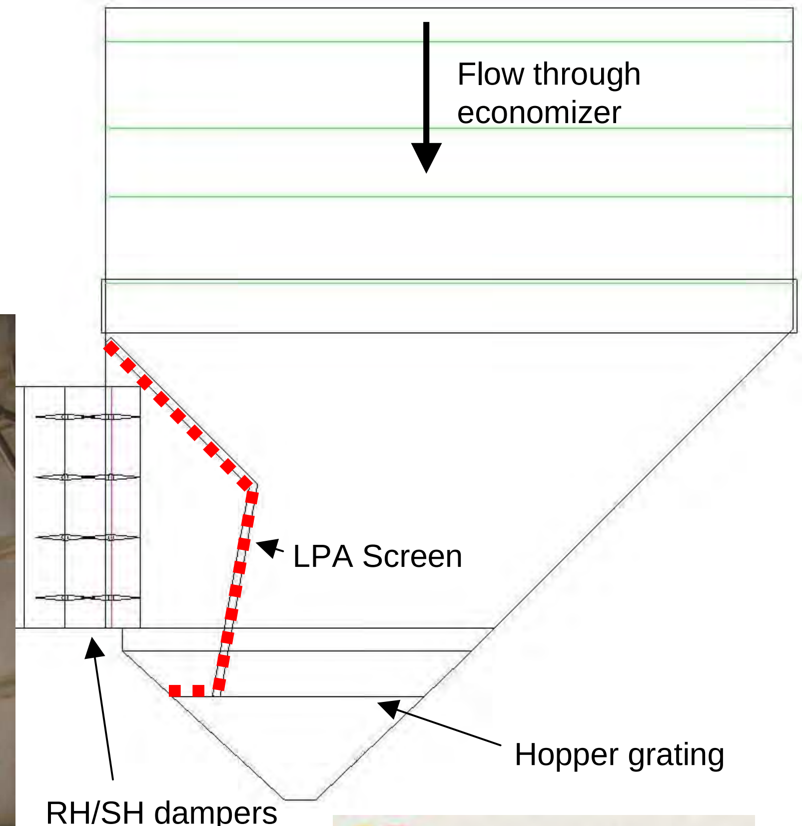
Roxboro 3 LPA Screen

- Located at economizer hopper
- Woven wire mesh with 4 mm square openings
- Two-segment flat screen
  - Upper section at 45 degree angle
  - Lower section at 80 degree angle
  - Floor on top of hopper grating



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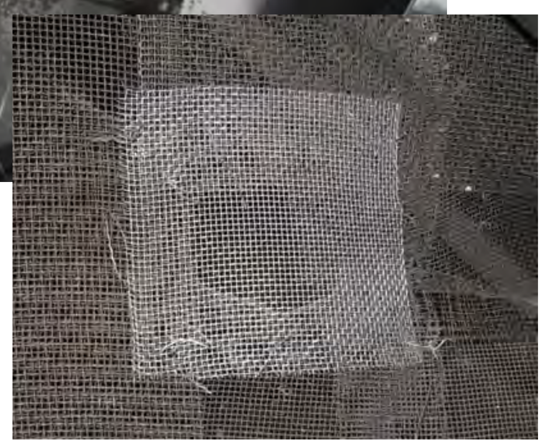
Problem Description – LPA Screen

- LPA screen at economizer hopper plugs with ash over time
- Screen erosion also evident; periodic patching required

Upper screen

Lower screen



Erosion and patch

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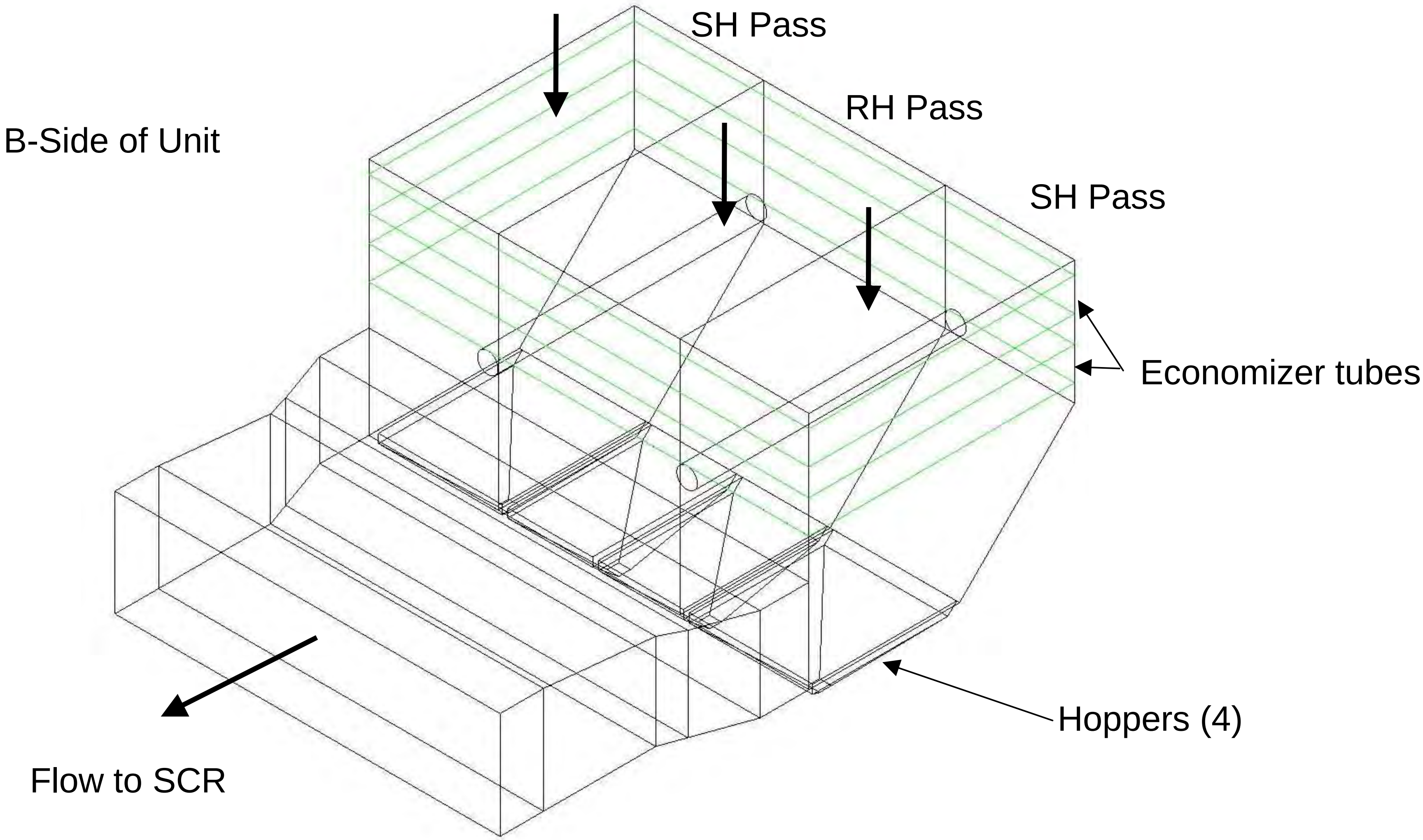
Solution Process

- Geometry, operational data, and observations from plant
- Detailed inspection and ash characterization (May 2009)
- Velocity and online video testing (June 2009)
- Computational Fluid Dynamics modeling (summer 2009)
  - Correlate CFD model to actual plant observations
  - Evaluate various design strategies
  - Develop final design
- Fabricate and install modifications (Oct 2009)
- Observe performance over time

Geometry – Economizer Hopper Region

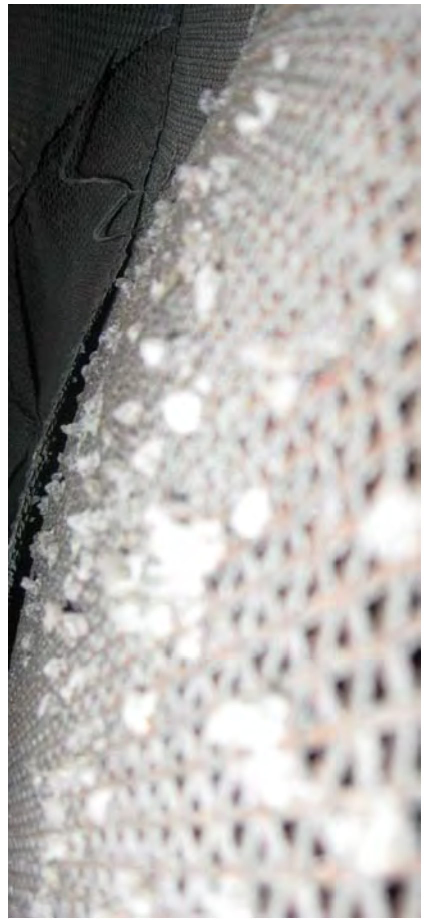


Inspection (May 8-15, 2009)

- LPA Screen
  - Pluggage and erosion primarily in SH passes
  - RH pass fairly clean and notably less erosion
  - Pluggage of upper screen estimated at 60% blocked
    - Combination of LPA and fine ash
    - Some evidence of moist ash
  - Lower screen slight pluggage near bottom, LPA wedged into screen openings
  - Erosion of SH pass lower screen is most pronounced
  - Erosion evident on floor section near hopper grating
  - Observed that it is difficult to patch screen completely

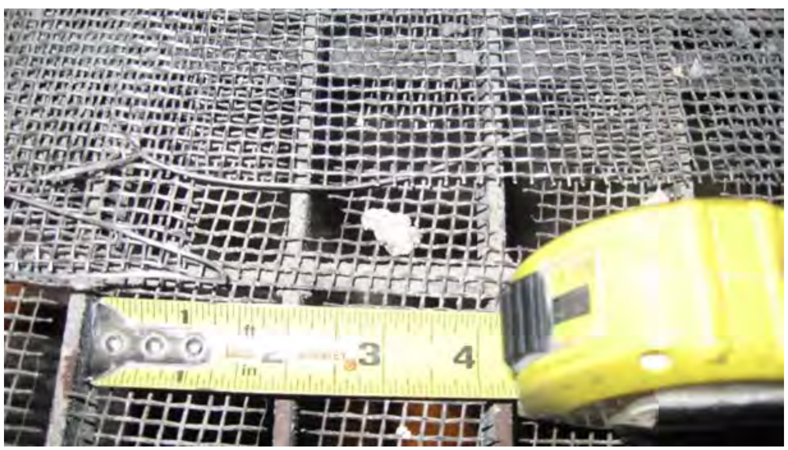
Inspection (May 8-15, 2009)

- LPA Screen



Lower Screen

LPA Screen



Hopper grating

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Inspection (May 8-15, 2009)

- SCR Reactors
  - Catalyst layer 1 empty
  - Large ash dunes on top of layers 2 and 3 starting from South wall (closest to boiler)
  - After vacuuming dunes, LPA and fine ash still present in catalyst channels
  - LPA present near North wall also
  - Fine ash build up noted on all trusses above catalyst, including monorail beams, empty first layer trusses, and rectifier supports
  - Fine ash build up on SCR inlet turning vanes (2-3 " deep)

Inspection (May 8-15, 2009)

- SCR Reactors

Before vacuuming

North wall LPA

After vacuuming

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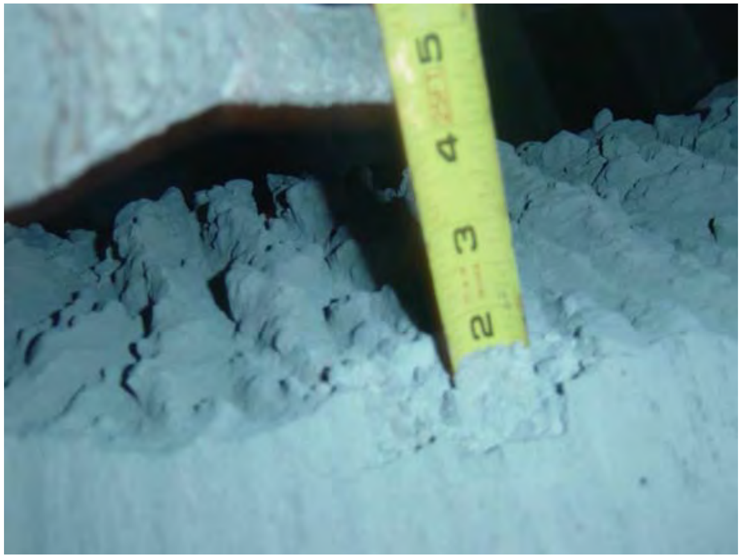
Inspection (May 8-15, 2009)

- Vanes, structure above catalyst



Monorail beams and trusses

Reactor inlet turning vanes

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Particle Characterization

Lower LPA Screen Pluggage

Catalyst Layer 2 Pluggage

Catalyst Layer 3 Pluggage

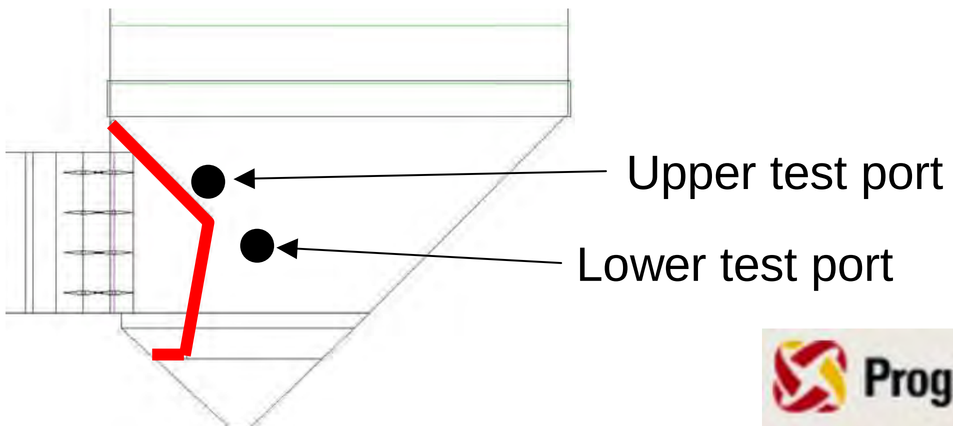
Field Testing

- Conducted ~3 weeks after outage
- Full load (June 8-9, 2009):
  - Measure velocity profile at catalyst and LPA screen
  - Video of ash pluggage situation at SCR and LPA screen
- Low load (June 9, 2009)
  - Video of SCR pluggage situation

Field Test Results

- Velocities at LPA screen
  - 2 ports on East walls (SH pass outboard)
  - Probe could only be inserted 7', while duct is 50' wide
  - 3D velocity probe, electronic data acquisition

	Upper port	Lower port
Average velocity (ft/sec)	25.5	40.8
Peak velocity (ft/sec)	41.3	46.3
Average flow direction (degrees CCW)	15.1	45.6
Static pressure (inches of water)	-2.79	-2.76
Average temperature (deg-F)	725	730



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Field Test Results – LPA Screen Video

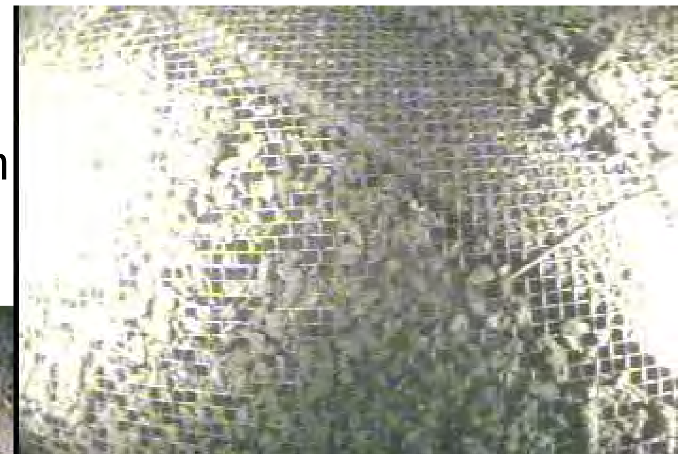
- Full load video at LPA screen
  - Insert camera 10’ deep from East walls (SH pass outboard)
  - Enertechnix Pyro-Remote camera

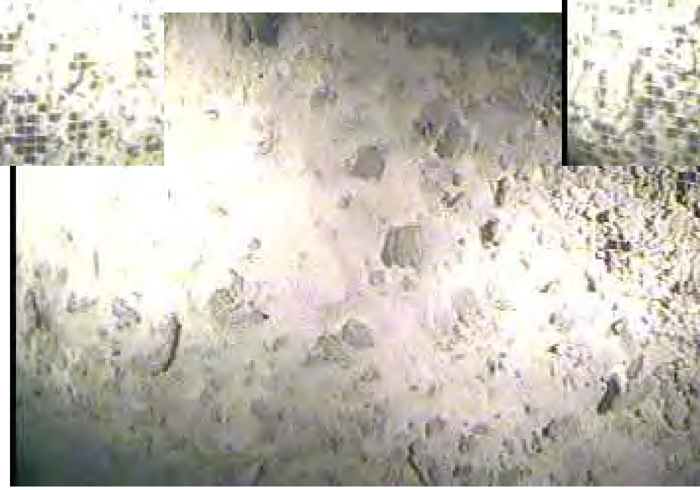
Videos were shown at this time during
the actual presentation

Field Test Results – LPA Screen Video

- Upper screen blockage estimated at 80-90%
- Lower screen only minor blockage noted

Upper LPA screen





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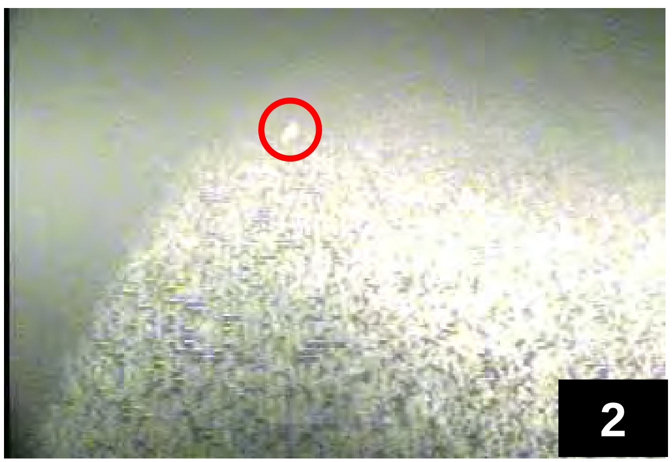
Field Test Results – LPA Screen Video

- Tracking an LPA particle to the upper screen



Field Test Results

- Velocity distribution in SCR
  - Measure 10’ deep from North & South walls (reactor width 35’-9”)
  - 3D velocity probe, electronic data acquisition

	North wall ports	South wall ports
Average velocity (ft/sec)	15.0	12.7
Peak velocity (ft/sec)	20.3	17.1
Minimum velocity (ft/sec)	7.8	3.0
Flow balance (% of measured ports)	54.1	45.9

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Field Test Results

- Full load video at SCR catalyst
  - Insert camera 12’ deep from South wall (closest to boiler)
  - Allowed observation of first 3 catalyst modules from south wall
  - Enertechnix Pyro-Remote camera

Along south wall, ash extends 1-2’ from wall

Along south wall, LPA evident

Video at SCR Catalyst

Videos were shown at this time during
the actual presentation

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Full Load Video at SCR Catalyst

Along south wall, ~6” wide module seal at bottom, LPA evident

Along N-S ~6” wide module seal

Along N-S module seal, starting to bridge over catalyst

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Full Load Video at SCR Catalyst

Ash build up on reactor trusswork

Ash avalanche event captured on video. No sonic horns in operation.

Randomly located pluggage regions, far from south wall.

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Low Load Video at SCR Catalyst

Ash build up along south wall increased

At some locations, ash extends over entire first module along seals

More bridging initiated along seals

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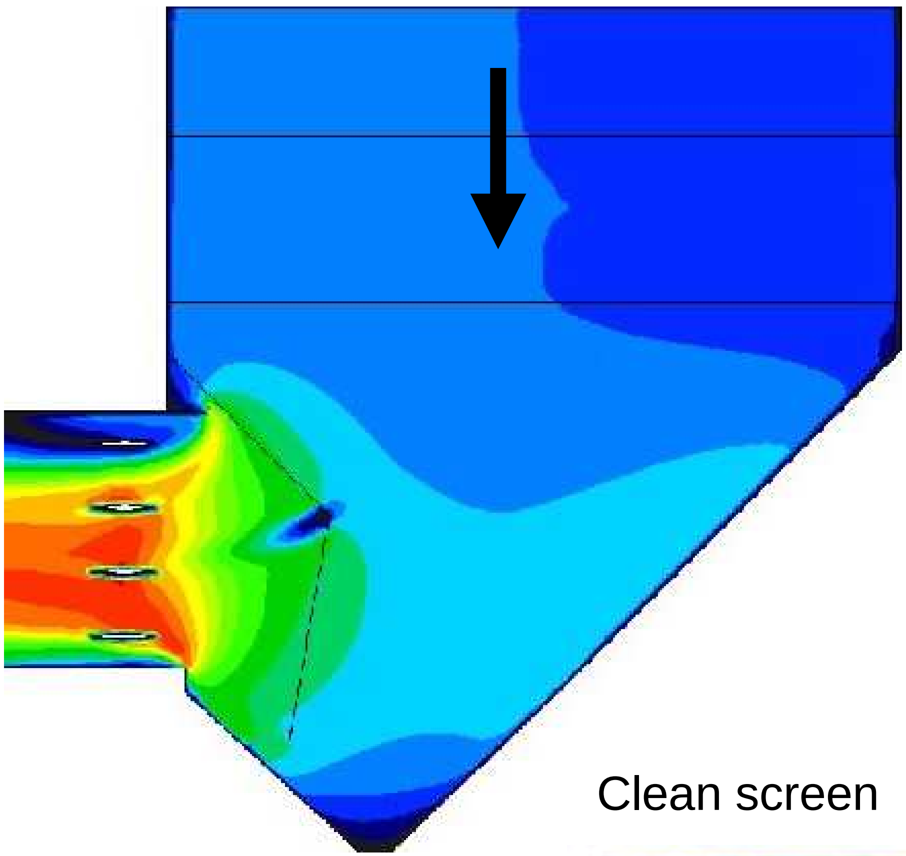
CFD Model Set Up

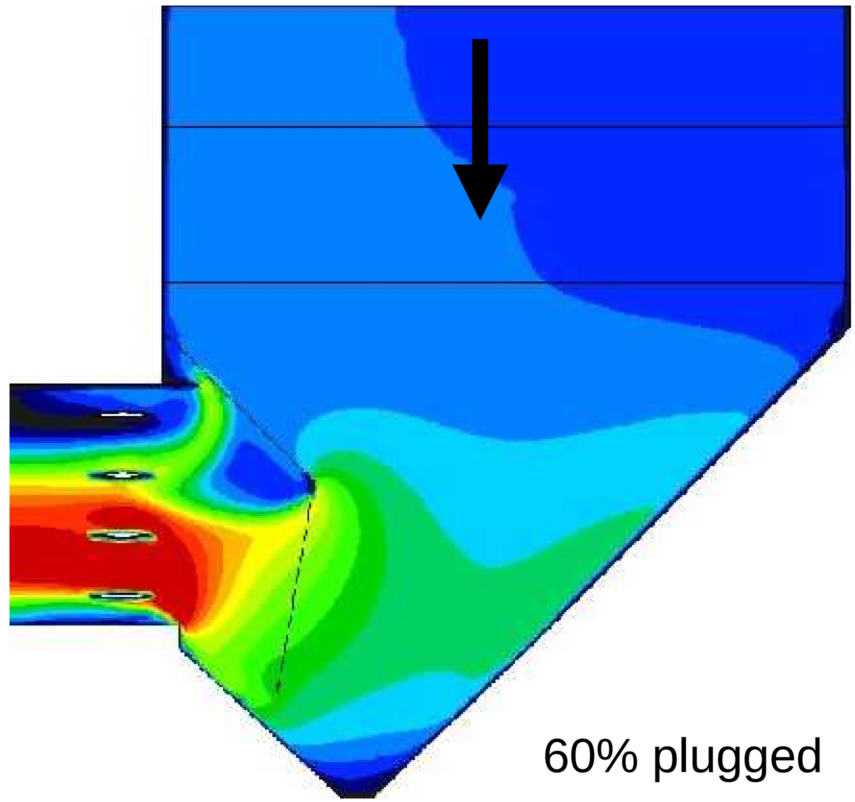
- Model 1: LPA Screen
  - 3-D domain from economizer inlet to SCR damper
    - Include econ tubes, LPA screen, trusses, headers, RH/SH dampers
  - Full load flow rate
  - Track 28,000 particles through system (3, 5, 7, & 9 mm)
  - Examine LPA screen pluggage, erosion, pressure drop
- Model 2: Reactor inlet
  - 2-D domain from SCR inlet duct to catalyst layer 2
    - Include reactor inlet vanes, rectifier, catalyst
  - Full load flow rate
  - Examine ash build up on reactor inlet vanes

Baseline LPA Screen Model Output

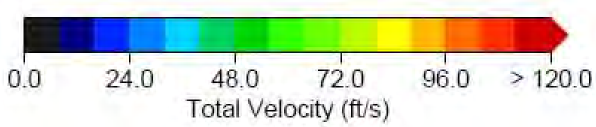
- Gas velocity distribution
  - Full load, clean screen and partially plugged upper screen



Clean screen



60% plugged upper screen



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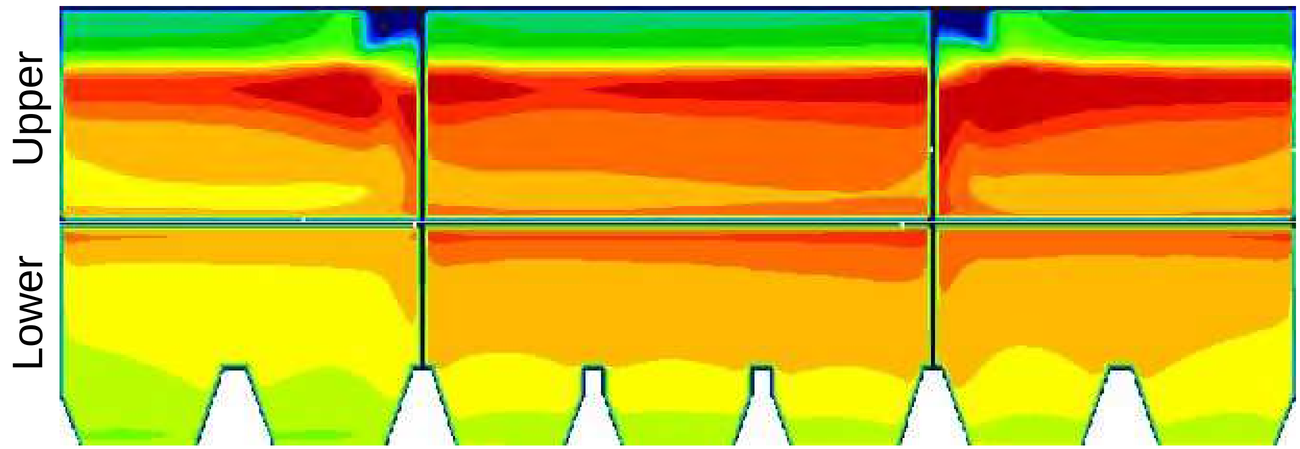
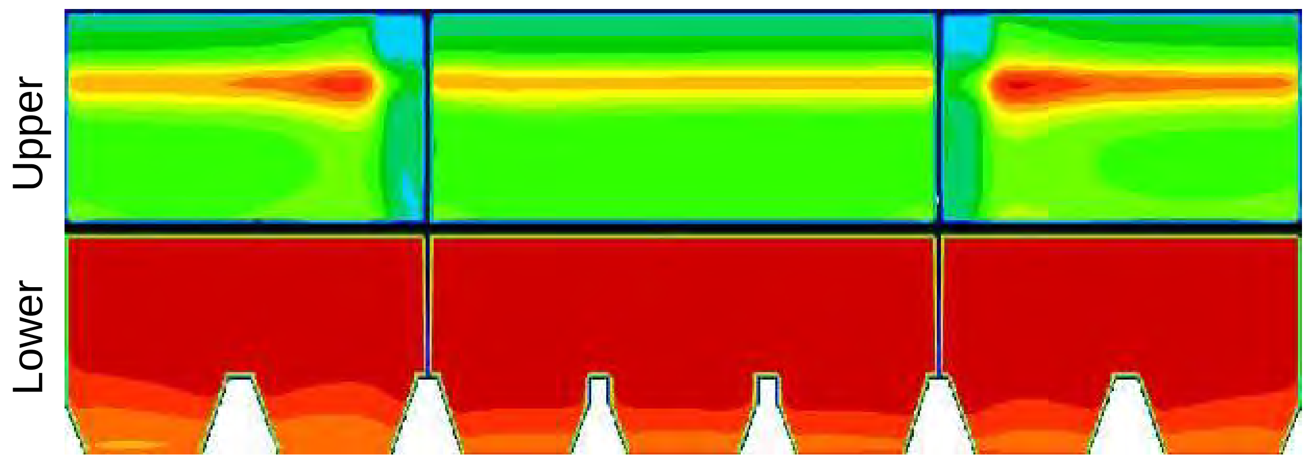
Baseline LPA Screen Model Output

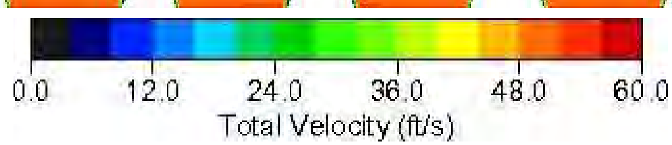
- Total velocity at face of screen



Clean screen
Average Vel = 43 ft/s
% area > 60 ft/s = 4%
Peak velocity 70 ft/s



60% plugged upper screen
Avg Vel Upper = 29 ft/s
Avg Vel Lower = 67 ft/s
% area > 60 ft/s = 35%
Peak velocity 90 ft/s
DP increase 0.8 in.H_2O



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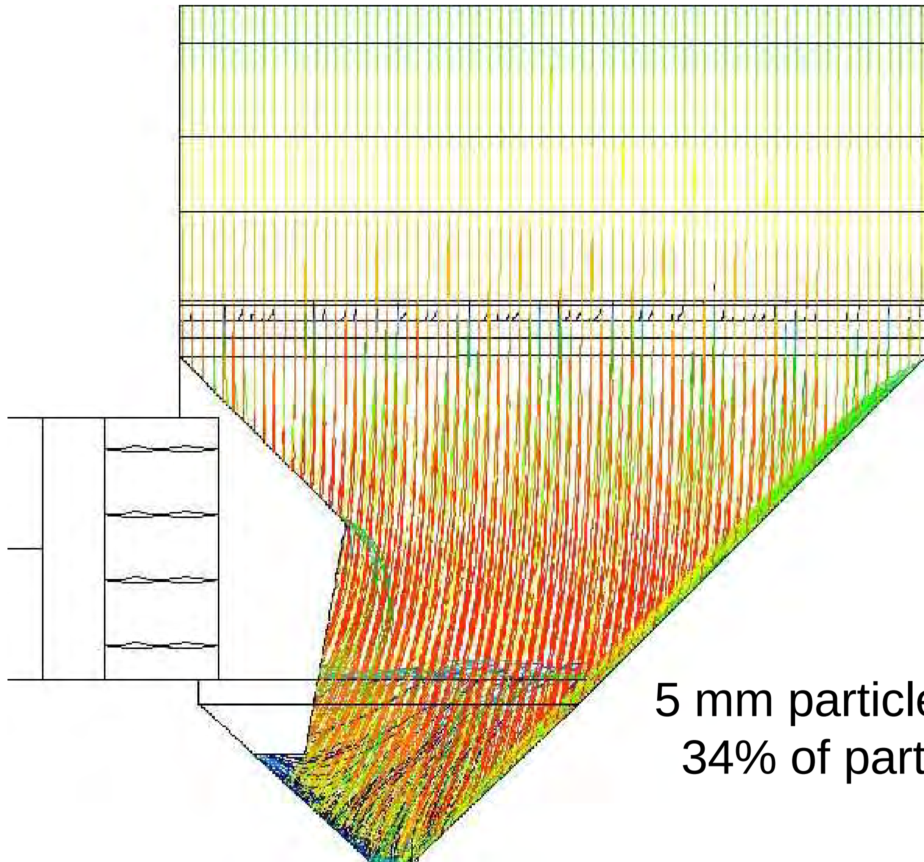
Baseline LPA Screen Model Output

- Particle trajectories
  - Impact locations on screen are similar for clean and plugged cases



5 mm particle trajectories
34% of particles impact screen

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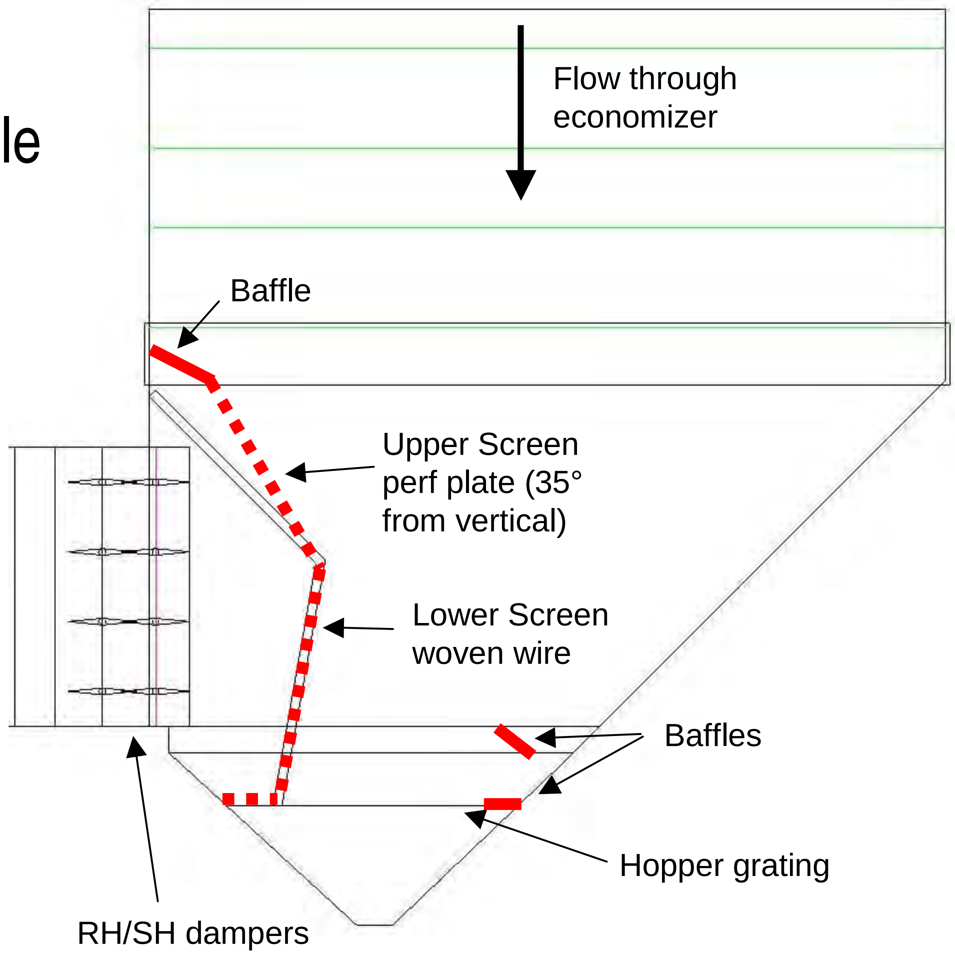
Design Changes

- Main goals
  - Primary → Steeper upper screen angle
  - Minimize peak velocity at screen
  - Reduce # of particles impacting screen
  - Minimize erosion
  - Minimize DP
  - Install Fall 2009
- 24 design variations evaluated



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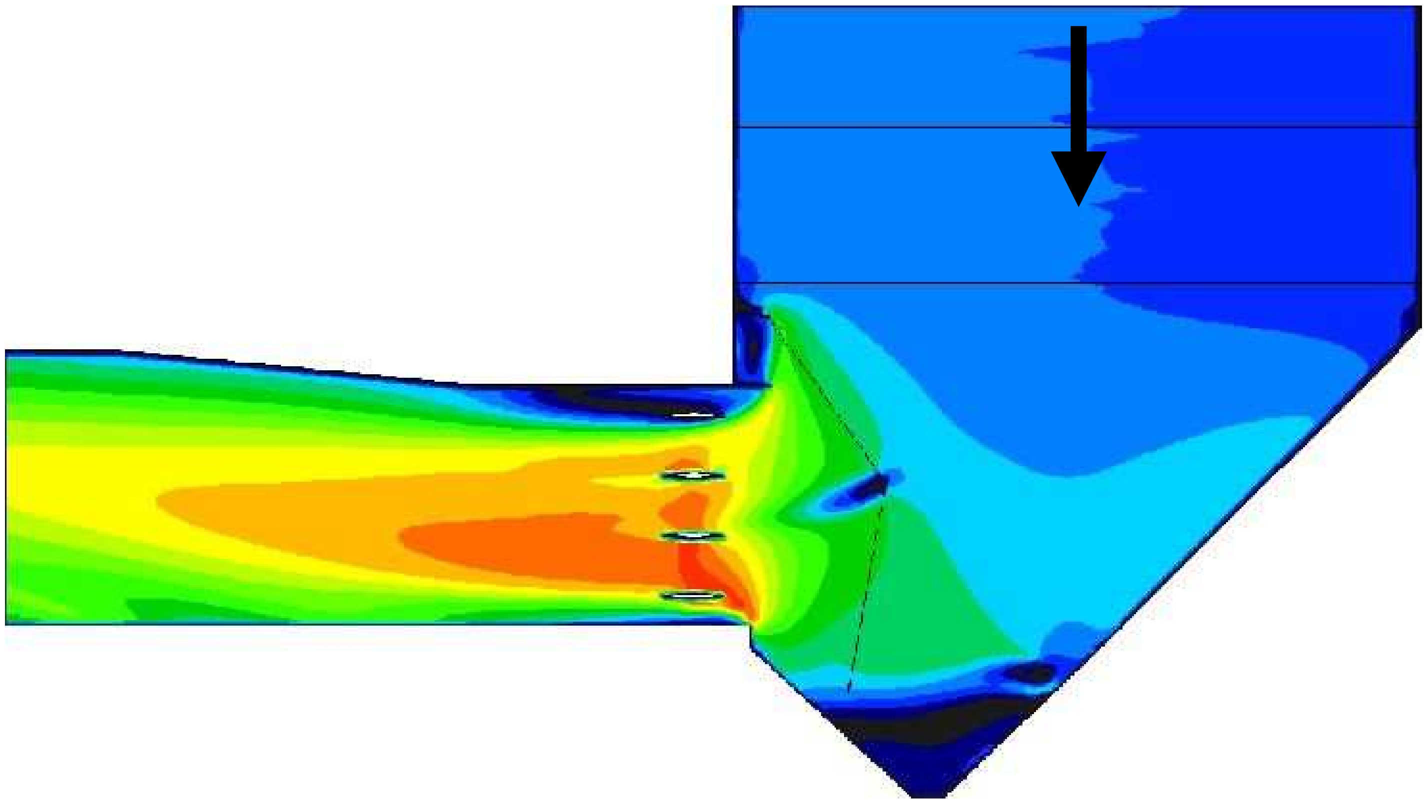
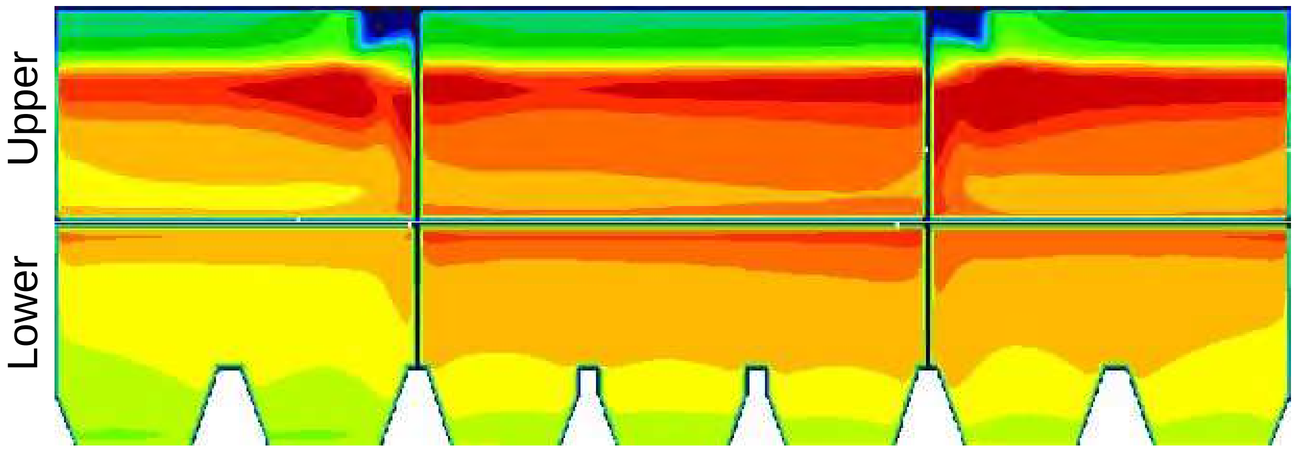
Final Design – Gas Velocity

- Slight increase in peak velocities on screen
- No change in screen DP

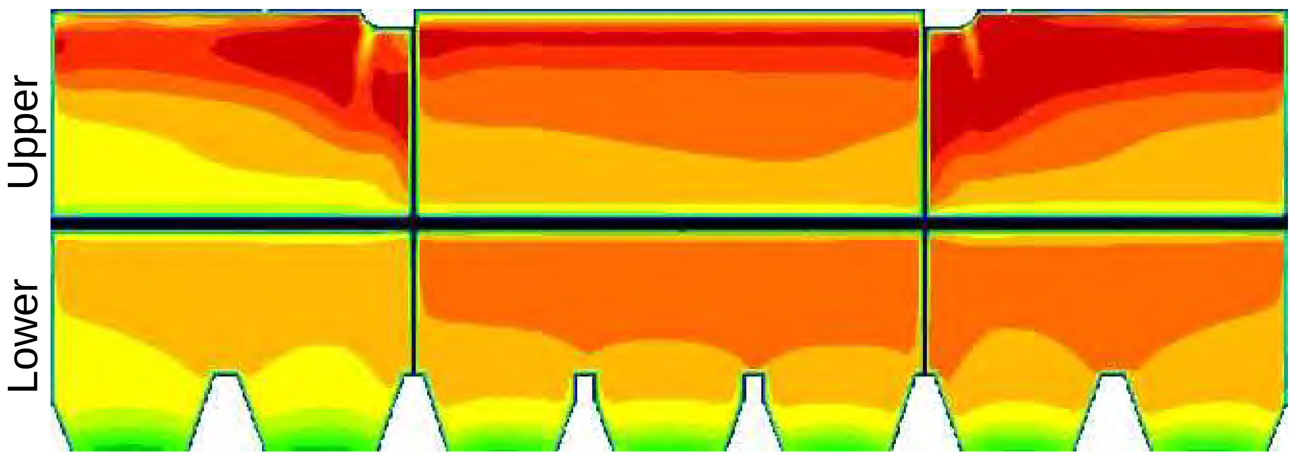


Final Design – Velocity at Screen

- Nearly identical to baseline clean screen



Clean screen
Avg Vel = 43 ft/s
% area > 60 ft/s = 4%
Peak velocity 70 ft/s



Final design screen
Avg Vel = 46 ft/s
% area > 60 ft/s = 4%
Peak velocity 73 ft/s
DP increase 0 in. H_2O

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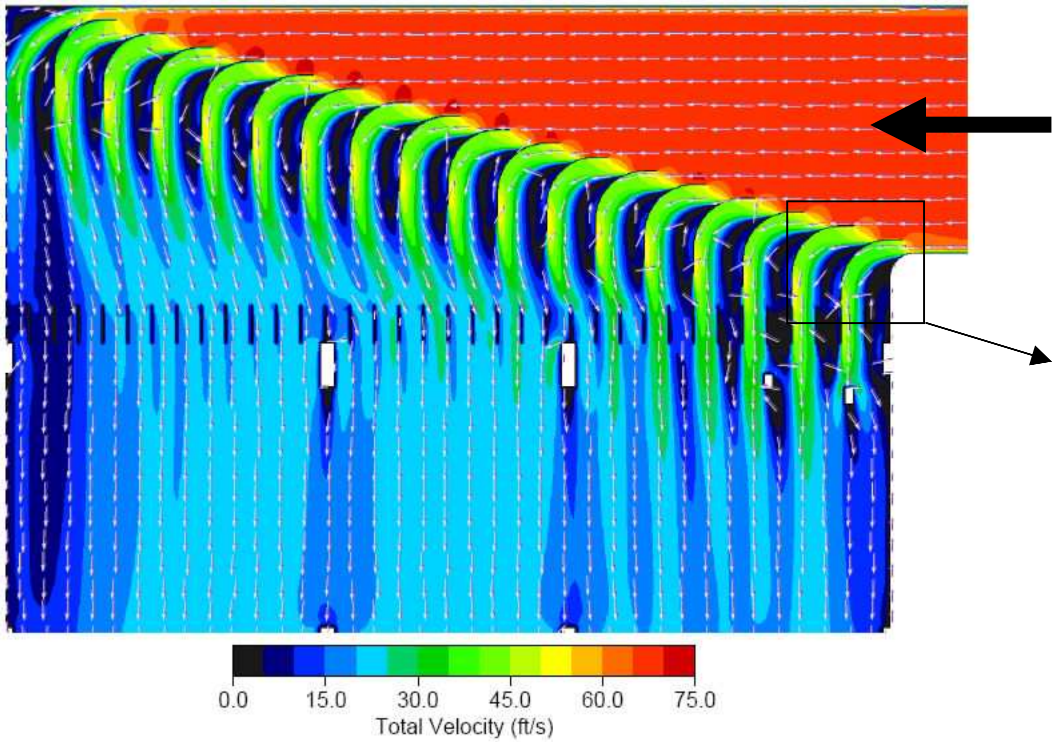
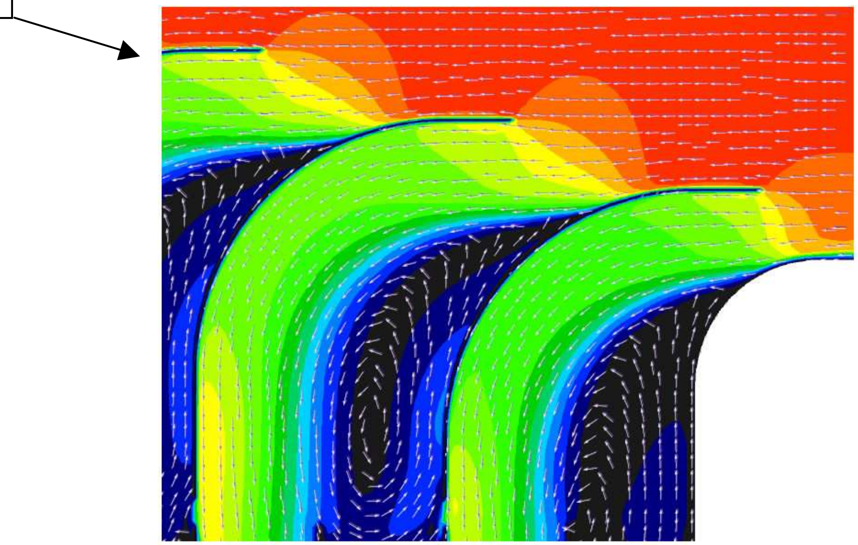
Reactor Inlet Vane Model

- Baseline velocity distribution through vanes



Close-up at inner corner



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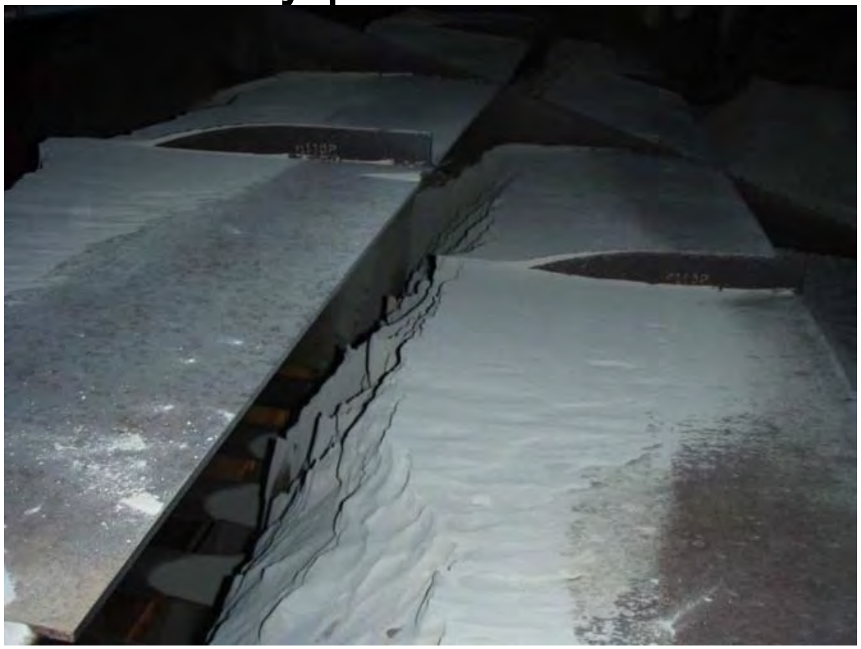
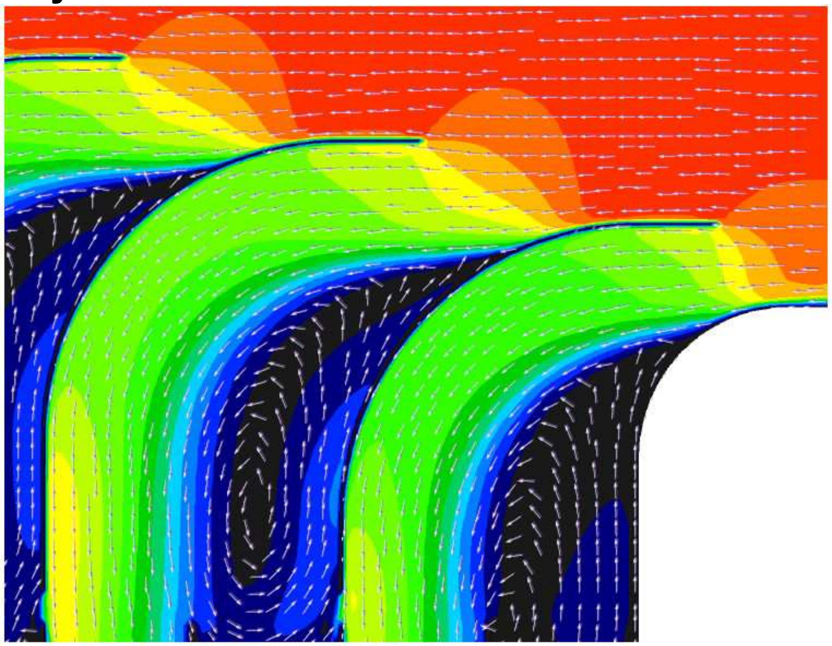
Reactor Inlet Vane Model

- Ash buildup on vanes occurs in flow recirculation zones above horizontal and curved vane surface
- Goal: Reduce size of recirculation zone without degrading velocity pattern at face of catalyst





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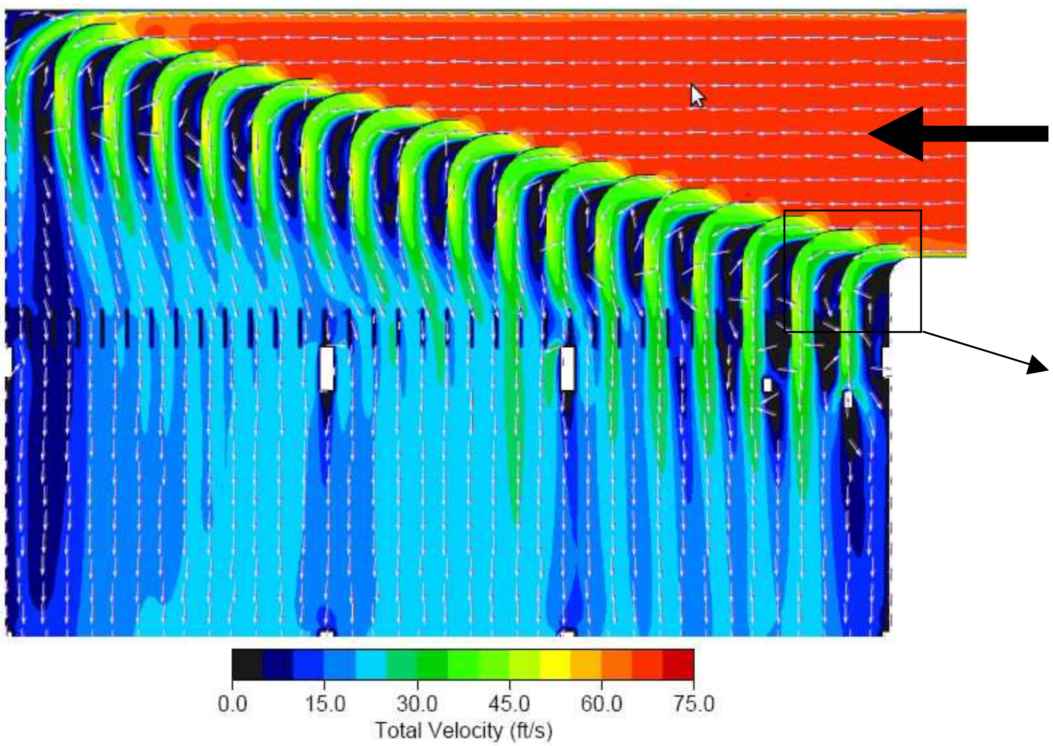
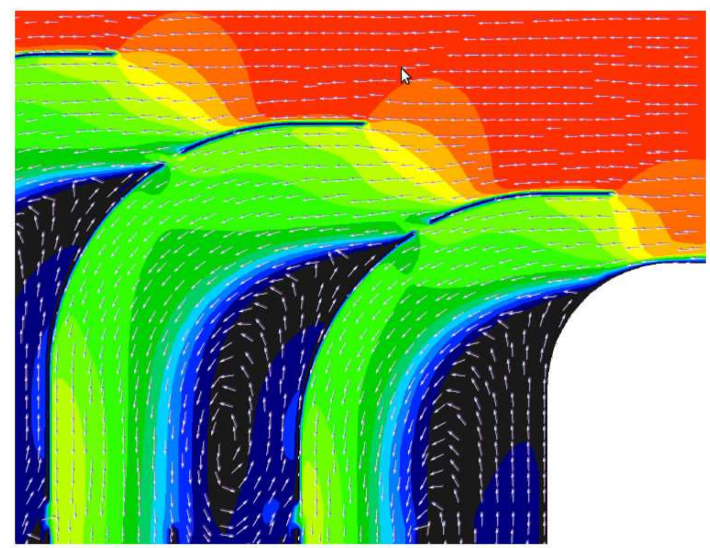
Reactor Inlet Vane Design Changes

- Revised Vane Geometry – 2 inch slot at strategic location



Close-up at inner corner



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LPA screen installation

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LPA screen installation

LPA screen installation

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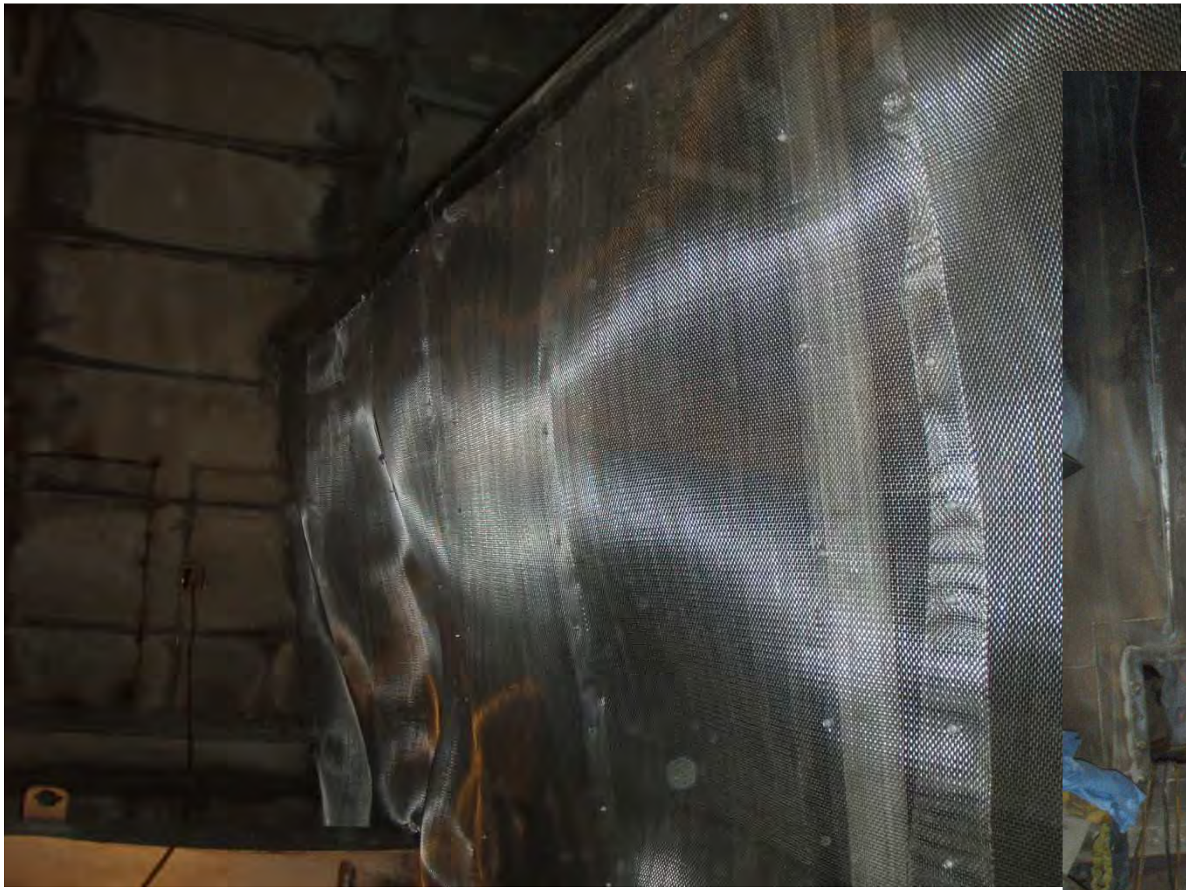
LPA Screen Installation



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Hopper baffle installation

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Hopper Baffle Installation

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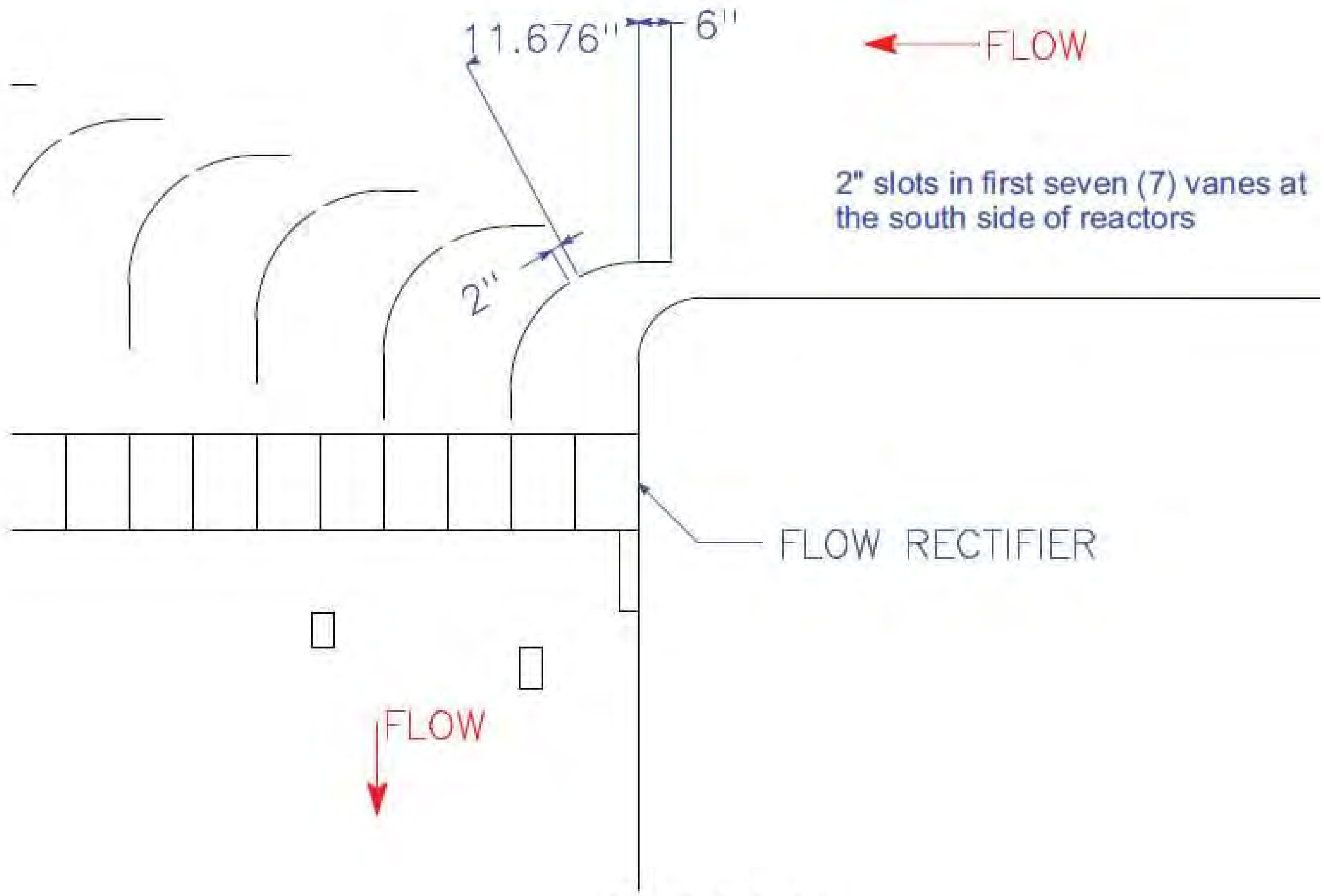
Turning vane slot modifications (first 7 vanes)



All units in inches

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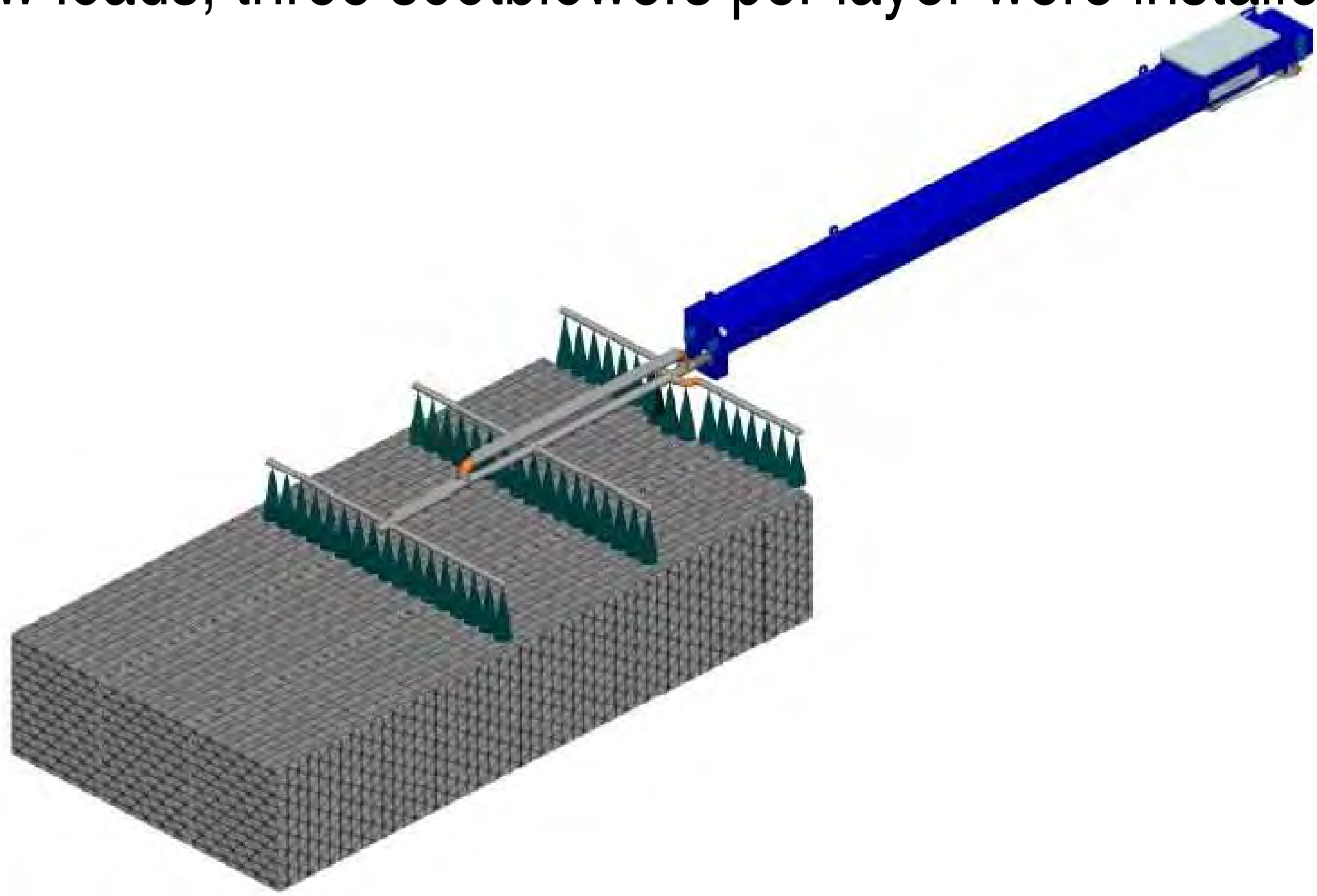
Turning vane mods

SCR sootblowers

- In order to prevent loose flyash from piling in the SCR at low loads, three sootblowers per layer were installed.



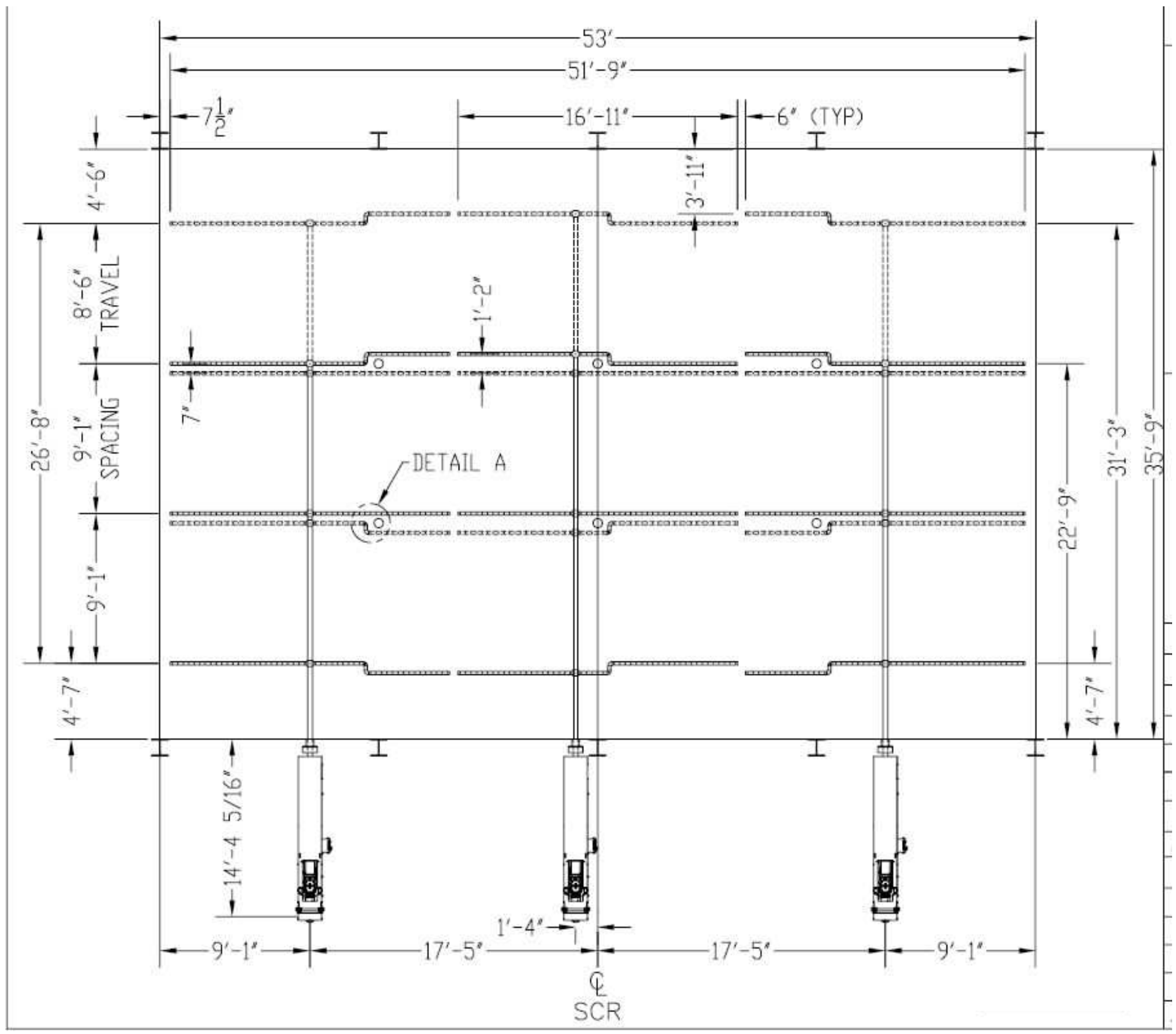
Sonic horn effectiveness

- Sonic horns have been effective in applications with little popcorn ash and sufficient flow conditions at low load.
- Ash loading in the Rox 3 SCR overwhelmed the sonic horns.

Ash lance effectiveness

- Plant-manufactured ash lances were installed in December 2008.
- The lances controlled the extent of the ash pile and shortened time needed to vacuum the SCR.

Sootblower design



Plan View

Sootblower installation

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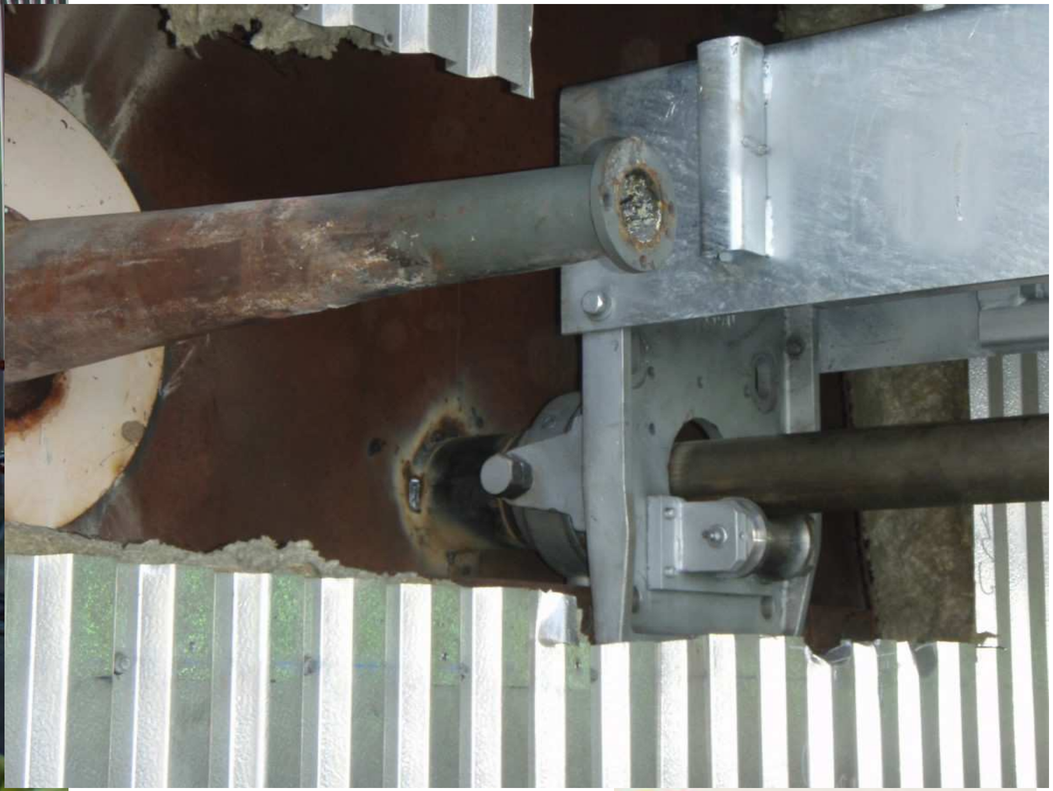
Sootblower Installation



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Sootblower Installation

Sootblower Installation

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Sootblower Installation

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Sootblower Installation

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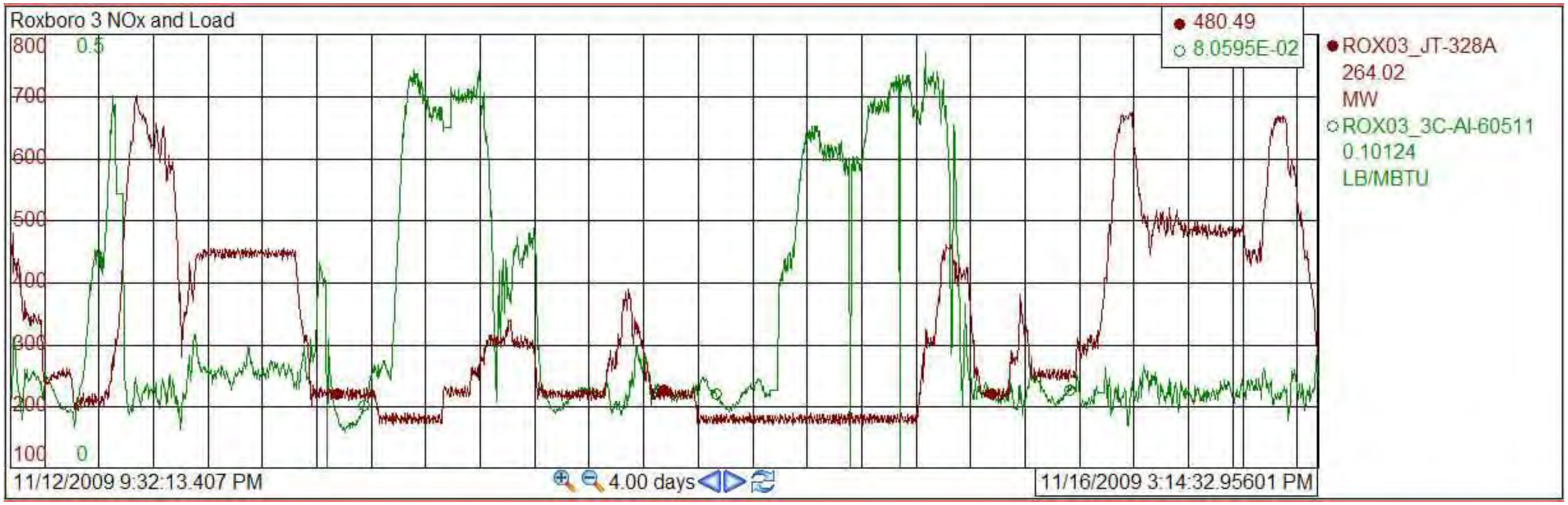
Installation Schedule and Cost

- All modifications installed during Fall 2009 outage (10/3 – 10/18) and included a catalyst layer change out.
- Costs totaled $806,000
  - Material: $288,000
  - Labor: $518,000 (includes installation mechanical labor, electrical labor, vacuuming, engineering, plant labor, insulation, C-B tech rep, ASC)

Field Results – Post Installation

- Nox emissions



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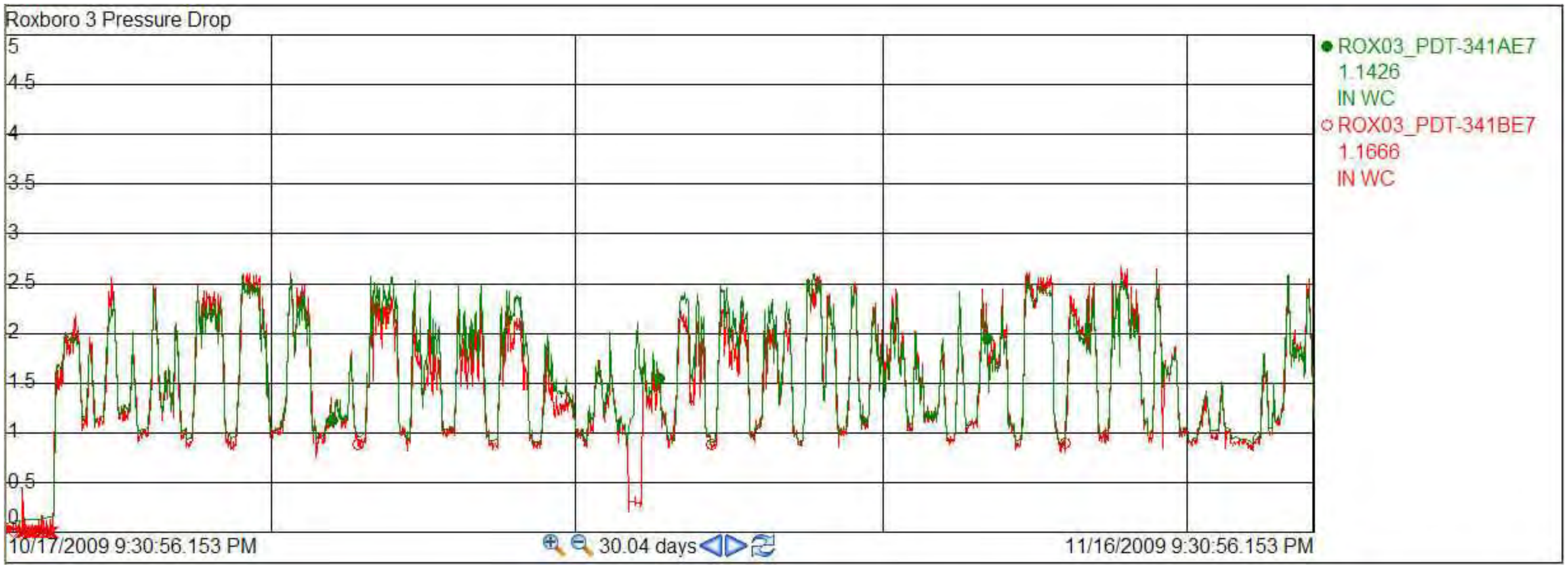
Field Results – Post Installation

- Reactor pressure differential (inH2O)



Reactor DP holding steady after 5 weeks operation

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Field Results – Post Installation

- Video at LPA screen (16 Nov 2009) ~50% load
- Unit had been operating for ~4 weeks since outage
- Less pluggage than with previous screen during May testing, but still occurring
- LPA appears to be pinned against screen by gas flow

Upper screen most areas estimated at 40% blocked

Field Results – Post Installation

- Video at first layer catalyst (16 Nov 2009)
- No ash dunes noted, even near South wall
- Compares very favorably to previous testing in May, when dunes extended 2-4' from wall
- Some LPA visible on top of catalyst, not sure how it traveled here
  - Holes in screen?
  - Had laid out in inlet ductwork prior to outage and was re-entrained during start up?

Conclusions

- Combination of CFD modeling and field testing used to analyze root causes of catalyst pluggage
- CFD modeling used to develop new design for LPA screen and reactor inlet vanes
- New sootblowers installed at all layers
- Catalyst pluggage situation appears to be under control based on observations after 4 weeks operation
  - No evidence of ash accumulation on catalyst
  - Will continue to monitor performance over time
- LPA screen upper section still showing pluggage; less than previous
  - Steeper angle or upper deflection baffles may be required to eliminate pluggage
  - Will continue to monitor over time to determine if design revisions are necessary