REINHOLD ENVIRONMENTAL Ltd.

2017 NOx-Combustion-CCR Round Table Presentation

February 27 & 28, 2017, in Cleveland, OH / Hosted by FirstEnergy

Reinhold Environmental 2017 NOx-Combustion Round Table

Preventative Maintenance: Cleaning Techniques and Catalyst Cleanliness

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Presented by: Dr. Greg Holscher
IBIDEN CERAM Environmental, Inc.
February 28, 2017

Special Thanks to the Panelist

- ***Jason Bookout**; Senior Engineer; Environmental Systems & Field Support; Catalyst Manager;* Southern Company; 6 years
- ***Dave Browning**; Consulting Engineer: Fleet Combustion & Performance; Technical Engineer; Outage Manager;* FirstEnergy Corporate Technical Services; 14 years
- ***Mike O'Connor**; Engineering Programs Manager;* Dynegy, Inc.; Prior at Duke, Cinergy and CG&E; 28 years
- ***Philp Elliot**; Director of SCR Services;* STEAG SCR-Tech, Inc.; 10 years; Prior at Progress Energy
- ***Robert Mudry**; President;* Air Flow Sciences Corporation; 29 years, started as a summer intern
- ***Jeff Shelton**; Vice President Environmental Solutions;* Integrated Global Services; 2 years; Prior at Martin Engineering for 8 years.

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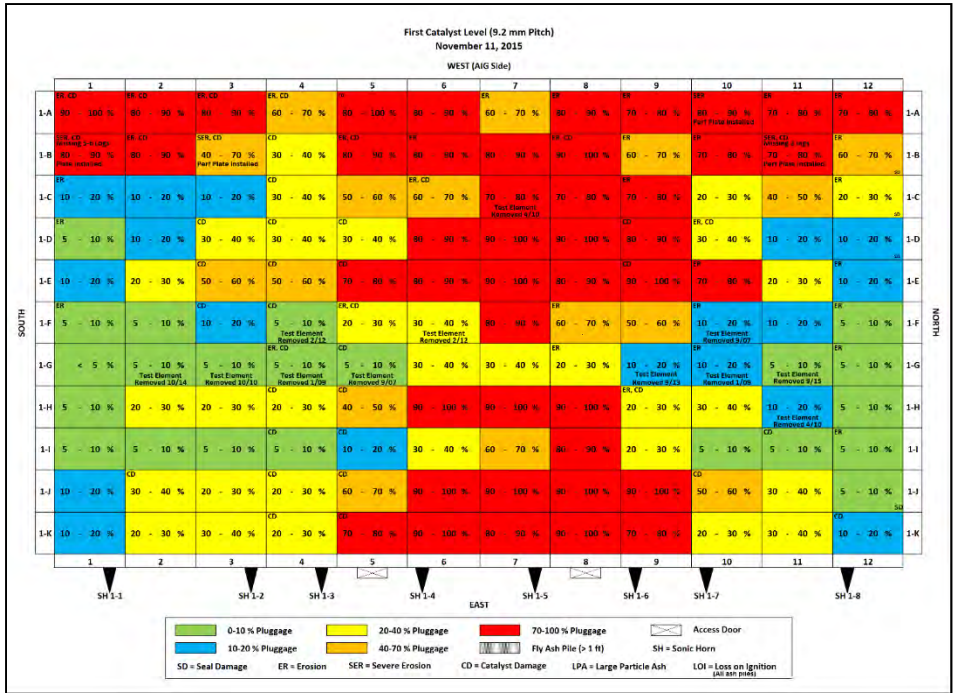
Topics for Panel Discussion

- Pluggage Resistance Catalyst
- Reactor Design & Configuration
- Factors Affecting Pluggage from Operations
- Online Cleaning Devices
- In-Situ Cleaning Technologies
- Fixing the Root Cause of Pluggage

What We Want to Avoid!



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Pluggage Resistance Catalyst?

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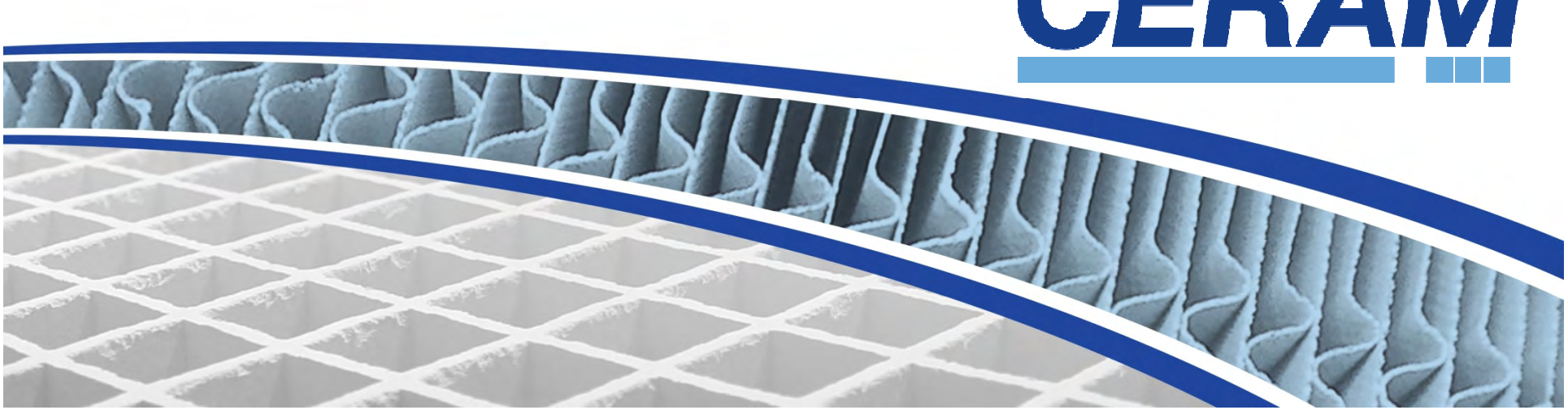
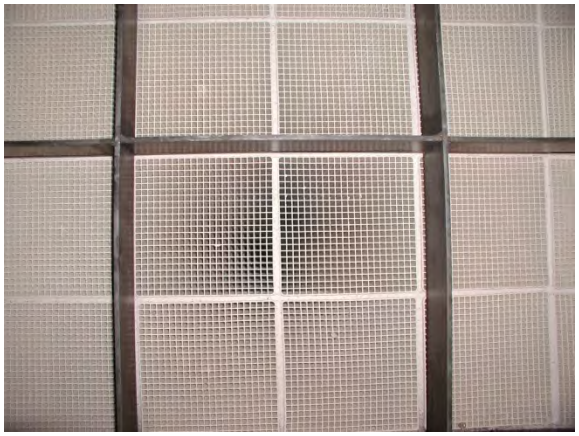
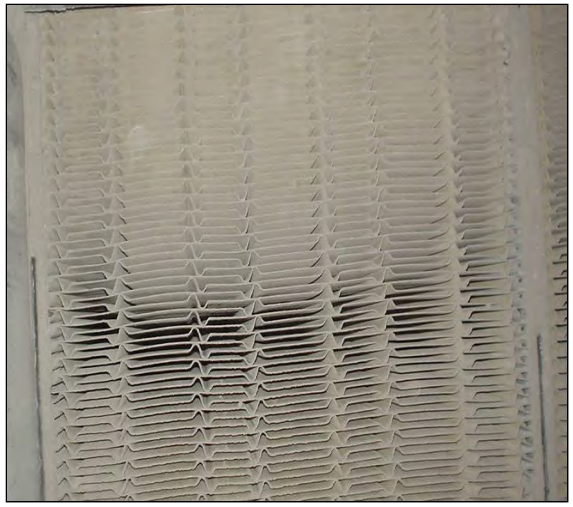


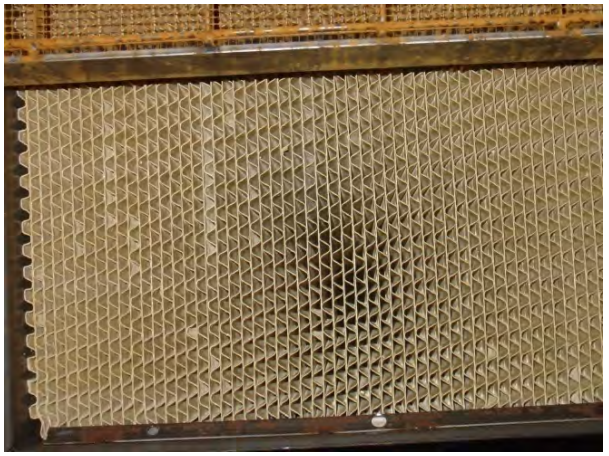
Any Catalyst Can Plug!



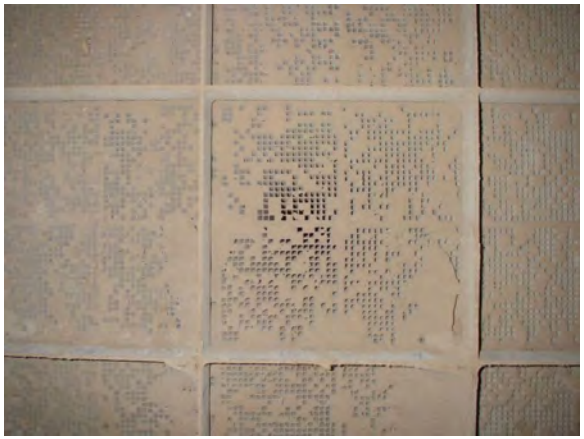
Honeycomb



Plate



Corrugated Fiber



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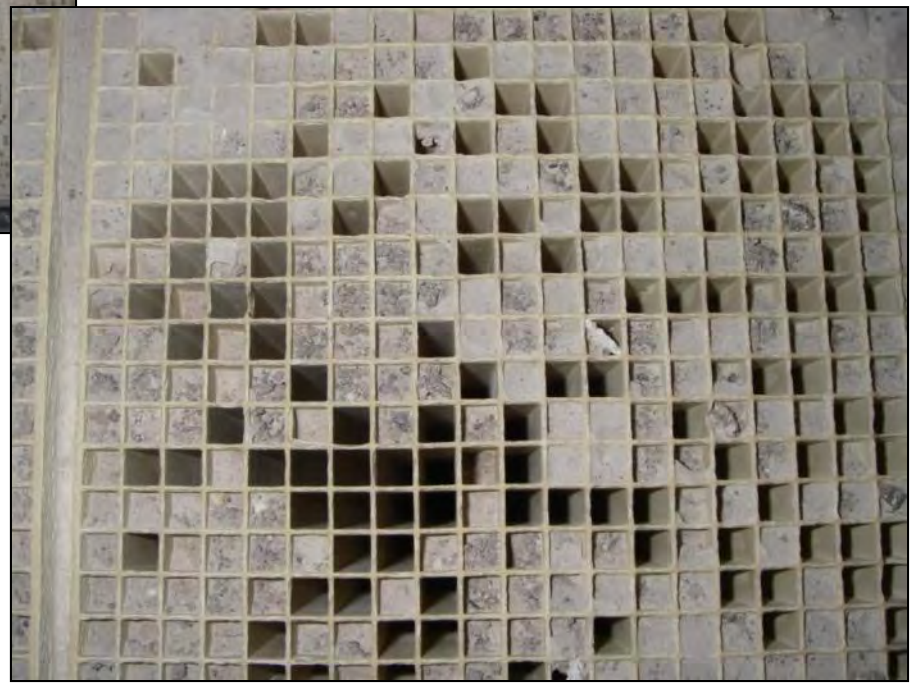
Catalyst Pluggage – LPA and LOI



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Catalyst Pluggage – Plate Catalyst

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Catalyst Pluggage – Plate Catalyst

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Catalyst Pluggage – Corrugated Catalyst

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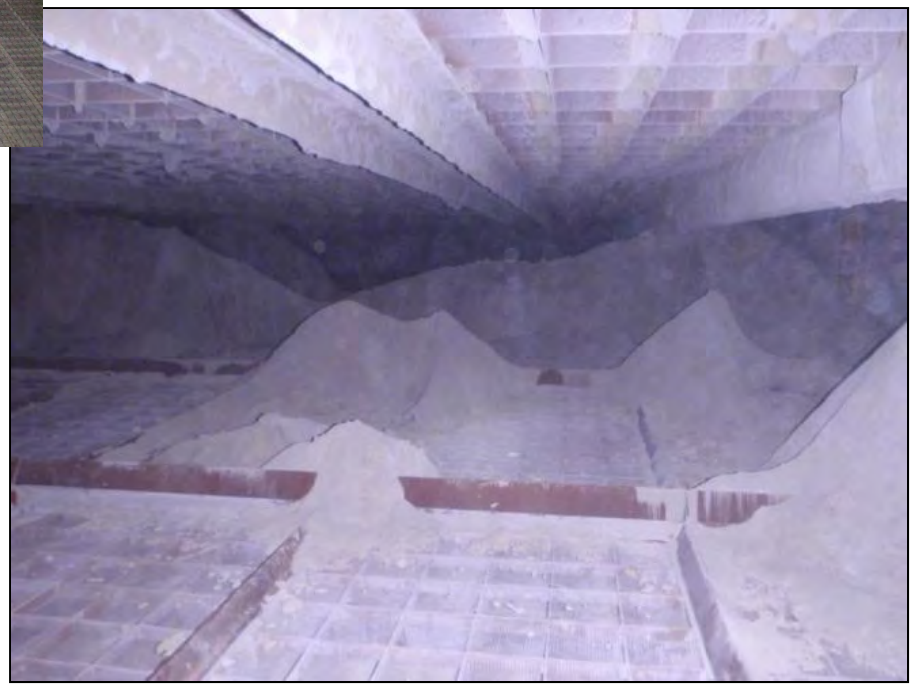
Ash Accumulation



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Ductwork – Ash Dropout

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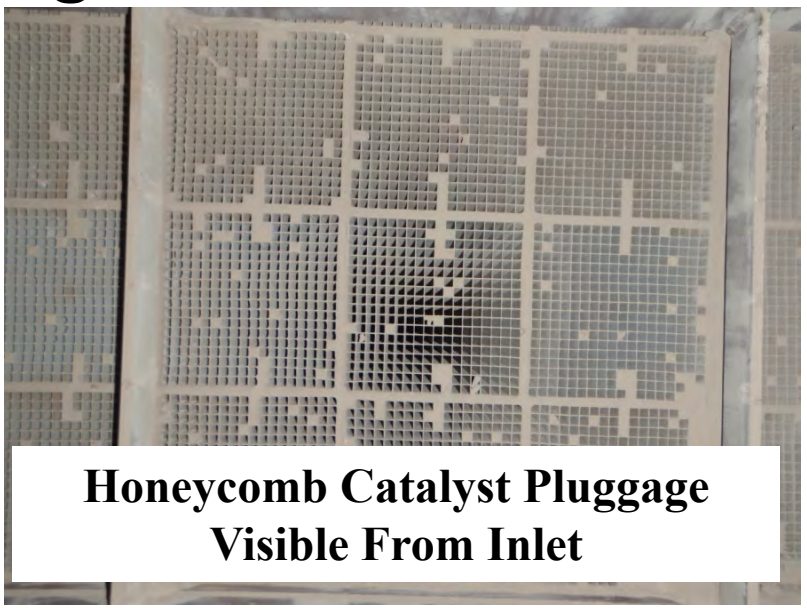
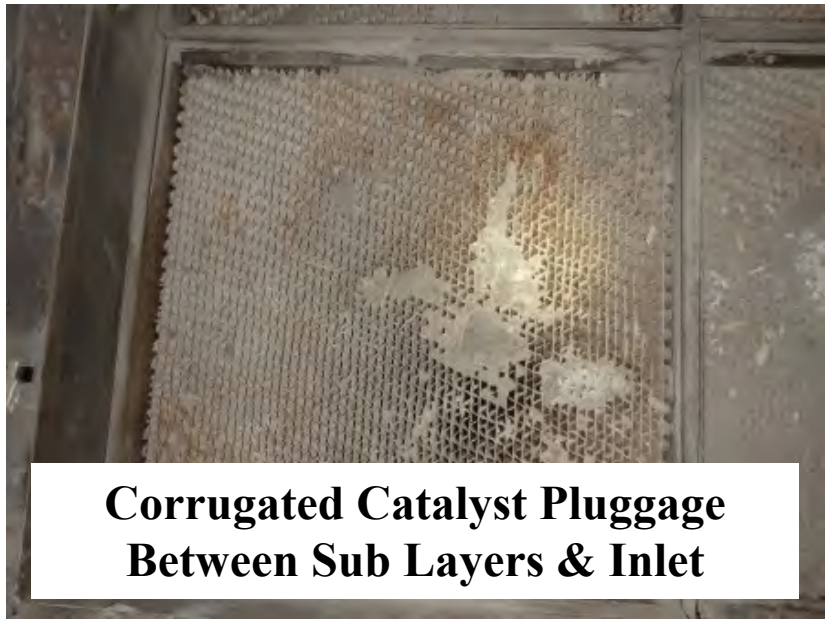
Relative Pluggage Risk

Plate Catalyst Pluggage Accumulates Between Sub Layers & Inlet



Honeycomb Catalyst Pluggage Visible From Inlet

- Pluggage Risk Dependent On…
  - Fuel Ash Loading and Characteristics
  - Flue Gas Flow Conditions Entering Catalyst
  - Catalyst Pitch Selection
- Provided Adequate Pitch & Flow Distributions
- What About Reactor Design or even Cover Grate Design or Varying Pitch Selection?



Corrugated Catalyst Pluggage Between Sub Layers & Inlet

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Cover Grate Design

CERAM Cover Grate in Level 1 (Welded Stainless Steel 1 mm Dia. with 5 mm Opening)

Woven Wire Mesh Cover Grate in Level 4 (4 mm or Less Opening)

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Wygen 3 Cover Grates from IGS

After 1 year of operation

Photos courtesy of Integrated Global Services

Reactor Design & Configuration

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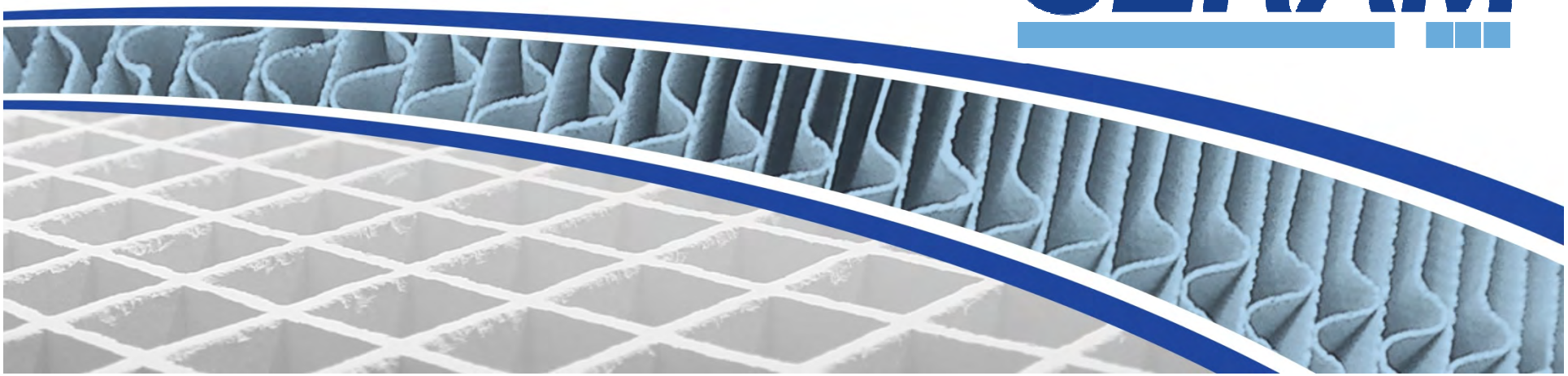

Reactor Design & Configuration

- Original Designs Over 10-15 Years May Not have Used CFD Modeling
  - Physical Modeling (1/12th Scale; Dust Test)
- Past Designs Driven by Engineering Before Flow Modeling Completed
- Lessons Learned – Flow Modeling Should Drive Engineering Design
- Real World Buildup Sometimes Does Not Appear During Modeling

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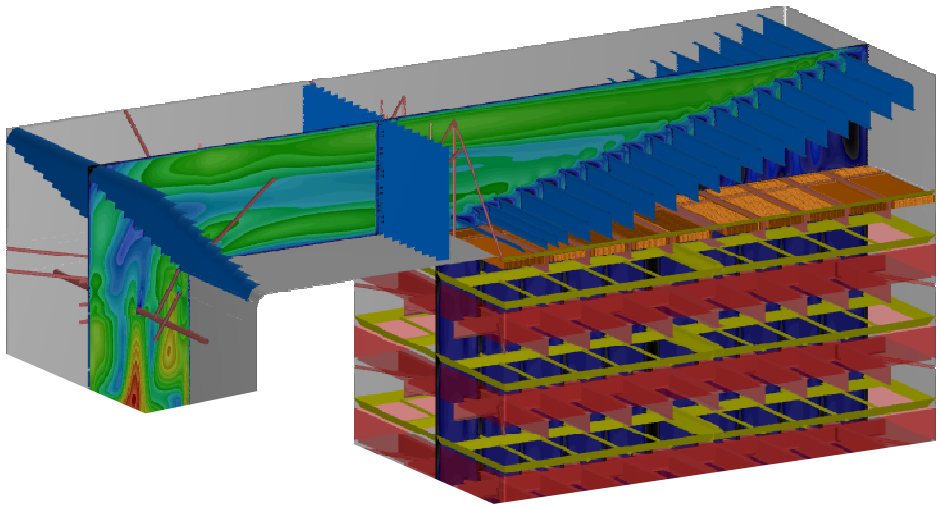
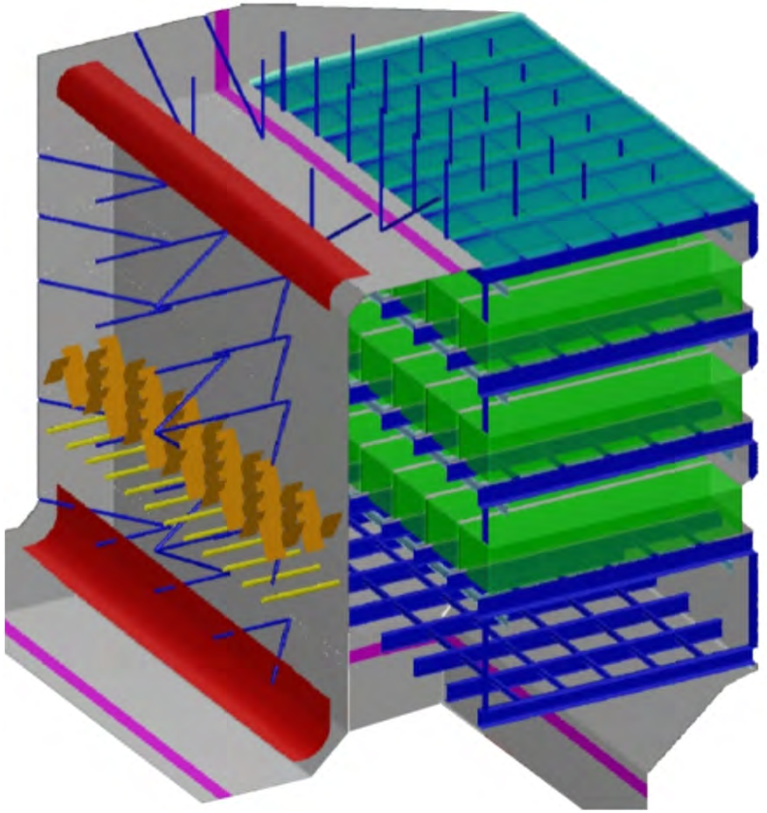
Reactor Hood Design: Critical

- Square hood
- Sloped hood





- Both work *if designed correctly*

Slide Courtesy of Airflow Sciences Corporation

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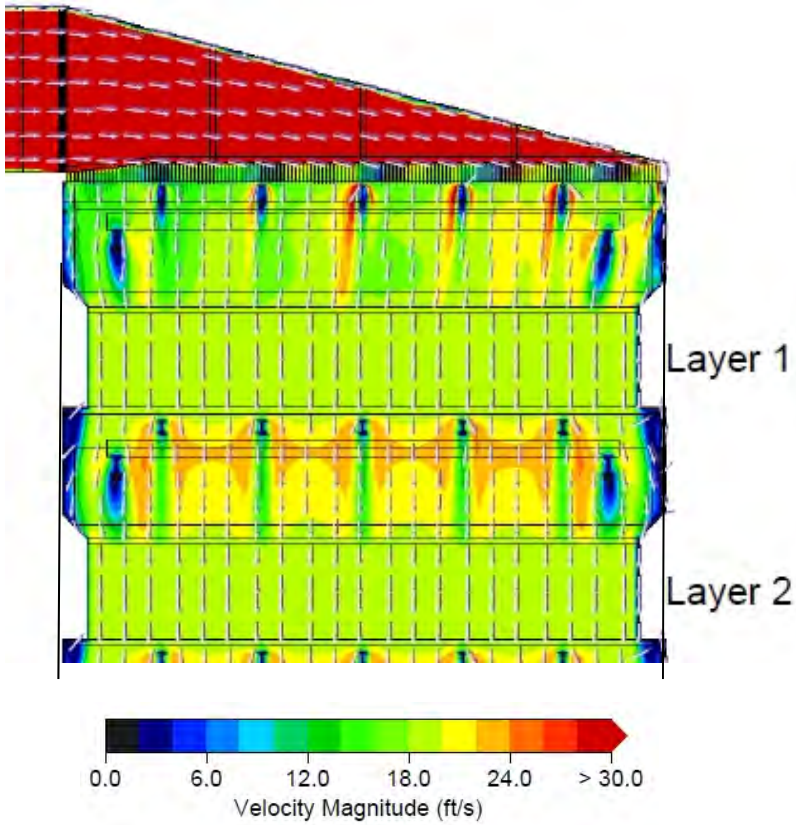
Reactor Hood Design: Critical

- Sloped hood uses rectifier to turn flow
  - Works well *if designed correctly*



Slide Courtesy of Airflow Sciences Corporation

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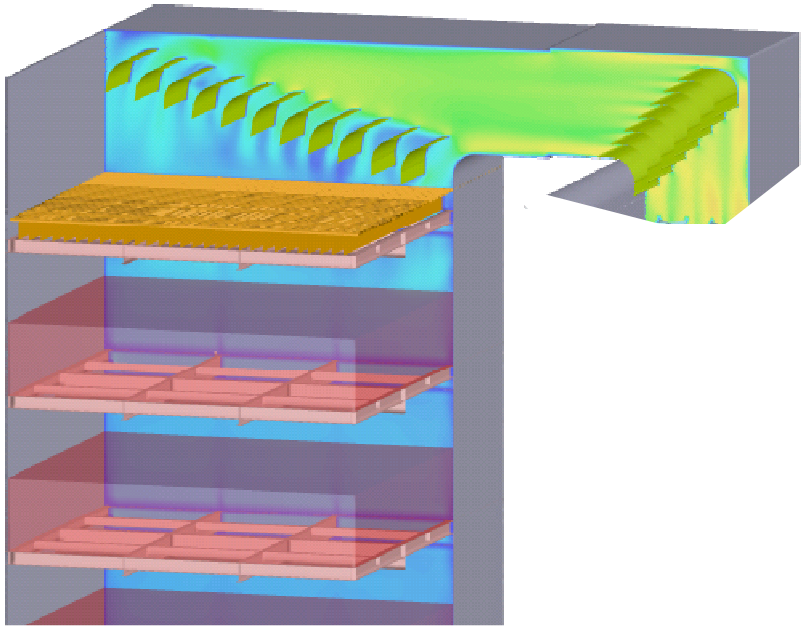
Reactor Hood Design: Critical

- Turning vanes
  - Curved vanes
  - Ladder vanes



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Slide Courtesy of Airflow Sciences Corporation

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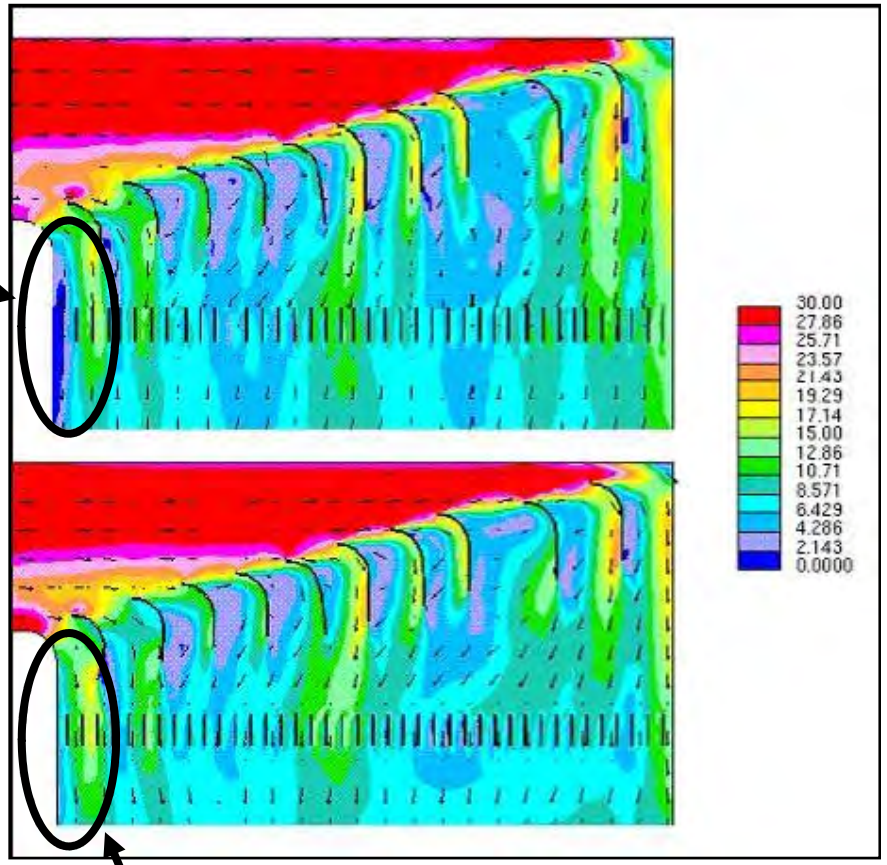
Reactor Configuration – Importance of Flow Modeling

- Reactor Configuration
  - Distance From Crossover Duct Down to Top of 1st Catalyst Layer
- Low Velocity Area Exists Even Though Distributions Are Achieved
- Low Vel = Increased Pluggage Risk
- Optimized Designs are Possible



Eliminate Through CFD Modeling

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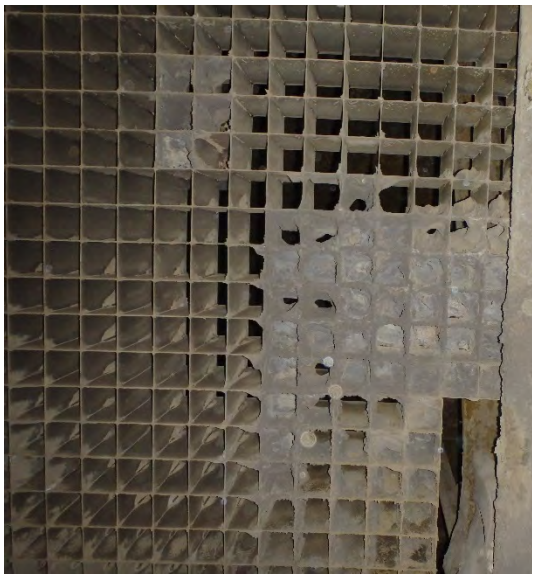
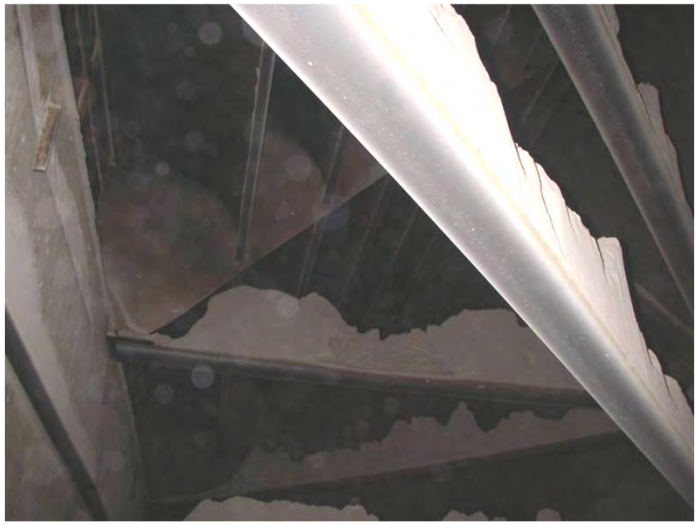
Reactor Configuration – Flow Modeling



Fly ash pile located below gusset plate due to ash shear

- Lessons Learned – Real World Buildup Sometimes Does Not Appear During Modeling
- Locations of Trusses and Gusset Plate Configurations



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Flow Distribution Device Design

- Lessons Learned – Ash Buildup on Vanes and Internal Structural Members
- Locations of Gusset Plates
- Turning Vane Design

Ash Buildup on Vanes

Affects of Ash Shear

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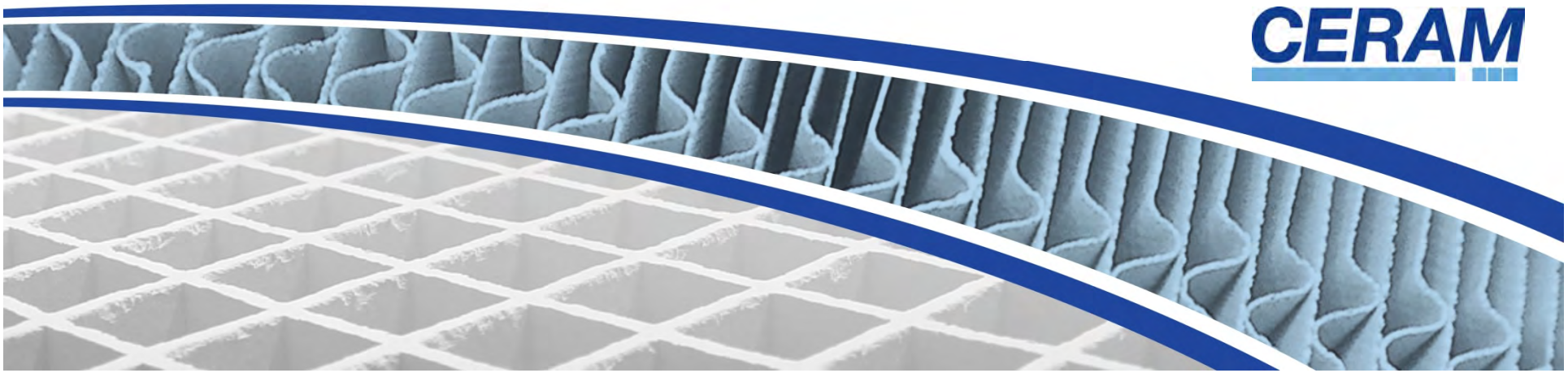
Factors Affecting Pluggage From Operations



Eliminate LPA Prior to Catalyst

Large Particle Ash (LPA)

STEAG LPA Screen

- **L**arge **P**article **A**sh Can Be Present and Should be Controlled as Part of System Design
- LPA Pluggage of Catalyst Leads to…
  - High Pressure Drops
  - Mechanical Damage
  - Reduced Performance Potential
- Effective and Durable Screen Designs are Required
  - Located With Ash Removal
  - Located at Proper Velocity
  - Simple and Advanced Designs Have Both Succeeded and Also Had Problems
- Flow Modeling and Physical Changes are Likely Necessary

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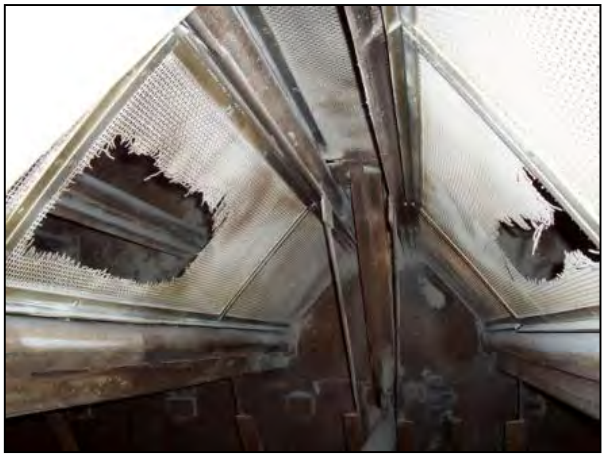
Simple & Advanced LPA Screens Can Succeed or Fail

- Proper Choices of LPA Screen Design are Site Specific
- Ensure Proper Velocity at LPA Screen
- Remove Material From Hoppers
- Cleaning Device (Sonic Horn, Rapper, etc.)

Coated & Non-Coated Screens Failed (High Velocity)

Stainless Steel Screen Failed at Fasteners (High Velocity)

Damaged LPA Screen Material



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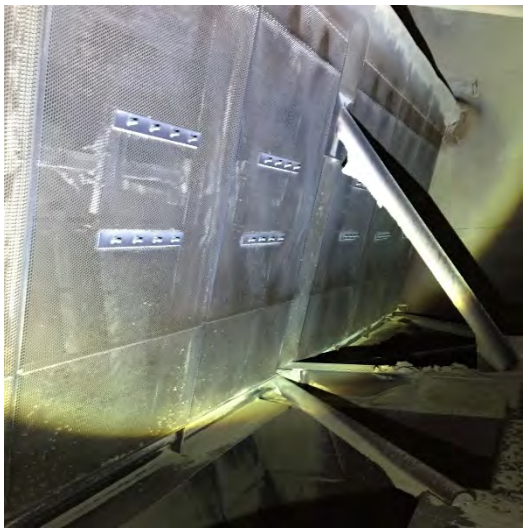
Pluggage Due to LPA

Before LPA Screen

After Install of LPA Screen



Photos courtesy of Integrated Global Services

Minimize Carbon Carryover

Reactor Accumulation of Unburned Carbon

Plate Catalyst With Accumulated Unburned Carbon

- The Control of Unburned Carbon is Important for Reliable DeNOx Operation
- All DeNOx Catalyst Has Oxidizing Properties and Will Tend to Oxidize Unburned Carbon
- Oxidized Carbon Sticks to Catalyst and Can Result in Pluggage
- Accumulation on Catalyst Increases Risk of Pluggage and Fires
- Increased Potential for Needing Offline, Out of Reactor Cleaning
- Homogeneous Honeycomb Catalyst Consists of Fully Oxidized Material
- Metal Substrates Can Lead to Increased Potential for Fires

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Pluggage Leads to Erosion Which Can Affect Any Catalyst Type

- Erosion Risk Varies as Ratio of Flow to 3rd or 4th Power
- Exposed Plate Stainless Steel Provides No Activity and Available for SO_2 to SO_3 Conversion
- Managed by Limiting Face Velocity
  - Minimize Catalyst Pluggage

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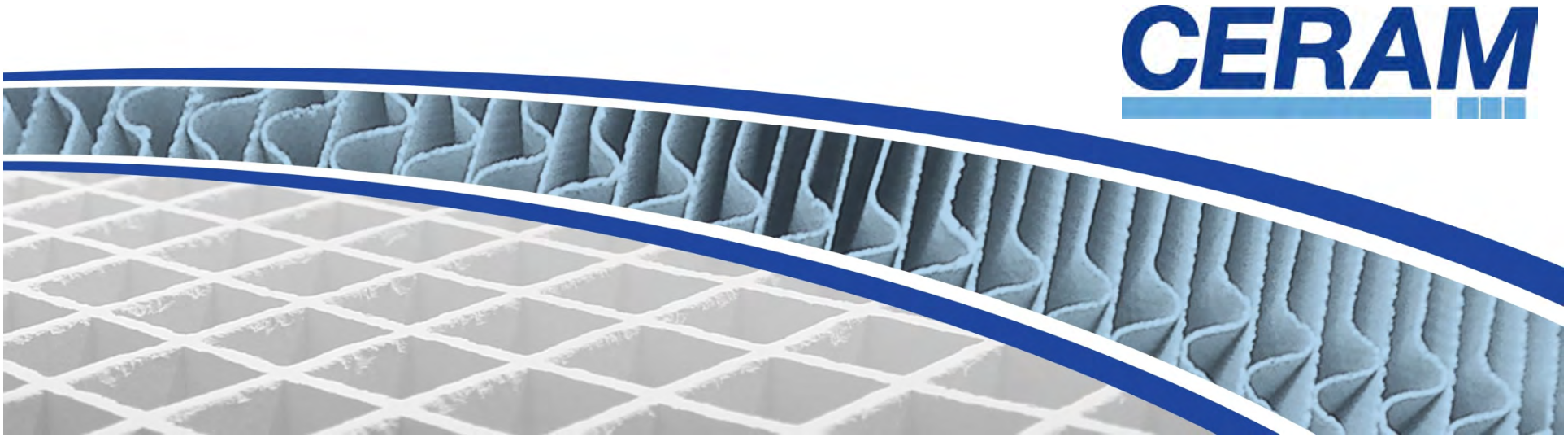
Online Cleaning Devices



Sootblowers – More O&M Cost Than Sonic Horns, But Are They Working?

Sootblower Set to Improper Pressure (Compressed Air Setting Instead of Steam Setting) Ineffective at Cleaning Catalyst

- Lessons Learned
  - Sootblowers Effective If Ash Fluidized; No Cleaning Device Effective with Poor Flow Distribution
  - Increase Frequency Based on Pressure Drop
  - Check Operation Daily

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Sonic Horns – Look Good Outside, But Are They Working?

- Lessons Learned
  - Sonic Horn Effective If Ash Fluidized; No Cleaning Device Effective with Poor Flow Distribution
  - Insulate Outside to Minimize Corrosion in Throat/Bell
  - Check Operation Daily

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Ash Sweepers

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Photo courtesy of Integrated Global Services

Ash Sweepers

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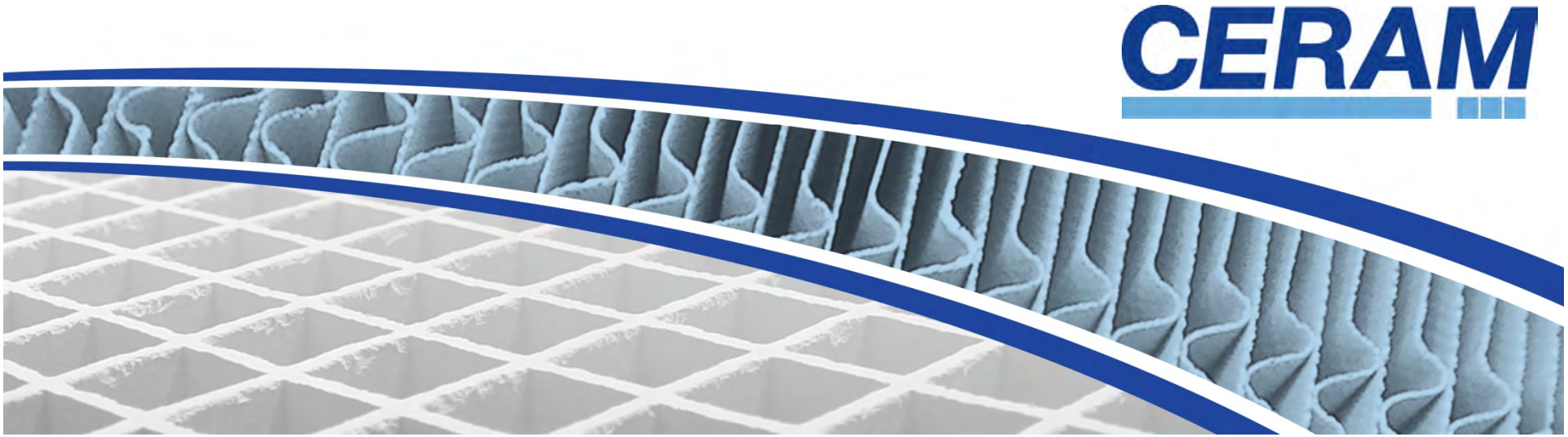
Photo courtesy of Integrated Global Services

In-situ Cleaning



Example of “Mechanical” Cleaning Not Recommended

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Vacuuming and Pneumatic Cleaning

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Vibrational Cleaning

Video courtesy of Michael Ware SCR Solutions, Inc.
& Thompson Industrial Services, LLC

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Sponge Blasting

Patent Pending ***Sponge Blasting*** *Process* utilizes polyurethane foam media to **Safely Remove Hardened Ash from the Surface and Within the Catalyst Modules.**

Before Sponge Blasting

After Sponge Blasting

Photos courtesy of Michael Ware SCR Solutions, Inc. & Thompson Industrial Services, LLC

Sponge Blasting Video

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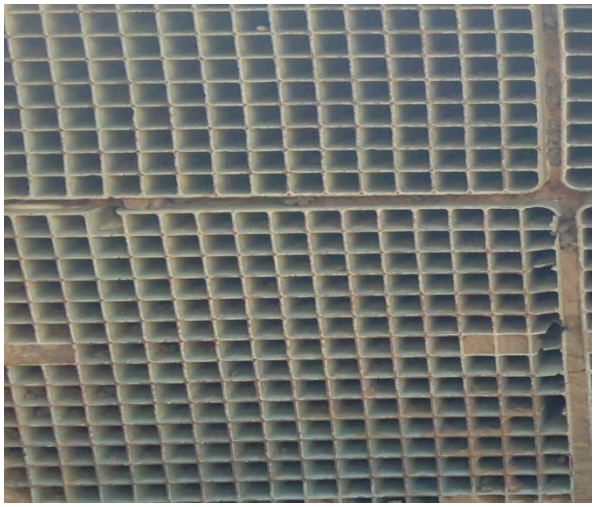
Video courtesy of Michael Ware SCR Solutions, Inc.
& Thompson Industrial Services, LLC

Sponge Blasting

BEFORE

AFTER



This combination of methods **Safely Clears the Catalyst of Potentially Harmful Contaminates that cannot be achieved by traditional methods.**

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Photos courtesy of Michael Ware SCR Solutions, Inc. & Thompson Industrial Services, LLC

Dry Ice Blasting

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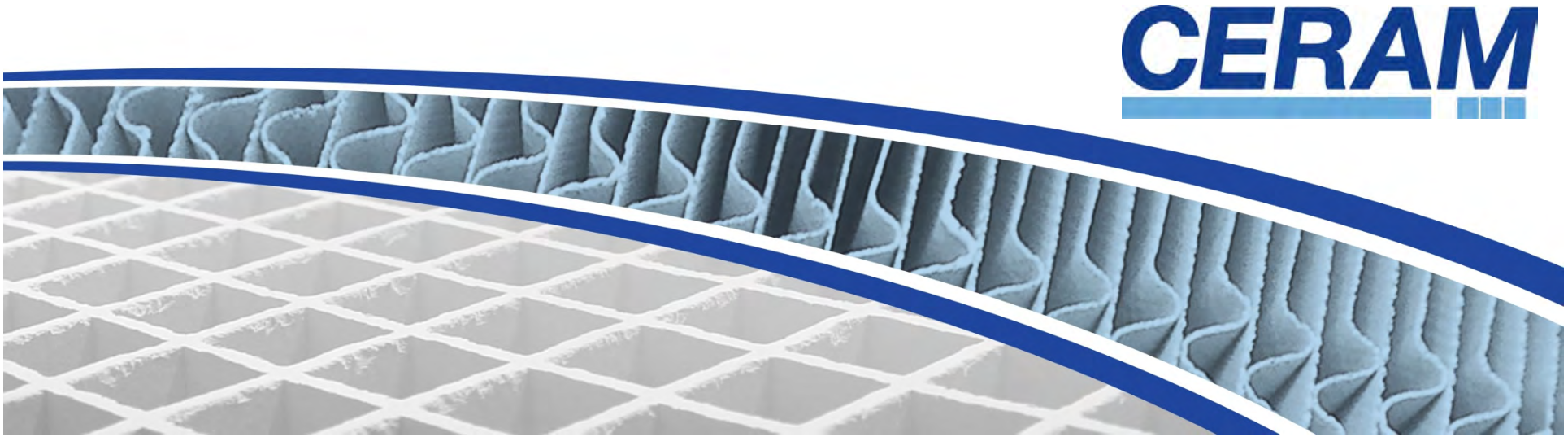
Video courtesy of STEAG SCR-Tech, Inc.

Fix “Root” Cause of Pluggage



Flow Modeling Methods

- CFD (Computational Fluid Dynamics)
- Cold Flow Scale Modeling (dust testing)
- Hot Flow Scale Modeling (real ash)
- Wind Tunnel Testing
  - To determine ash drop-out and re-entrainment aerodynamic behavior
  - Ambient or Hot Wind Tunnel

Slide Courtesy of Airflow Sciences Corporation

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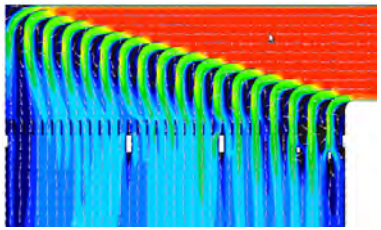
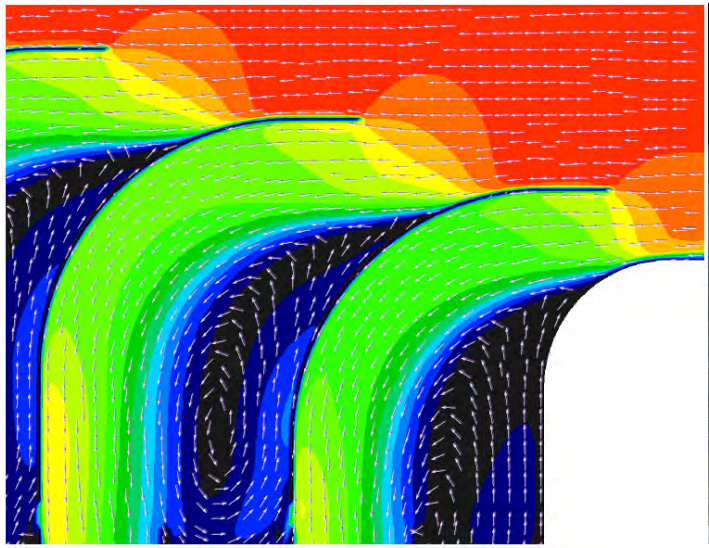
Ash Deposition – Reactor Hood Vanes

- CFD model and field observations show root cause
  - Flow separation and recirculation on vane surface
  - Not *designed correctly*
  - Occasional avalanche can cause catalyst pluggage issue
  - Hood vane redesign required

Hood vanes



Vane detail



(black = recirc zone)

Ash buildup

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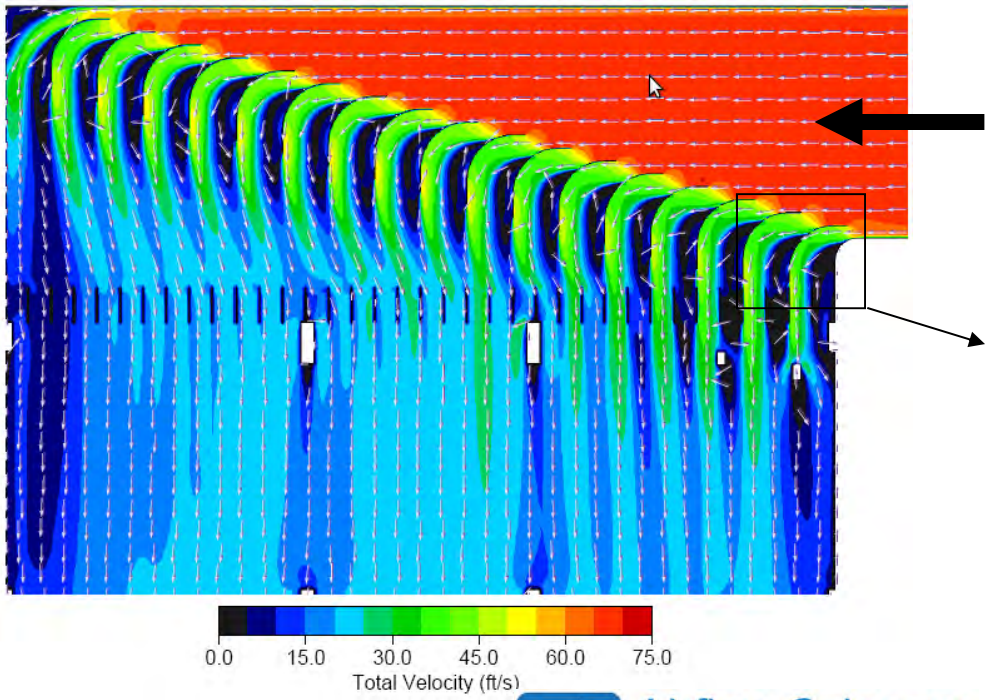
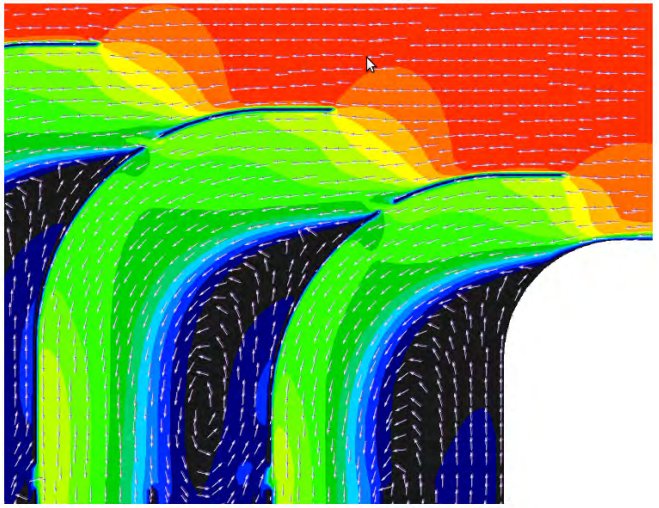
Slide Courtesy of Airflow Sciences Corporation

Ash Deposition – Reactor Hood Vanes

- CFD model used to evaluate design mods
  - Reduce ash accumulation with minimal degradation of velocity uniformity to catalyst
  - "Slots" can be cut in vanes with strategic location and



Close-up at inner corner



CEI Slide Courtesy of Airflow Sciences Corporation

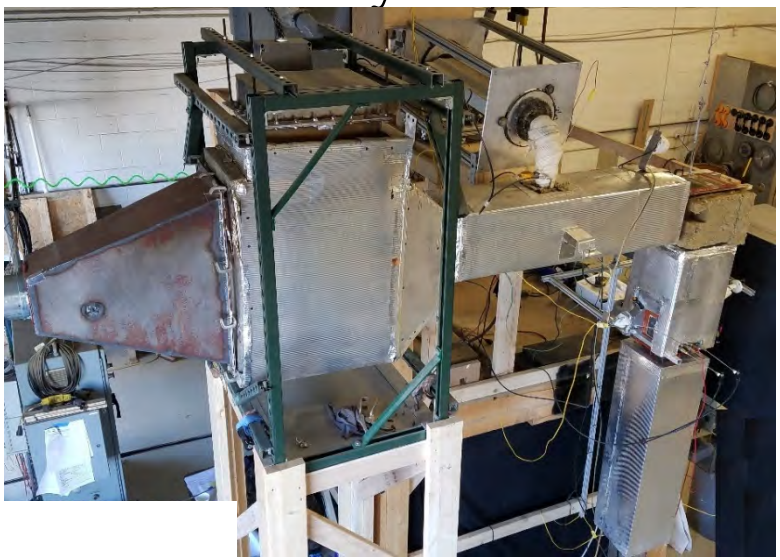
Ash Deposition – Reactor Hood Vanes

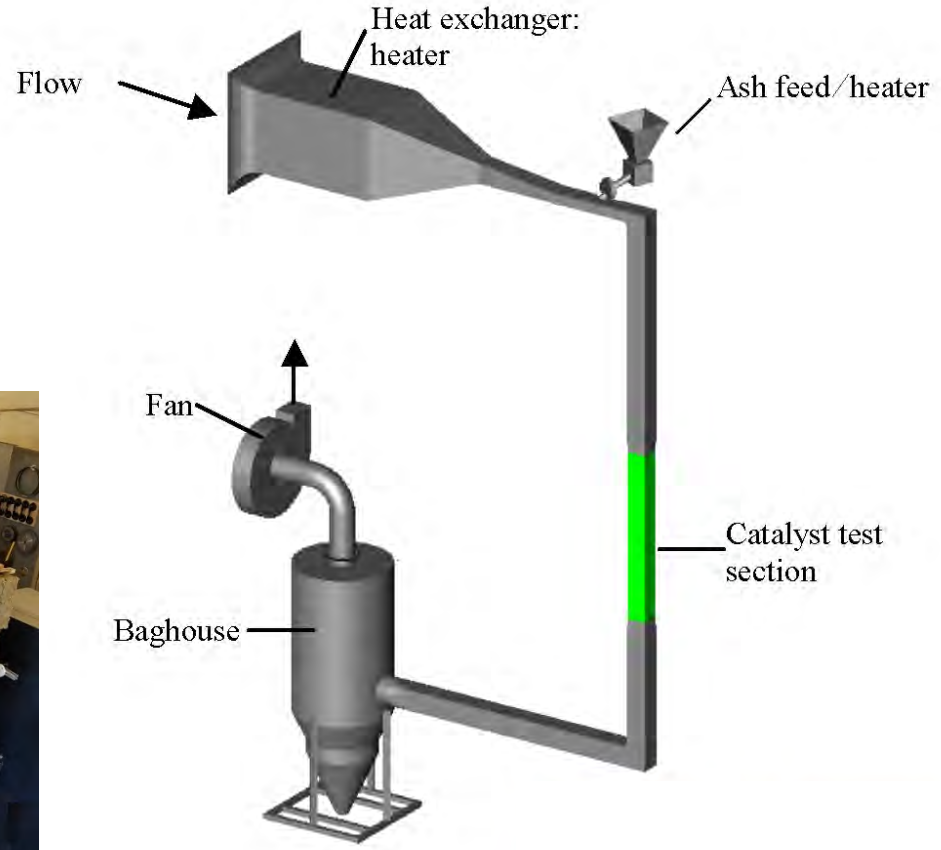
- CFD model used to evaluate design mods
  - Reduce ash accumulation with minimal degradation of velocity uniformity to catalyst
  - "Slots" cut in vanes at strategic location and size

Slide Courtesy of Airflow Sciences Corporation

Ash Deposition – Hot Flow Modeling

- Hot Flow Model
  - Testing under actual temperature conditions
  - Real ash, not laboratory dust





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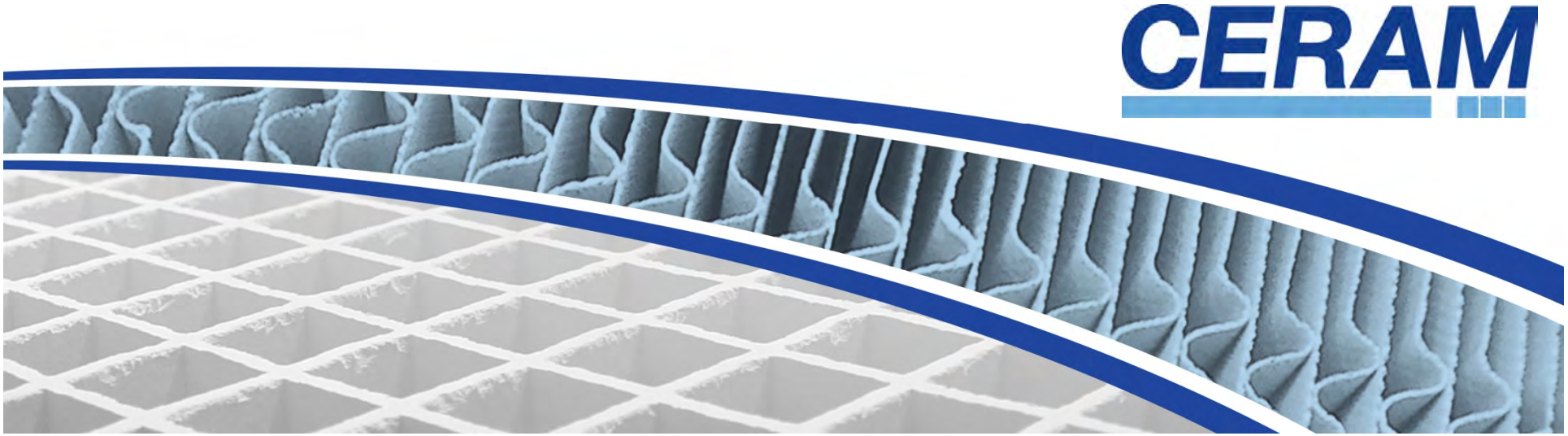
Summary



Pluggage is Minimized By…

- Pluggage is Minimized by….
  - Proper Pitch and Wall Thickness Selection
  - Proper Cover Grate Selection
  - Proper Gas Velocity in Ductwork and the Reactor (Flow Modeling)
  - Proper Boiler Operation (e.g., LOI, LPA, etc.)
    - LPA Screen Design
  - Proper Maintenance and Operation of Online Cleaning Devices
  - Proper Isolation During Outages (Avoiding Condensation if Possible)
- In-situ Cleaning Technologies
  - Vacuuming/Air Lancing; Vibrational/Sponge; Dry Ice Blasting
  - Cost Considerations
- Flow Modeling Very Effective at “Fixing” Root Cause
  - Rate of Return with Less Pressure Drop & More Surface Area (Longer Time Between Catalyst Events)

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Reinhold Environmental 2017 NOx-Combustion Round Table

Preventative Maintenance: Cleaning Techniques and Catalyst Cleanliness

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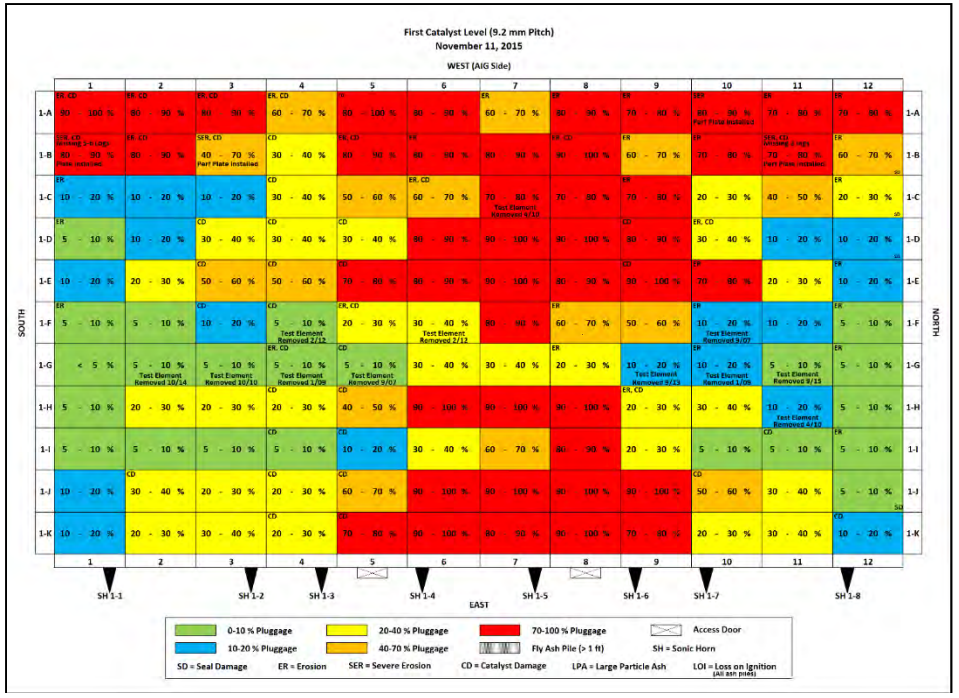
- Online Cleaning Devices
- In-Situ Cleaning Technologies
- Fixing the Root Cause of Pluggage

What We Want to Avoid!



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Pluggage Resistance Catalyst?

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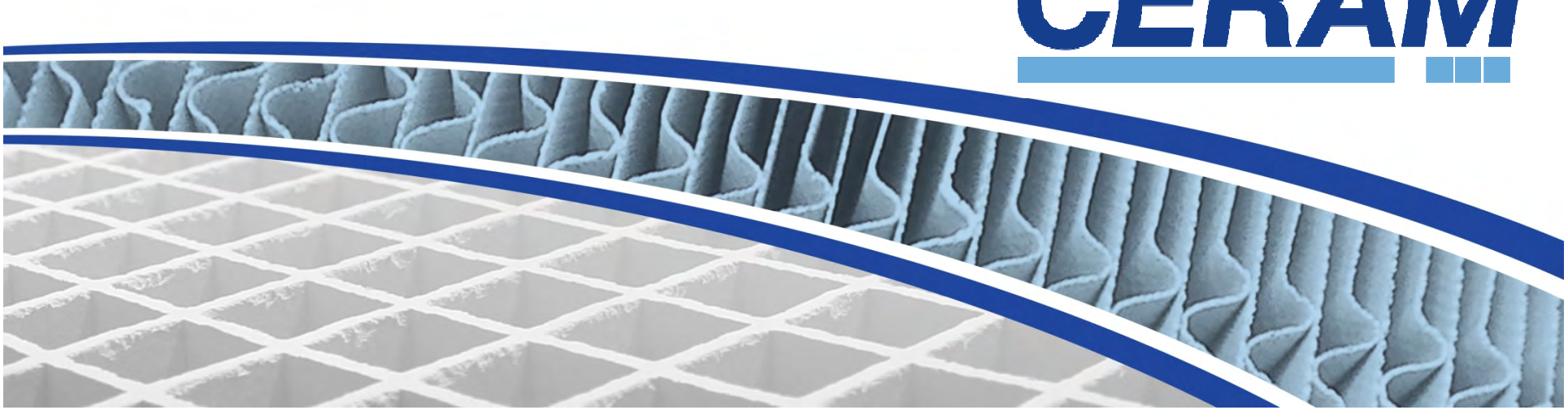

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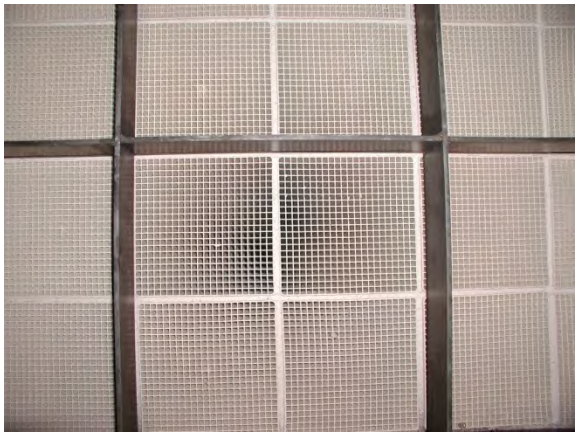
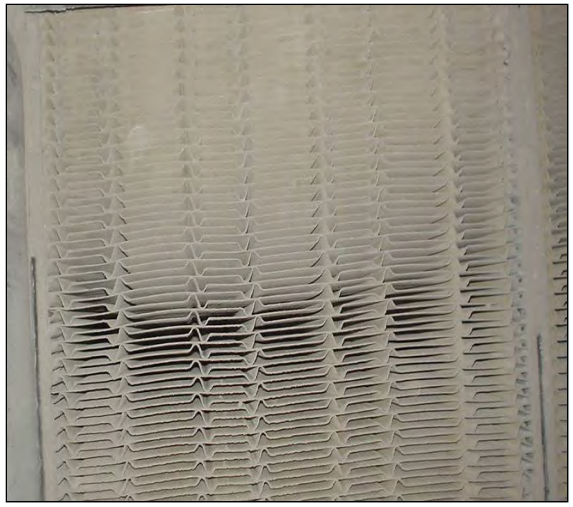
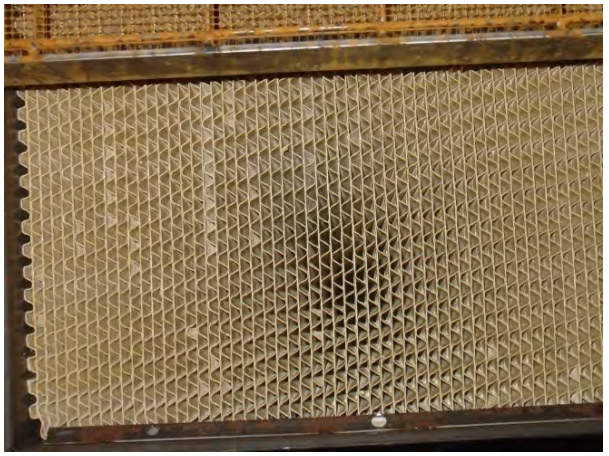


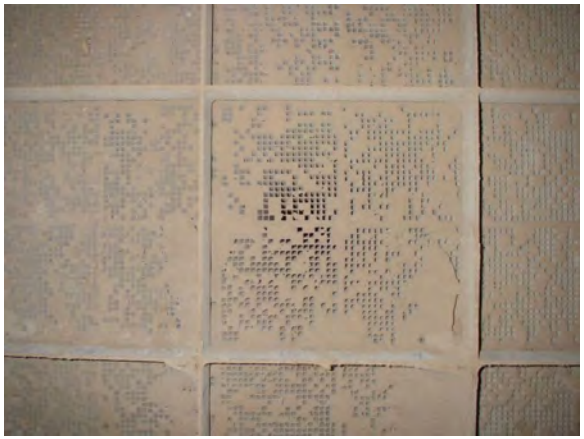
Honeycomb



Plate



Corrugated Fiber



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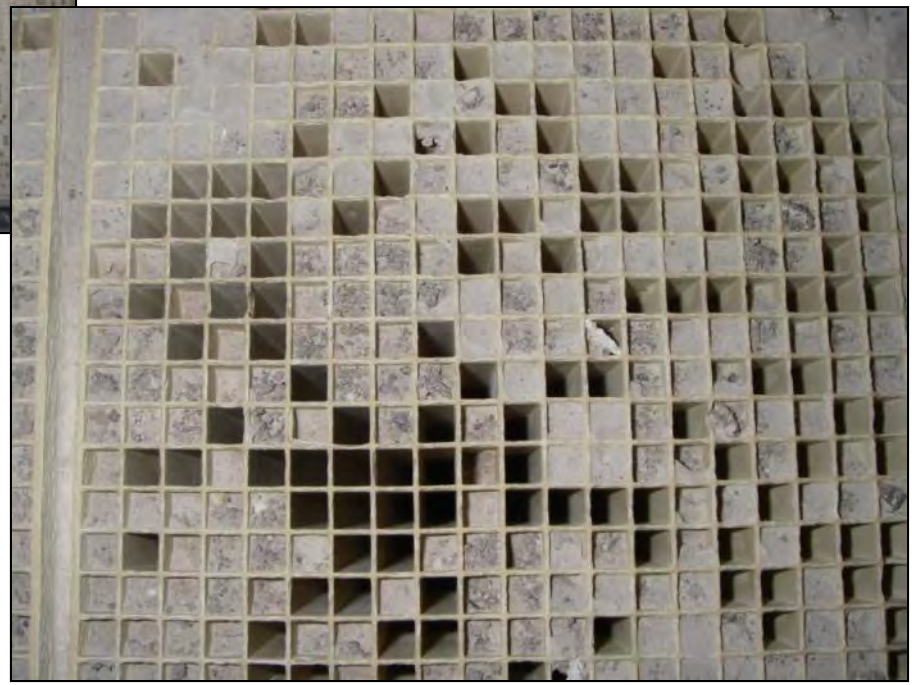
Catalyst Pluggage – LPA and LOI



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Catalyst Pluggage – Plate Catalyst

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Catalyst Pluggage – Plate Catalyst

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Catalyst Pluggage – Corrugated Catalyst

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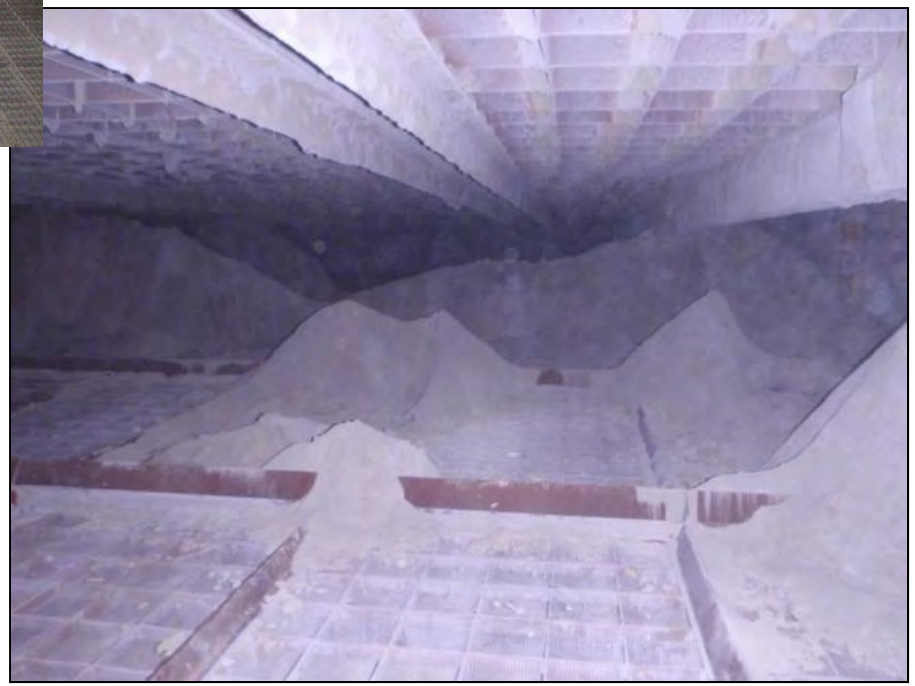
Ash Accumulation



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Ductwork – Ash Dropout

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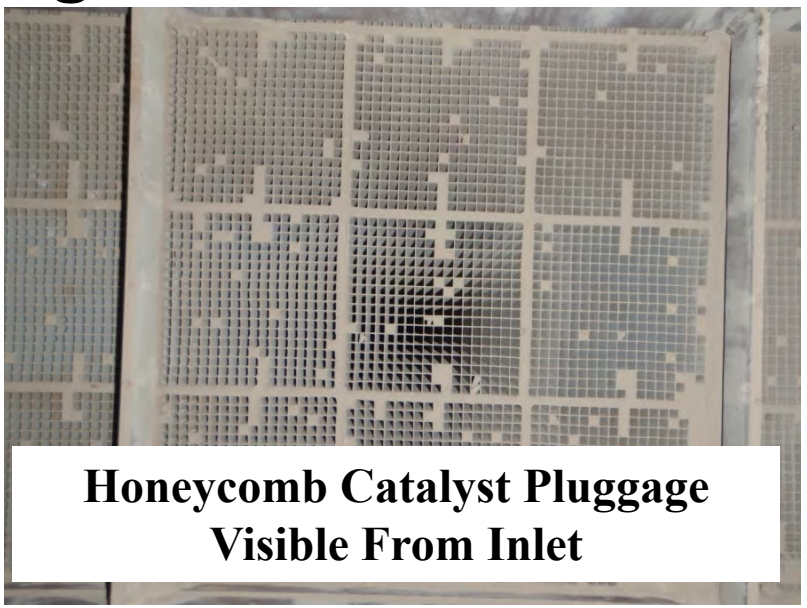
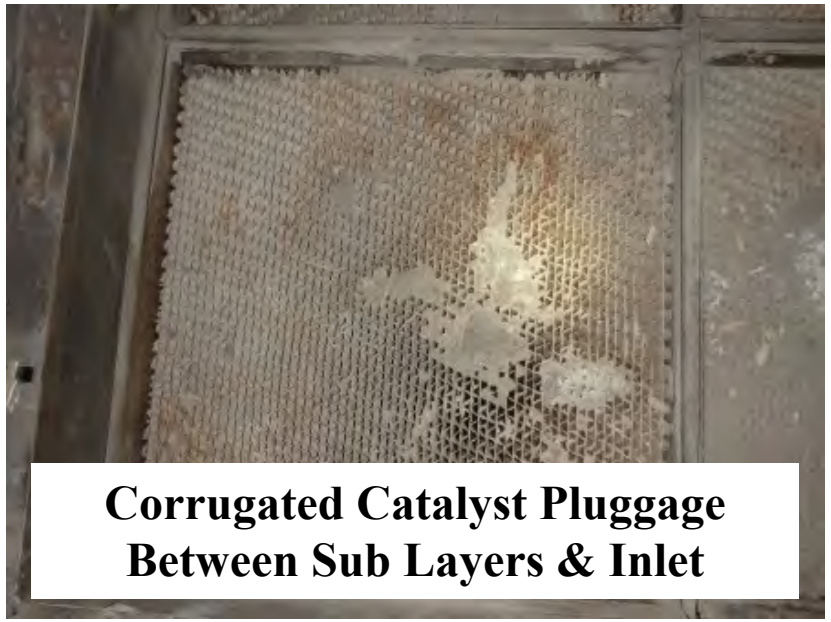
Relative Pluggage Risk

Plate Catalyst Pluggage Accumulates Between Sub Layers & Inlet



Honeycomb Catalyst Pluggage Visible From Inlet

- Pluggage Risk Dependent On…
  - Fuel Ash Loading and Characteristics
  - Flue Gas Flow Conditions Entering Catalyst
  - Catalyst Pitch Selection
- Provided Adequate Pitch & Flow Distributions
- What About Reactor Design or even Cover Grate Design or Varying Pitch Selection?



Corrugated Catalyst Pluggage Between Sub Layers & Inlet

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Cover Grate Design

CERAM Cover Grate in Level 1 (Welded Stainless Steel 1 mm Dia. with 5 mm Opening)

Woven Wire Mesh Cover Grate in Level 4 (4 mm or Less Opening)

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Wygen 3 Cover Grates from IGS

After 1 year of operation

Photos courtesy of Integrated Global Services

Reactor Design & Configuration

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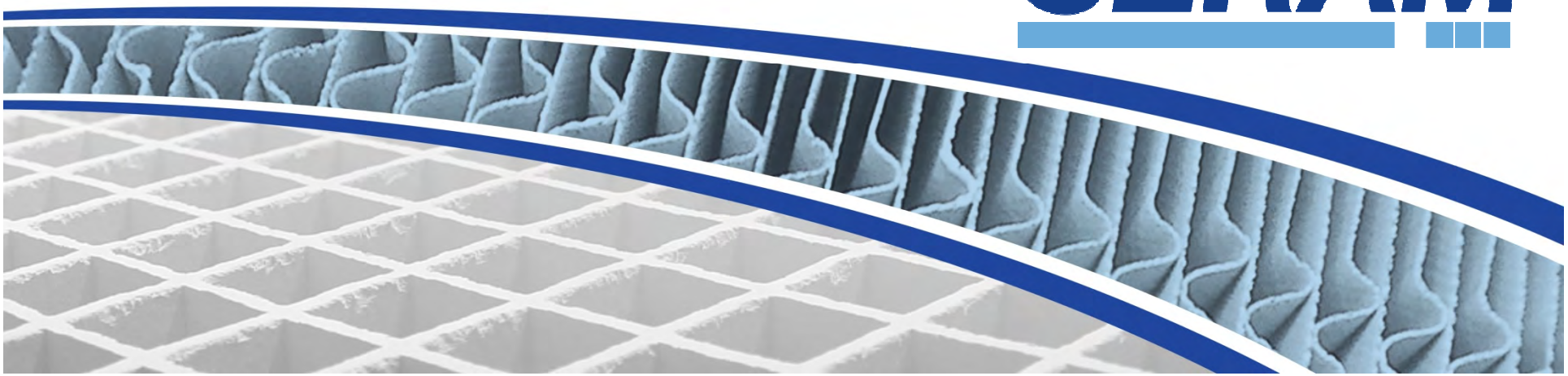

Reactor Design & Configuration

- Original Designs Over 10-15 Years May Not have Used CFD Modeling
  - Physical Modeling (1/12th Scale; Dust Test)
- Past Designs Driven by Engineering Before Flow Modeling Completed
- Lessons Learned – Flow Modeling Should Drive Engineering Design
- Real World Buildup Sometimes Does Not Appear During Modeling

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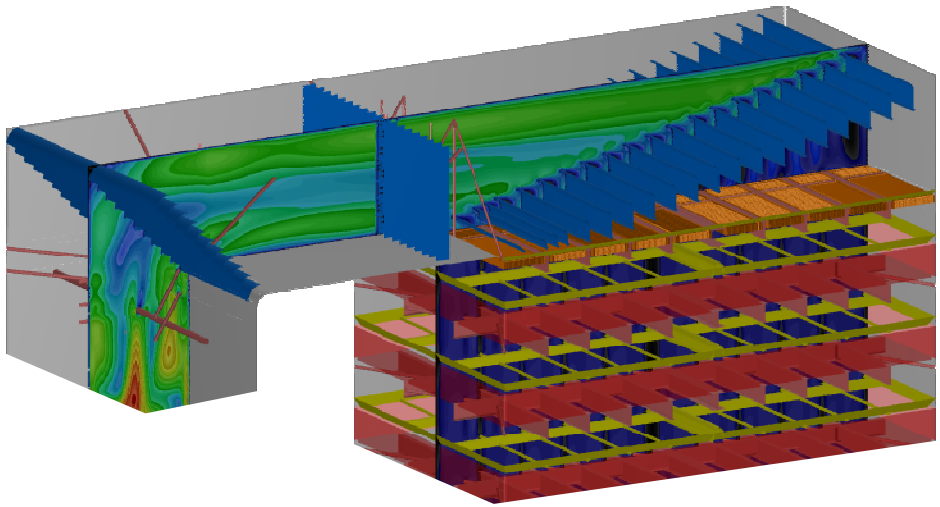
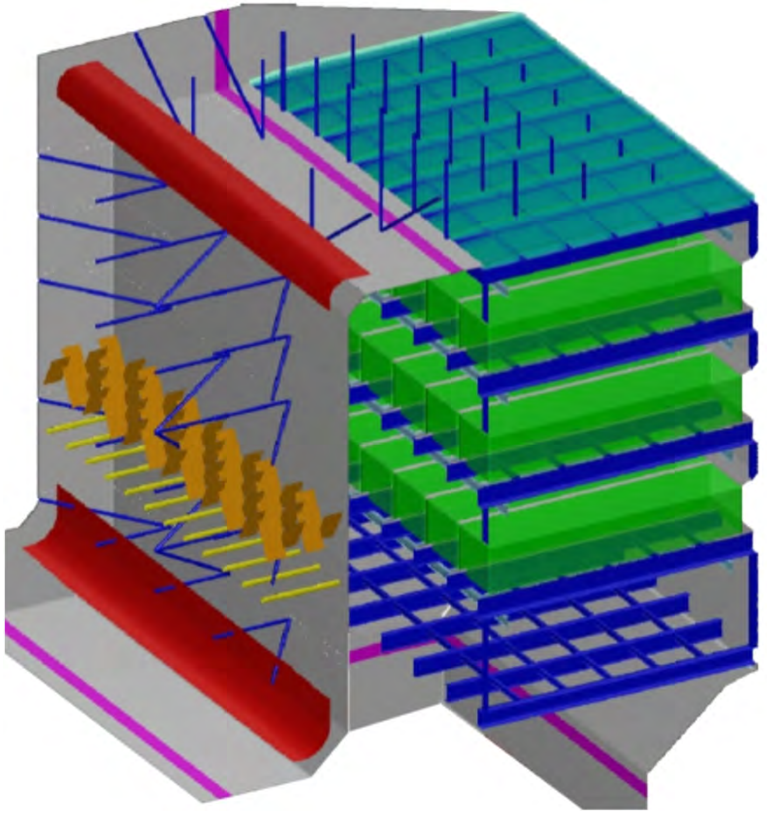
Reactor Hood Design: Critical

- Square hood
- Sloped hood





- Both work *if designed correctly*

Slide Courtesy of Airflow Sciences Corporation

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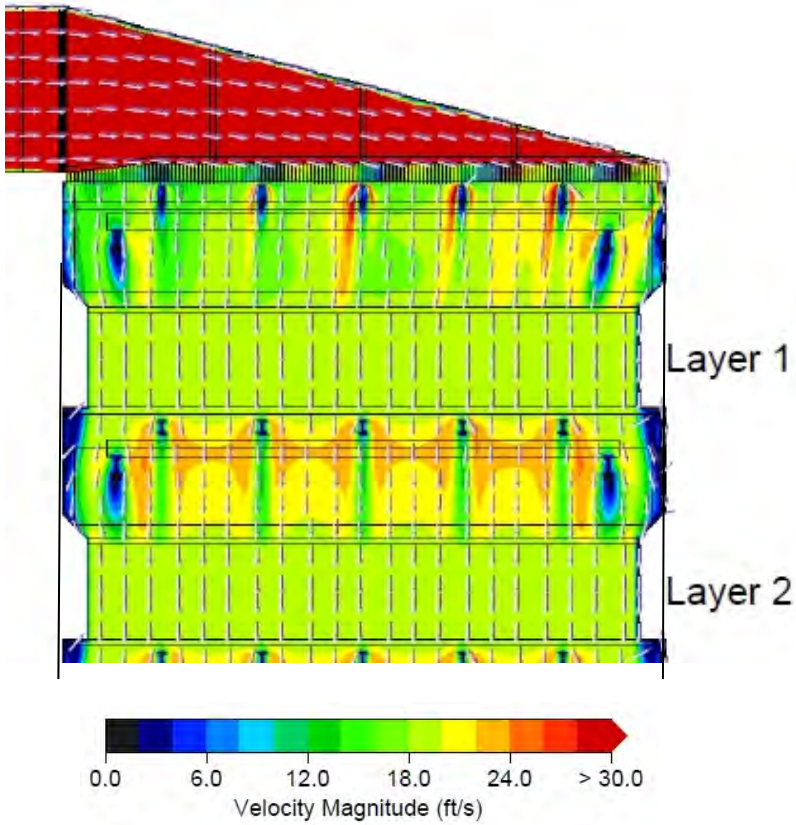
Reactor Hood Design: Critical

- Sloped hood uses rectifier to turn flow
  - Works well *if designed correctly*



Slide Courtesy of Airflow Sciences Corporation

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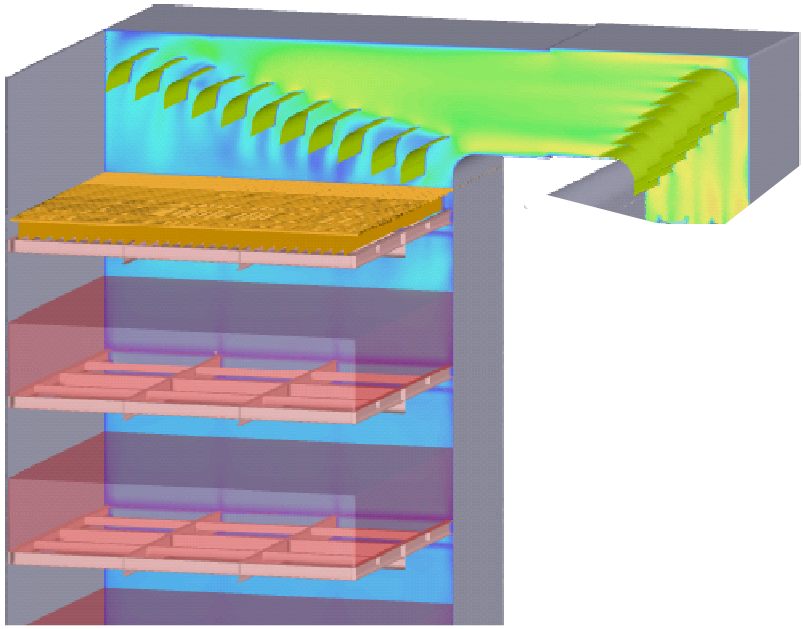
Reactor Hood Design: Critical

- Turning vanes
  - Curved vanes
  - Ladder vanes



- Both work *if designed correctly*

Slide Courtesy of Airflow Sciences Corporation

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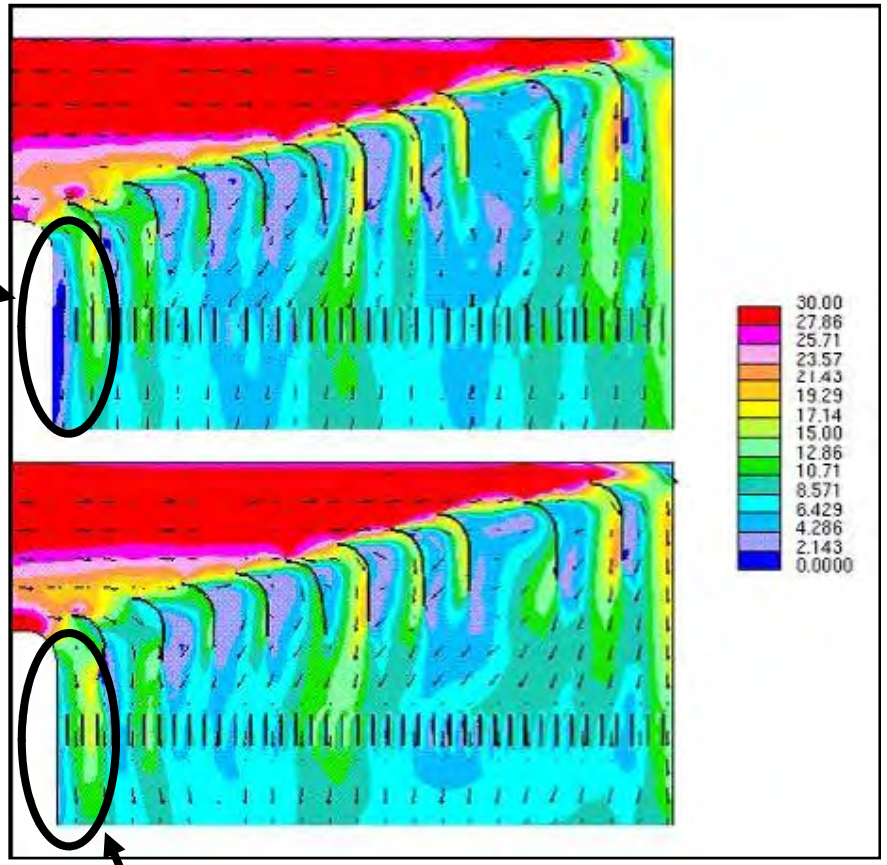
Reactor Configuration – Importance of Flow Modeling

- Reactor Configuration
  - Distance From Crossover Duct Down to Top of 1st Catalyst Layer
- Low Velocity Area Exists Even Though Distributions Are Achieved
- Low Vel = Increased Pluggage Risk
- Optimized Designs are Possible



Eliminate Through CFD Modeling

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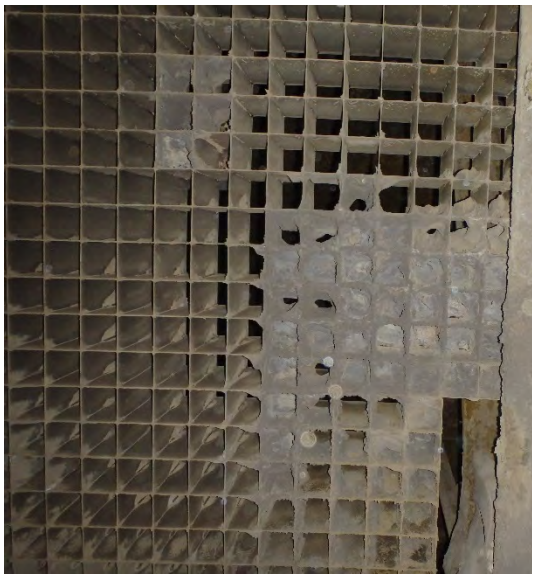
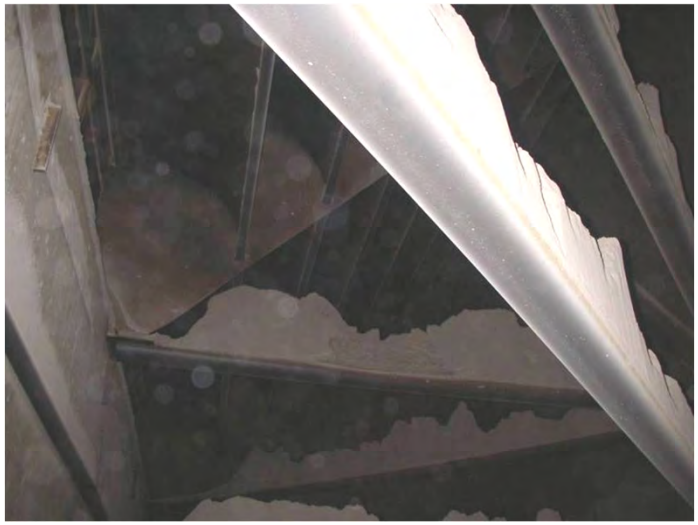
Reactor Configuration – Flow Modeling



Fly ash pile located below gusset plate due to ash shear

- Lessons Learned – Real World Buildup Sometimes Does Not Appear During Modeling
- Locations of Trusses and Gusset Plate Configurations



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Flow Distribution Device Design

- Lessons Learned – Ash Buildup on Vanes and Internal Structural Members
- Locations of Gusset Plates
- Turning Vane Design

Ash Buildup on Vanes

Affects of Ash Shear

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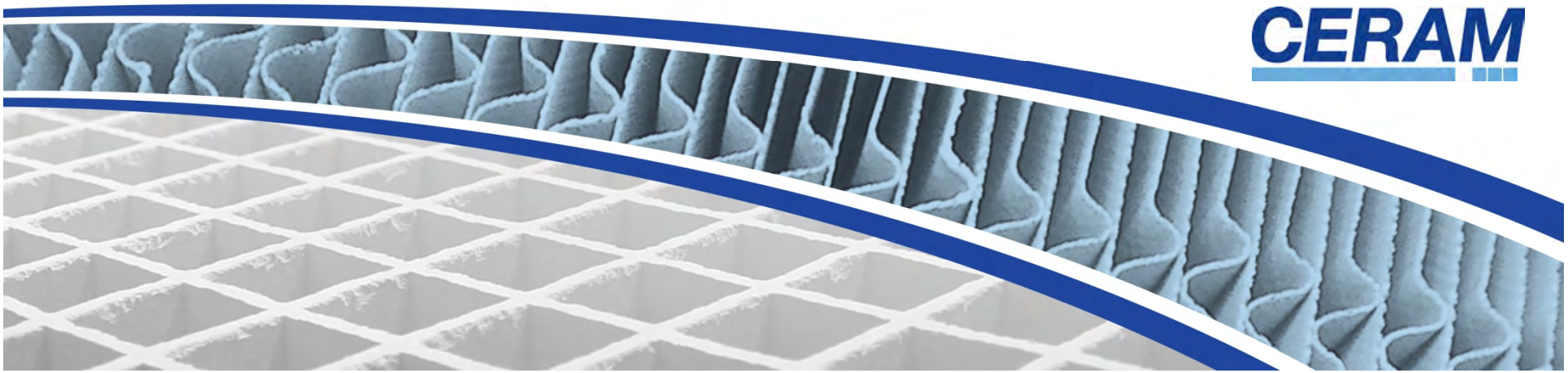
Factors Affecting Pluggage From Operations



Eliminate LPA Prior to Catalyst

Large Particle Ash (LPA)

STEAG LPA Screen

- **L**arge **P**article **A**sh Can Be Present and Should be Controlled as Part of System Design
- LPA Pluggage of Catalyst Leads to…
  - High Pressure Drops
  - Mechanical Damage
  - Reduced Performance Potential
- Effective and Durable Screen Designs are Required
  - Located With Ash Removal
  - Located at Proper Velocity
  - Simple and Advanced Designs Have Both Succeeded and Also Had Problems
- Flow Modeling and Physical Changes are Likely Necessary

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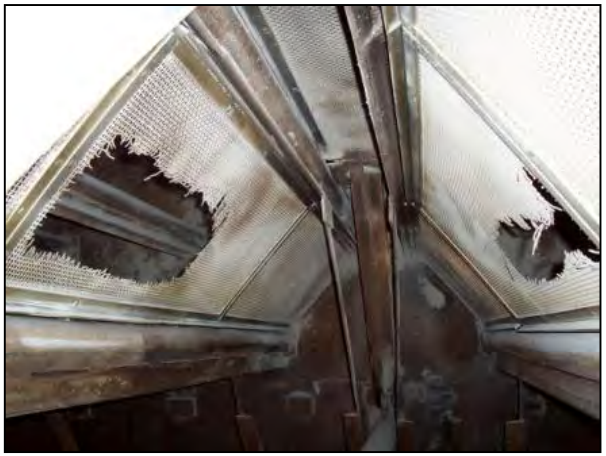
Simple & Advanced LPA Screens Can Succeed or Fail

- Proper Choices of LPA Screen Design are Site Specific
- Ensure Proper Velocity at LPA Screen
- Remove Material From Hoppers
- Cleaning Device (Sonic Horn, Rapper, etc.)

Coated & Non-Coated Screens Failed (High Velocity)

Stainless Steel Screen Failed at Fasteners (High Velocity)

Damaged LPA Screen Material



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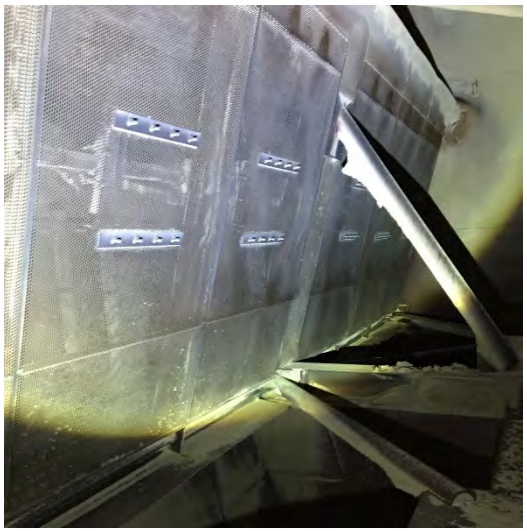
Pluggage Due to LPA

Before LPA Screen

After Install of LPA Screen



Photos courtesy of Integrated Global Services

Minimize Carbon Carryover

Reactor Accumulation of Unburned Carbon

Plate Catalyst With Accumulated Unburned Carbon

- The Control of Unburned Carbon is Important for Reliable DeNOx Operation
- All DeNOx Catalyst Has Oxidizing Properties and Will Tend to Oxidize Unburned Carbon
- Oxidized Carbon Sticks to Catalyst and Can Result in Pluggage
- Accumulation on Catalyst Increases Risk of Pluggage and Fires
- Increased Potential for Needing Offline, Out of Reactor Cleaning
- Homogeneous Honeycomb Catalyst Consists of Fully Oxidized Material
- Metal Substrates Can Lead to Increased Potential for Fires

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Pluggage Leads to Erosion Which Can Affect Any Catalyst Type

- Erosion Risk Varies as Ratio of Flow to 3rd or 4th Power
- Exposed Plate Stainless Steel Provides No Activity and Available for SO_2 to SO_3 Conversion
- Managed by Limiting Face Velocity
  - Minimize Catalyst Pluggage

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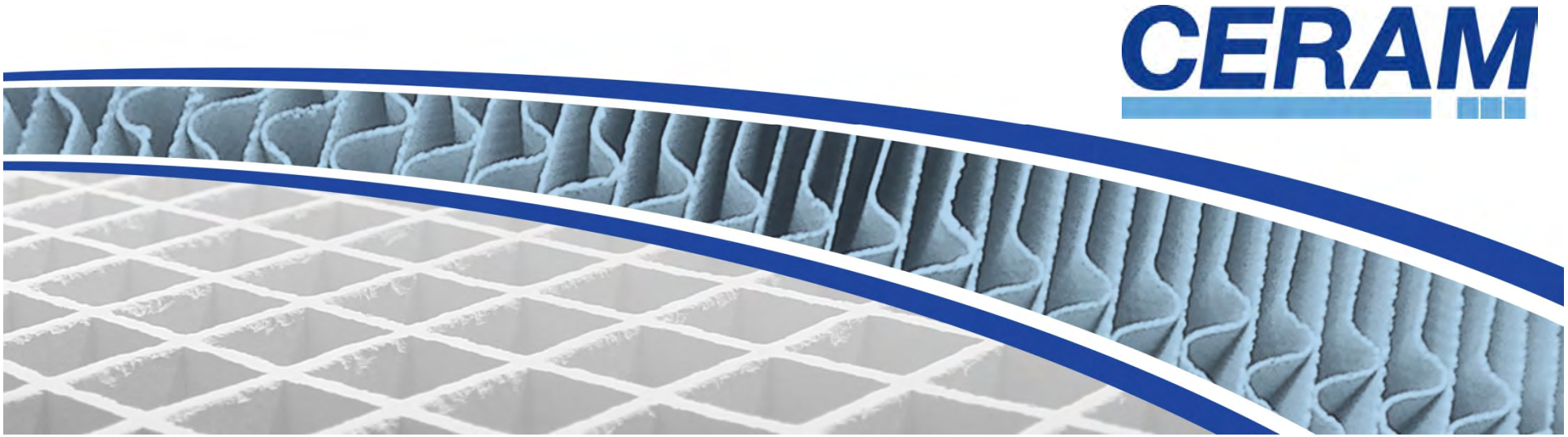
Online Cleaning Devices



Sootblowers – More O&M Cost Than Sonic Horns, But Are They Working?

Sootblower Set to Improper Pressure (Compressed Air Setting Instead of Steam Setting) Ineffective at Cleaning Catalyst

- Lessons Learned
  - Sootblowers Effective If Ash Fluidized; No Cleaning Device Effective with Poor Flow Distribution
  - Increase Frequency Based on Pressure Drop
  - Check Operation Daily

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Sonic Horns – Look Good Outside, But Are They Working?

- Lessons Learned
  - Sonic Horn Effective If Ash Fluidized; No Cleaning Device Effective with Poor Flow Distribution
  - Insulate Outside to Minimize Corrosion in Throat/Bell
  - Check Operation Daily

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Ash Sweepers

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Photo courtesy of Integrated Global Services

Ash Sweepers

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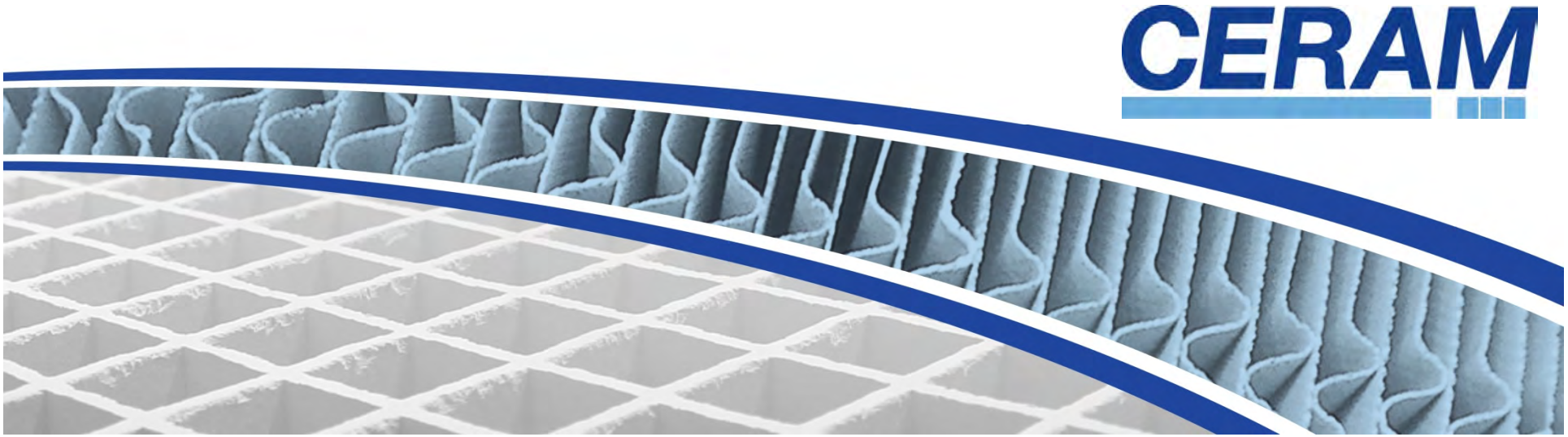
Photo courtesy of Integrated Global Services

In-situ Cleaning



Example of “Mechanical” Cleaning Not Recommended

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Vacuuming and Pneumatic Cleaning

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Vibrational Cleaning

Video courtesy of Michael Ware SCR Solutions, Inc.
& Thompson Industrial Services, LLC

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Sponge Blasting

Patent Pending ***Sponge Blasting*** *Process* utilizes polyurethane foam media to **Safely Remove Hardened Ash from the Surface and Within the Catalyst Modules.**

Before Sponge Blasting

After Sponge Blasting

Photos courtesy of Michael Ware SCR Solutions, Inc. & Thompson Industrial Services, LLC

Sponge Blasting Video

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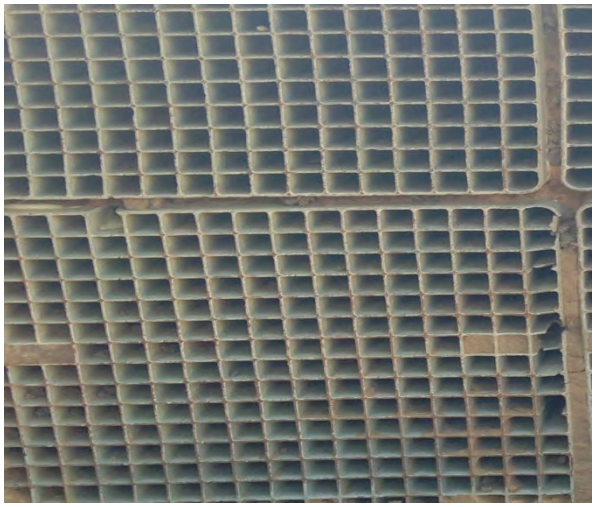
Video courtesy of Michael Ware SCR Solutions, Inc.
& Thompson Industrial Services, LLC

Sponge Blasting

BEFORE

AFTER



This combination of methods **Safely Clears the Catalyst of Potentially Harmful Contaminates that cannot be achieved by traditional methods.**

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Photos courtesy of Michael Ware SCR Solutions, Inc. & Thompson Industrial Services, LLC

Dry Ice Blasting

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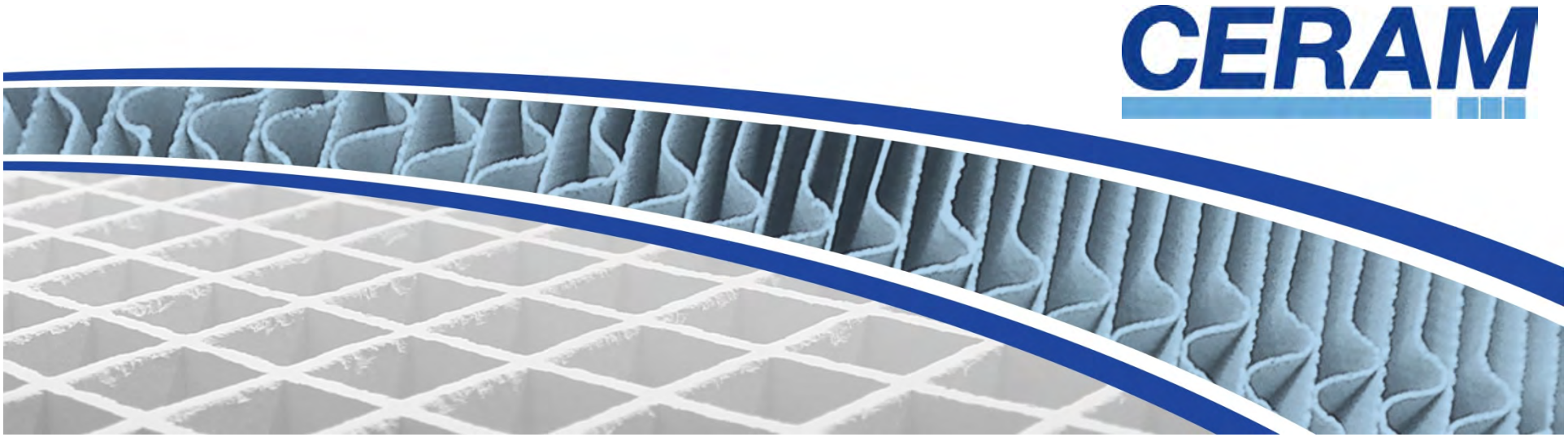
Video courtesy of STEAG SCR-Tech, Inc.

Fix “Root” Cause of Pluggage



Flow Modeling Methods

- CFD (Computational Fluid Dynamics)
- Cold Flow Scale Modeling (dust testing)
- Hot Flow Scale Modeling (real ash)
- Wind Tunnel Testing
  - To determine ash drop-out and re-entrainment aerodynamic behavior
  - Ambient or Hot Wind Tunnel

Slide Courtesy of Airflow Sciences Corporation

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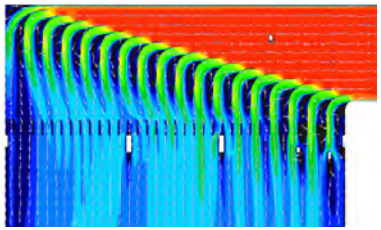
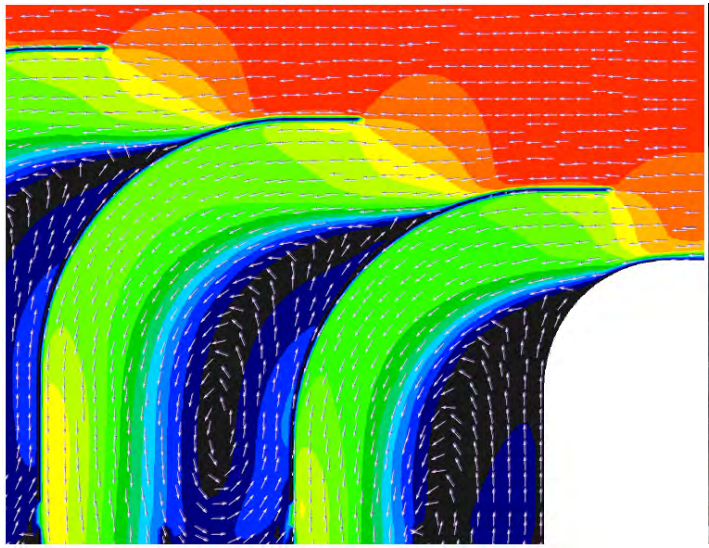
Ash Deposition – Reactor Hood Vanes

- CFD model and field observations show root cause
  - Flow separation and recirculation on vane surface
  - Not *designed correctly*
  - Occasional avalanche can cause catalyst pluggage issue
  - Hood vane redesign required

Hood vanes



Vane detail



(black = recirc zone)

Ash buildup

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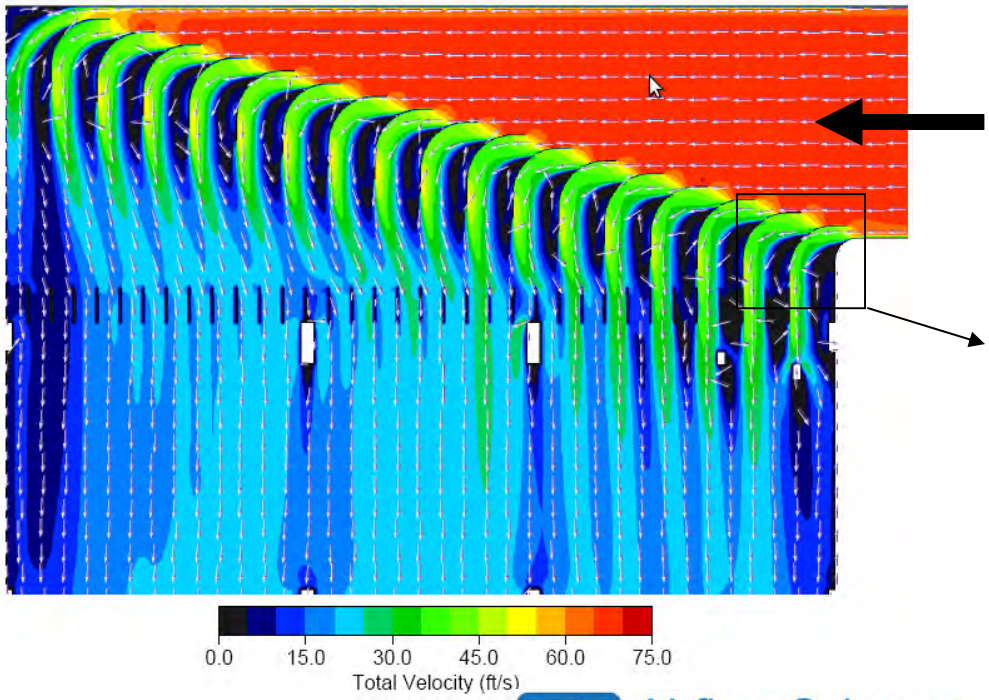
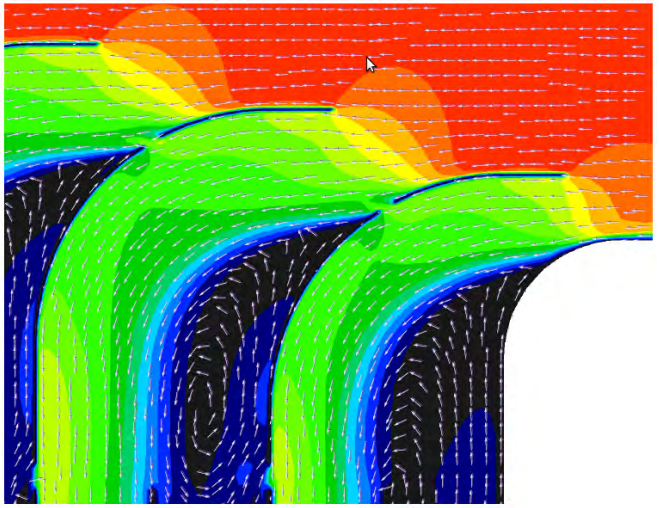
Slide Courtesy of Airflow Sciences Corporation

Ash Deposition – Reactor Hood Vanes

- CFD model used to evaluate design mods
  - Reduce ash accumulation with minimal degradation of velocity uniformity to catalyst
  - "Slots" can be cut in vanes with strategic location and



Close-up at inner corner



CEI Slide Courtesy of Airflow Sciences Corporation

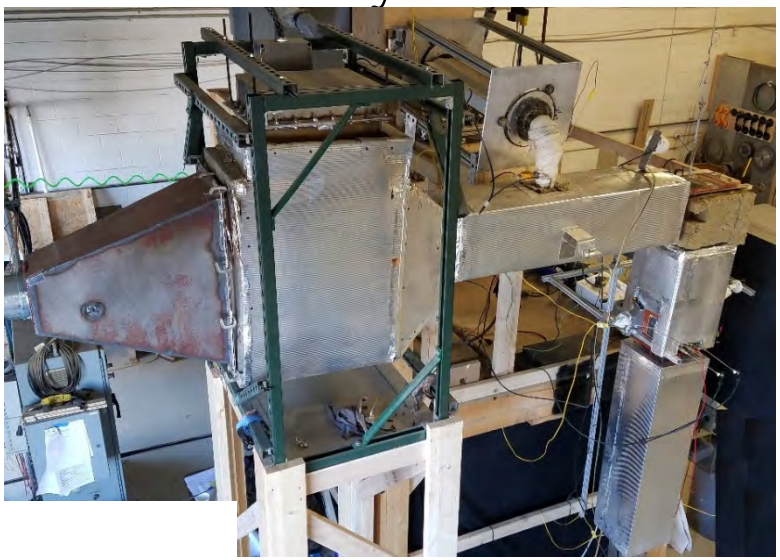
Ash Deposition – Reactor Hood Vanes

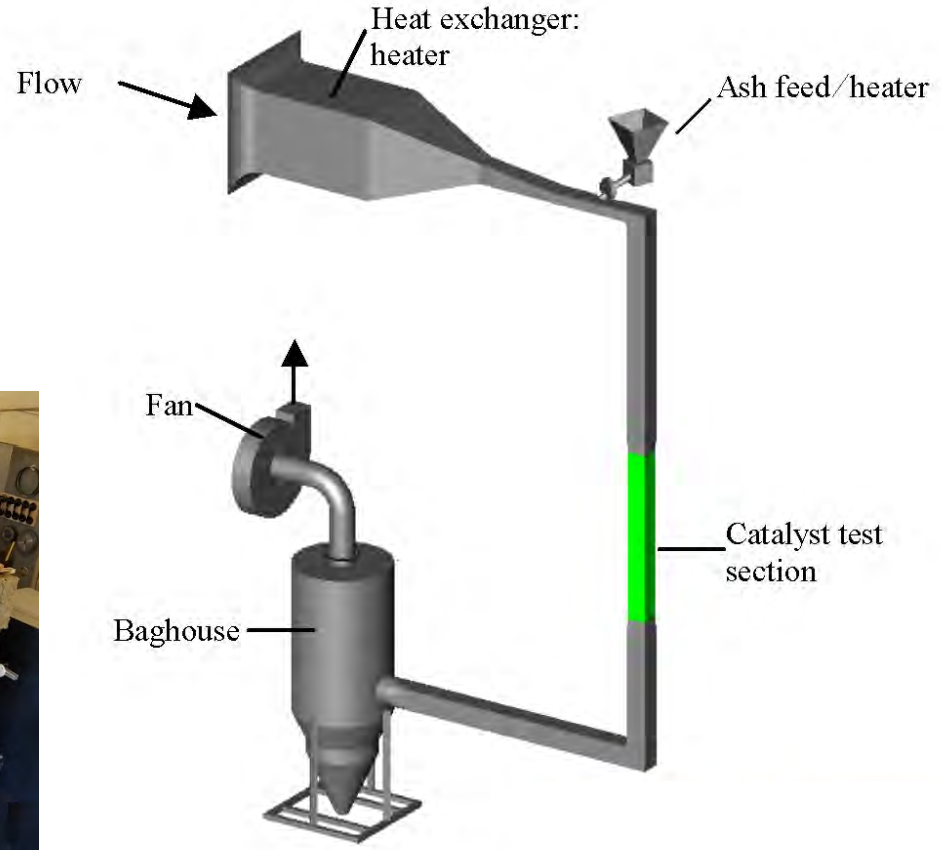
- CFD model used to evaluate design mods
  - Reduce ash accumulation with minimal degradation of velocity uniformity to catalyst
  - "Slots" cut in vanes at strategic location and size

Slide Courtesy of Airflow Sciences Corporation

Ash Deposition – Hot Flow Modeling

- Hot Flow Model
  - Testing under actual temperature conditions
  - Real ash, not laboratory dust





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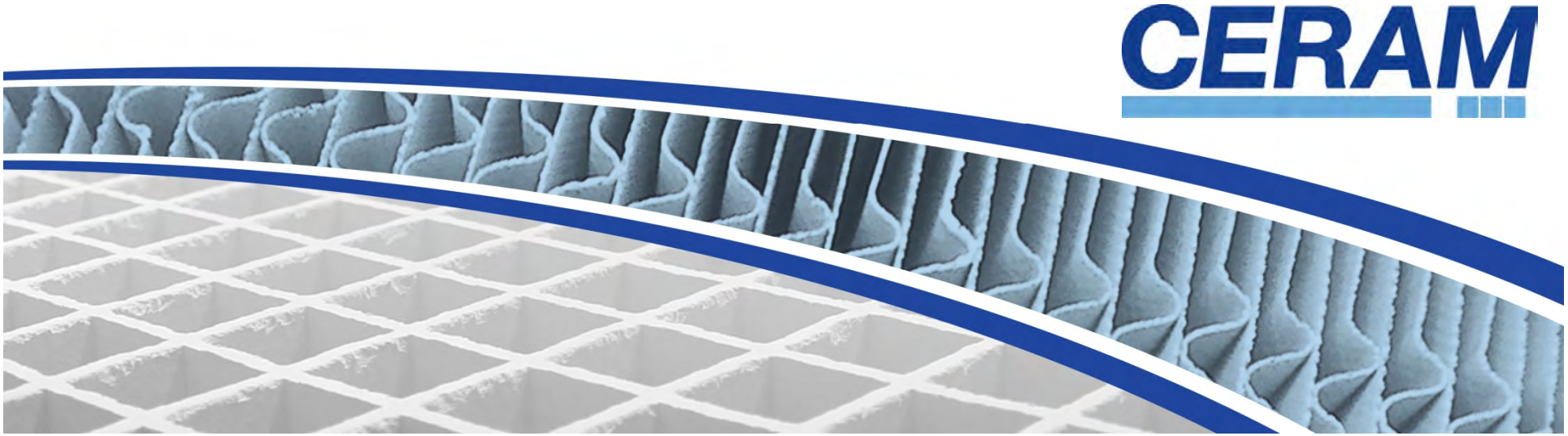
Slide Courtesy of Airflow Sciences Corporation

Summary



Pluggage is Minimized By…

- Pluggage is Minimized by….
  - Proper Pitch and Wall Thickness Selection
  - Proper Cover Grate Selection
  - Proper Gas Velocity in Ductwork and the Reactor (Flow Modeling)
  - Proper Boiler Operation (e.g., LOI, LPA, etc.)
    - LPA Screen Design
  - Proper Maintenance and Operation of Online Cleaning Devices
  - Proper Isolation During Outages (Avoiding Condensation if Possible)
- In-situ Cleaning Technologies
  - Vacuuming/Air Lancing; Vibrational/Sponge; Dry Ice Blasting
  - Cost Considerations
- Flow Modeling Very Effective at “Fixing” Root Cause
  - Rate of Return with Less Pressure Drop & More Surface Area (Longer Time Between Catalyst Events)

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Reinhold Environmental 2017 NOx-Combustion Round Table

Preventative Maintenance: Cleaning Techniques and Catalyst Cleanliness

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IBIDEN

Presented by: Dr. Greg Holscher
IBIDEN CERAM Environmental, Inc.
February 28, 2017

Special Thanks to the Panelist

- ***Jason Bookout**; Senior Engineer; Environmental Systems & Field Support; Catalyst Manager;* Southern Company; 6 years
- ***Dave Browning**; Consulting Engineer: Fleet Combustion & Performance; Technical Engineer; Outage Manager;* FirstEnergy Corporate Technical Services; 14 years
- ***Mike O'Connor**; Engineering Programs Manager;* Dynegy, Inc.; Prior at Duke, Cinergy and CG&E; 28 years
- ***Philp Elliot**; Director of SCR Services;* STEAG SCR-Tech, Inc.; 10 years; Prior at Progress Energy
- ***Robert Mudry**; President;* Air Flow Sciences Corporation; 29 years, started as a summer intern
- ***Jeff Shelton**; Vice President Environmental Solutions;* Integrated Global Services; 2 years; Prior at Martin Engineering for 8 years.

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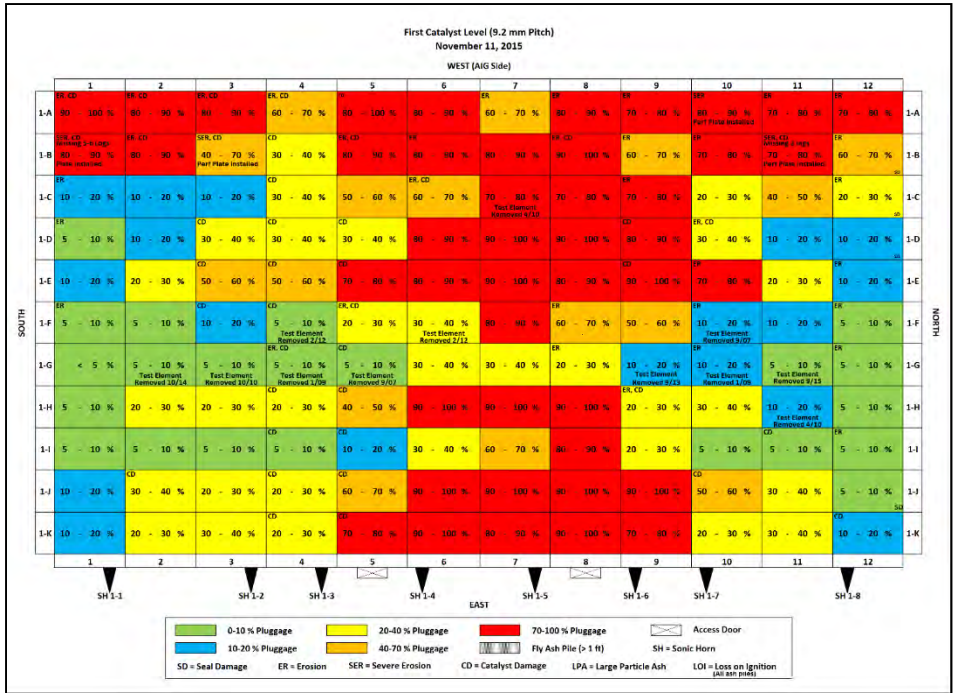
Topics for Panel Discussion

- Pluggage Resistance Catalyst
- Reactor Design & Configuration
- Factors Affecting Pluggage from Operations
- Online Cleaning Devices
- In-Situ Cleaning Technologies
- Fixing the Root Cause of Pluggage

What We Want to Avoid!



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Pluggage Resistance Catalyst?

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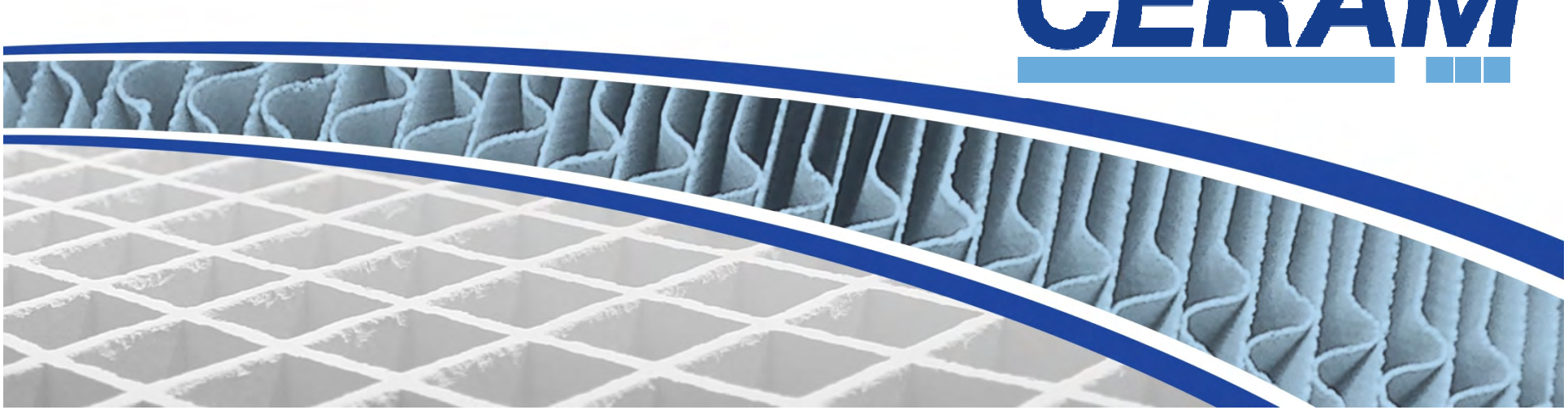
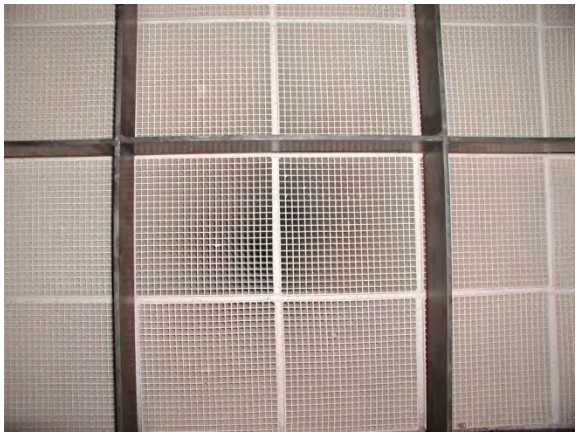
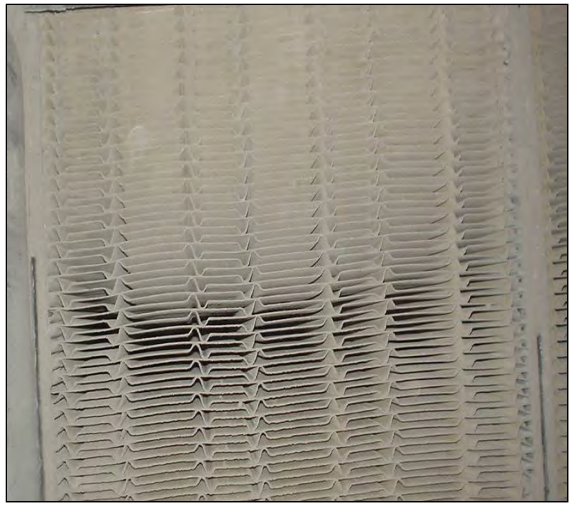


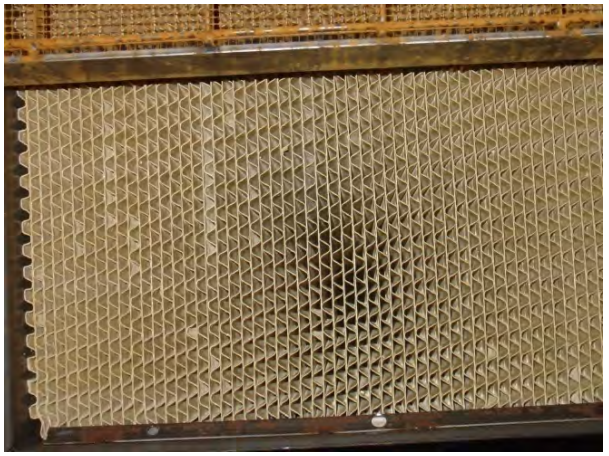
Any Catalyst Can Plug!



Honeycomb



Plate



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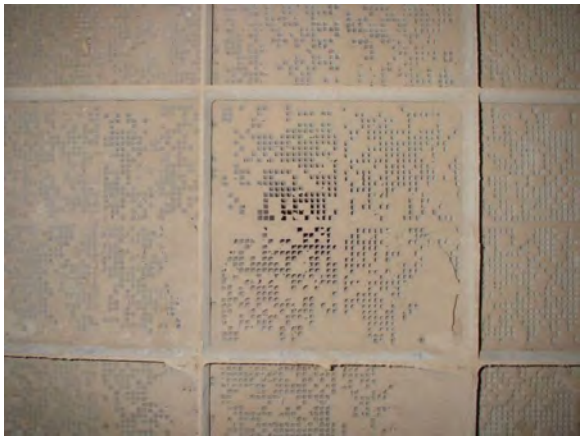

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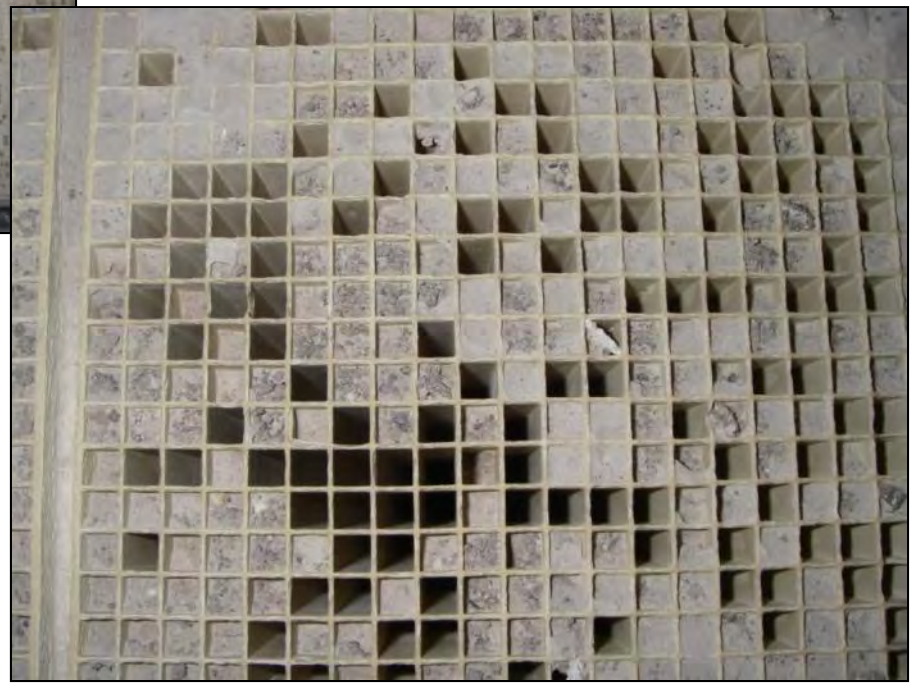
Catalyst Pluggage – LPA and LOI



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Catalyst Pluggage – Plate Catalyst

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Catalyst Pluggage – Plate Catalyst

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Catalyst Pluggage – Corrugated Catalyst

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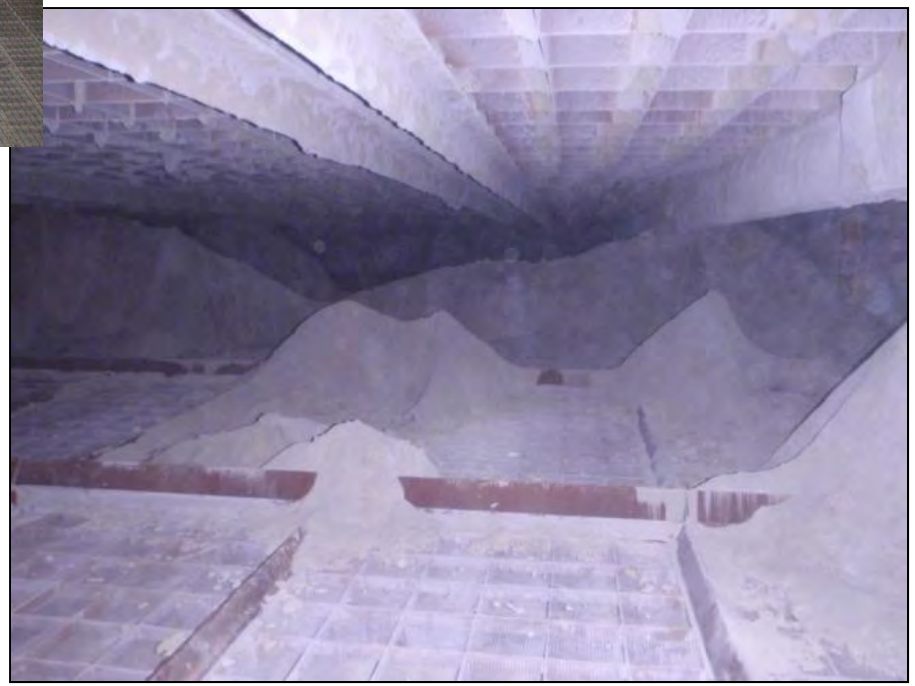
Ash Accumulation



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Ductwork – Ash Dropout

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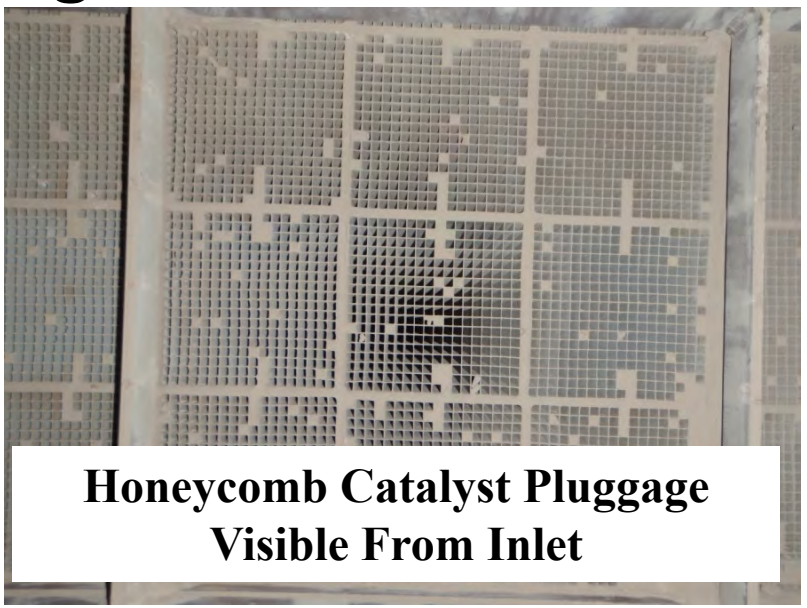
Relative Pluggage Risk

Plate Catalyst Pluggage Accumulates Between Sub Layers & Inlet



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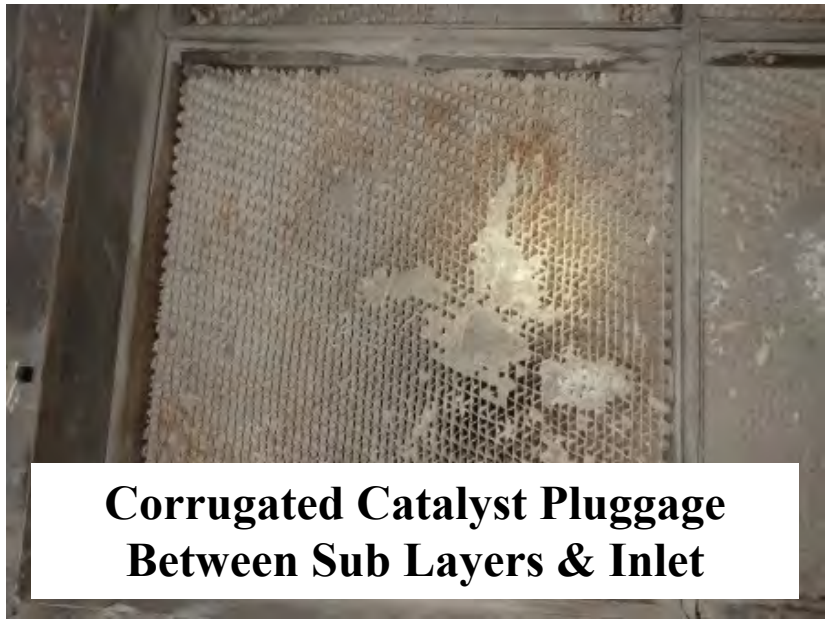

Corrugated Catalyst Pluggage Between Sub Layers & Inlet

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Cover Grate Design

CERAM Cover Grate in Level 1 (Welded Stainless Steel 1 mm Dia. with 5 mm Opening)

Woven Wire Mesh Cover Grate in Level 4 (4 mm or Less Opening)

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Wygen 3 Cover Grates from IGS

After 1 year of operation

Photos courtesy of Integrated Global Services

Reactor Design & Configuration

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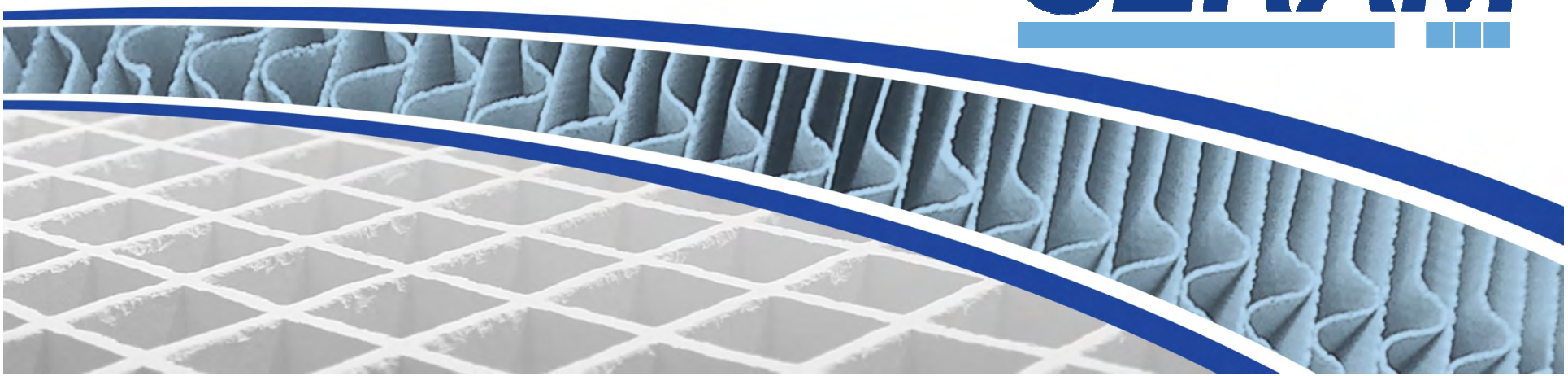

Reactor Design & Configuration

- Original Designs Over 10-15 Years May Not have Used CFD Modeling
  - Physical Modeling (1/12th Scale; Dust Test)
- Past Designs Driven by Engineering Before Flow Modeling Completed
- Lessons Learned – Flow Modeling Should Drive Engineering Design
- Real World Buildup Sometimes Does Not Appear During Modeling

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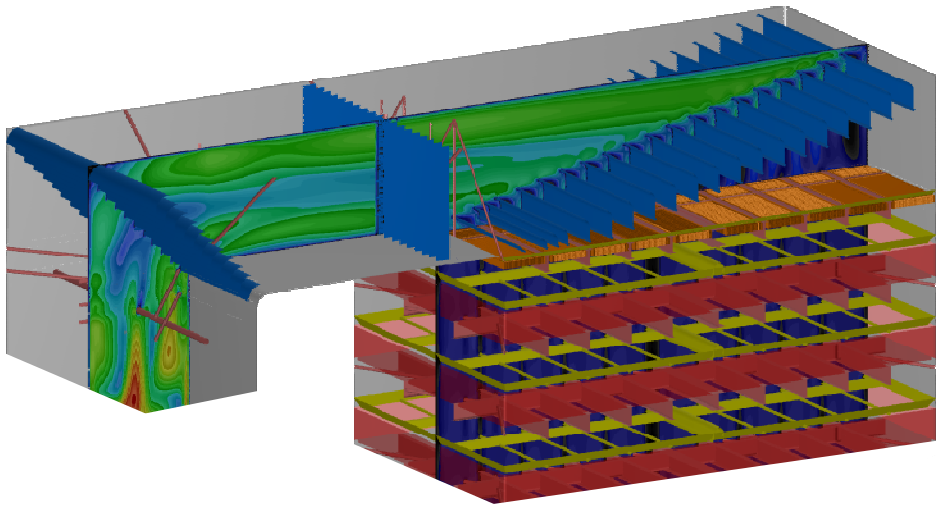
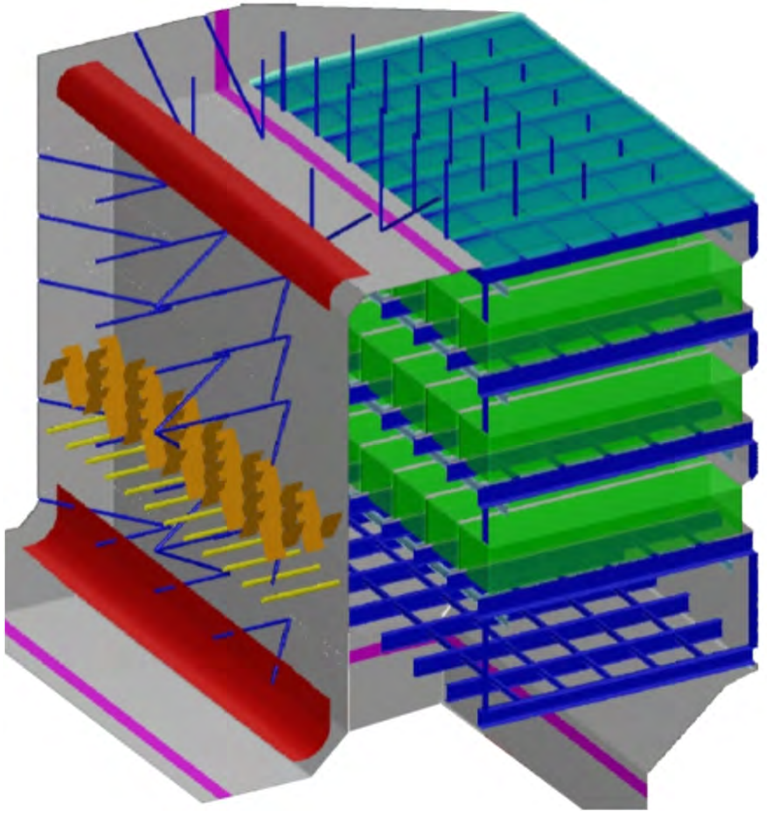
Reactor Hood Design: Critical

- Square hood
- Sloped hood





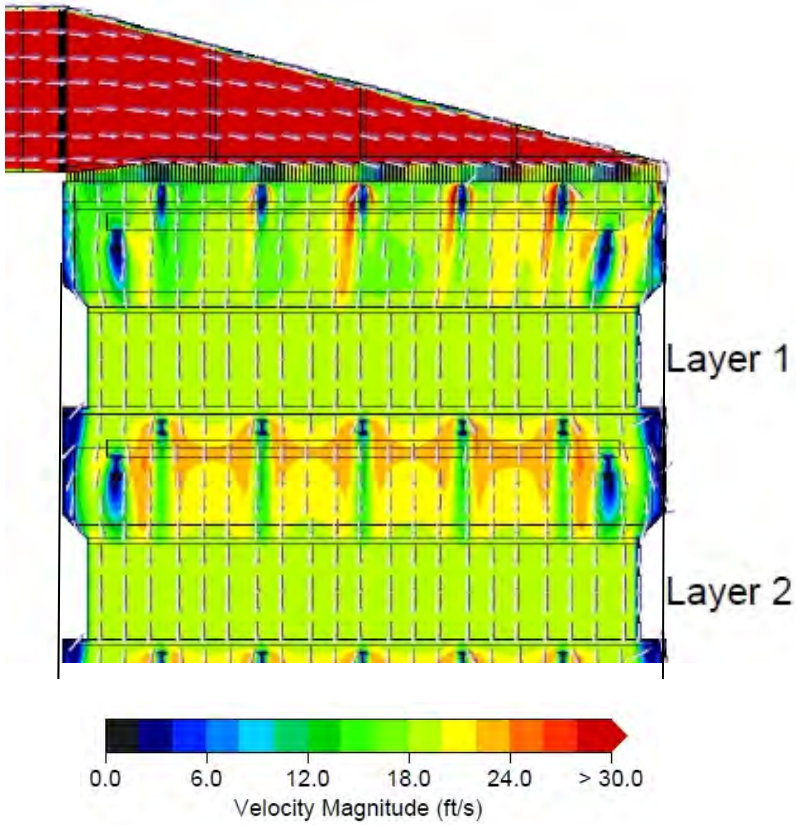
- Both work *if designed correctly*

Slide Courtesy of Airflow Sciences Corporation

CERAM

Reactor Hood Design: Critical

- Sloped hood uses rectifier to turn flow
  - Works well *if designed correctly*



Slide Courtesy of Airflow Sciences Corporation

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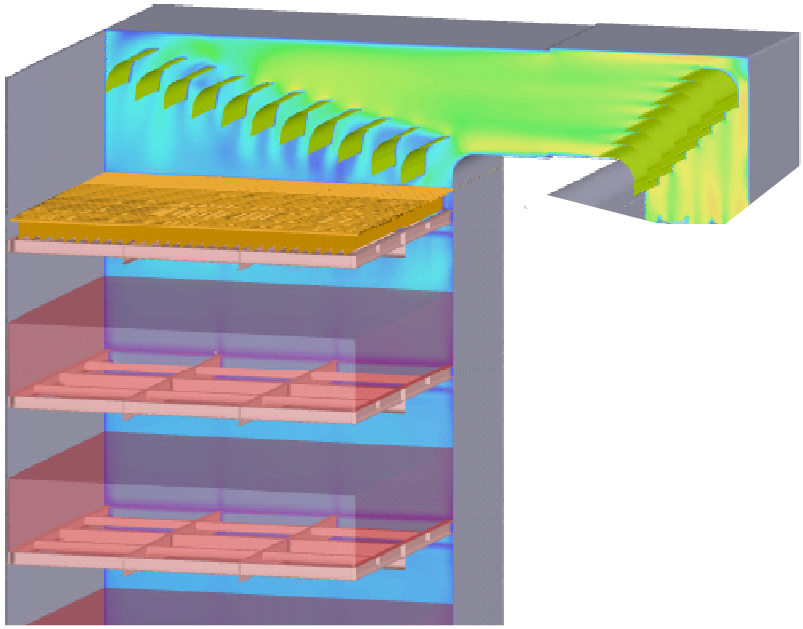
Reactor Hood Design: Critical

- Turning vanes
  - Curved vanes
  - Ladder vanes



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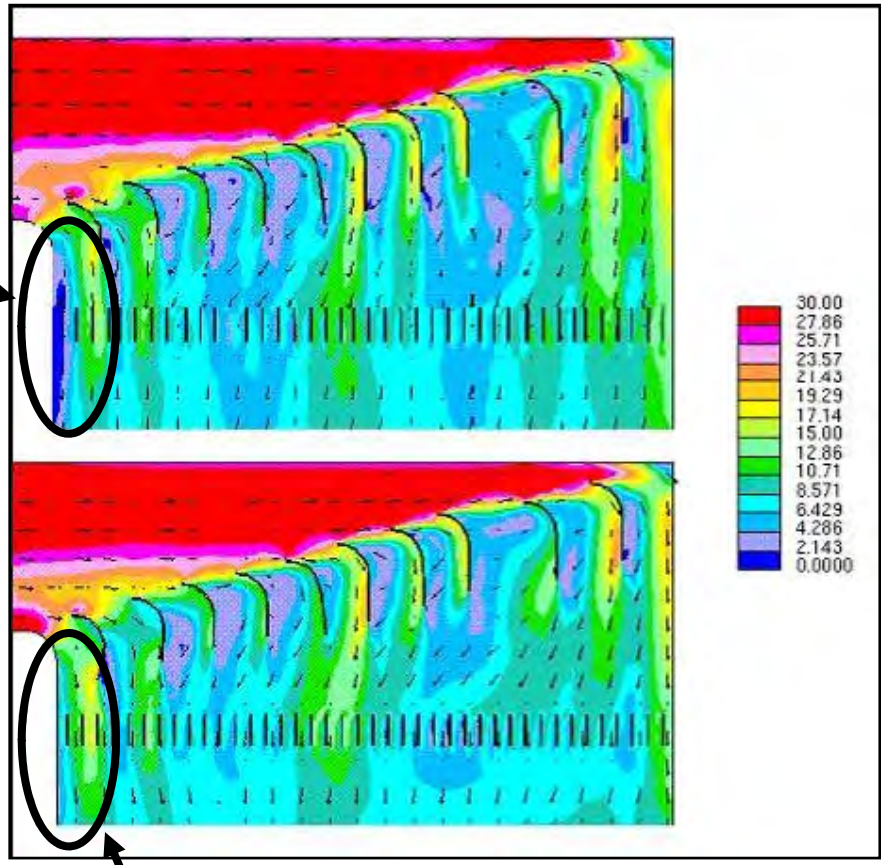
Reactor Configuration – Importance of Flow Modeling

- Reactor Configuration
  - Distance From Crossover Duct Down to Top of 1st Catalyst Layer
- Low Velocity Area Exists Even Though Distributions Are Achieved
- Low Vel = Increased Pluggage Risk
- Optimized Designs are Possible



Eliminate Through CFD Modeling

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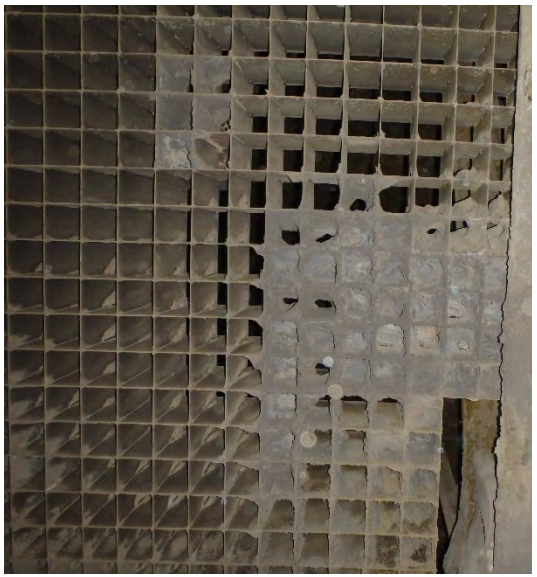
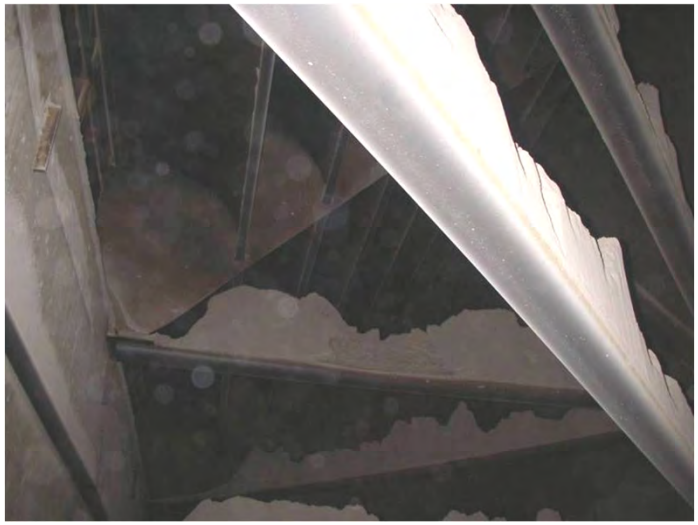
Reactor Configuration – Flow Modeling



Fly ash pile located below gusset plate due to ash shear

- Lessons Learned – Real World Buildup Sometimes Does Not Appear During Modeling
- Locations of Trusses and Gusset Plate Configurations



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Flow Distribution Device Design

- Lessons Learned – Ash Buildup on Vanes and Internal Structural Members
- Locations of Gusset Plates
- Turning Vane Design

Ash Buildup on Vanes

Affects of Ash Shear

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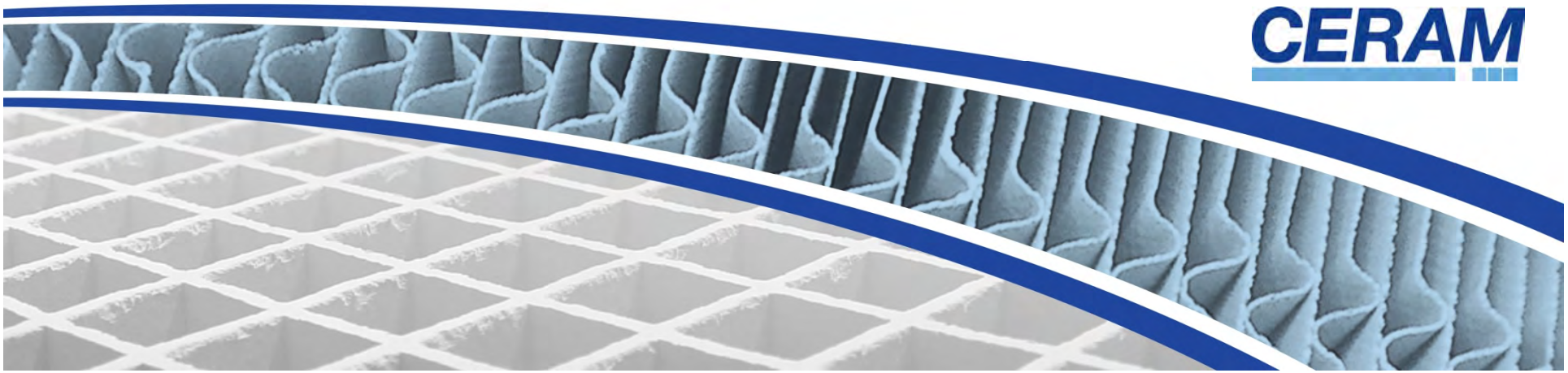
Factors Affecting Pluggage From Operations



Eliminate LPA Prior to Catalyst

Large Particle Ash (LPA)

STEAG LPA Screen

- **L**arge **P**article **A**sh Can Be Present and Should be Controlled as Part of System Design
- LPA Pluggage of Catalyst Leads to…
  - High Pressure Drops
  - Mechanical Damage
  - Reduced Performance Potential
- Effective and Durable Screen Designs are Required
  - Located With Ash Removal
  - Located at Proper Velocity
  - Simple and Advanced Designs Have Both Succeeded and Also Had Problems
- Flow Modeling and Physical Changes are Likely Necessary

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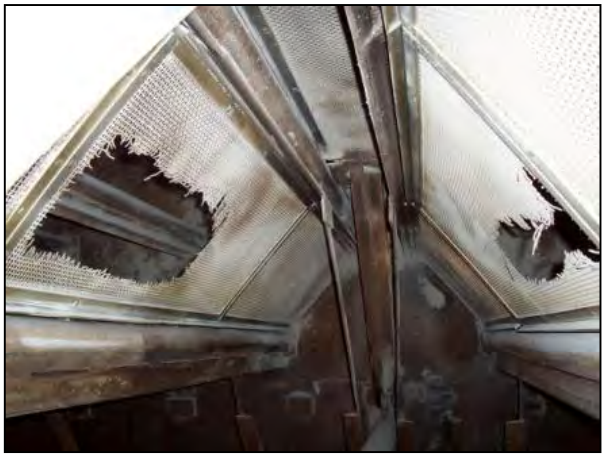
Simple & Advanced LPA Screens Can Succeed or Fail

- Proper Choices of LPA Screen Design are Site Specific
- Ensure Proper Velocity at LPA Screen
- Remove Material From Hoppers
- Cleaning Device (Sonic Horn, Rapper, etc.)

Coated & Non-Coated Screens Failed (High Velocity)

Stainless Steel Screen Failed at Fasteners (High Velocity)

Damaged LPA Screen Material



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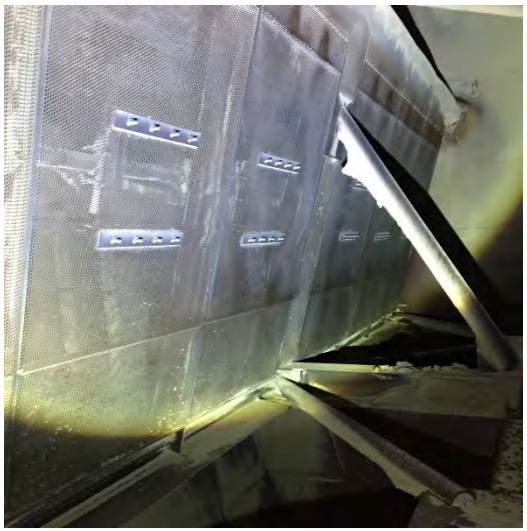
Pluggage Due to LPA

Before LPA Screen

After Install of LPA Screen



Photos courtesy of Integrated Global Services

Minimize Carbon Carryover

Reactor Accumulation of Unburned Carbon

Plate Catalyst With Accumulated Unburned Carbon

- The Control of Unburned Carbon is Important for Reliable DeNOx Operation
- All DeNOx Catalyst Has Oxidizing Properties and Will Tend to Oxidize Unburned Carbon
- Oxidized Carbon Sticks to Catalyst and Can Result in Pluggage
- Accumulation on Catalyst Increases Risk of Pluggage and Fires
- Increased Potential for Needing Offline, Out of Reactor Cleaning
- Homogeneous Honeycomb Catalyst Consists of Fully Oxidized Material
- Metal Substrates Can Lead to Increased Potential for Fires

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Pluggage Leads to Erosion Which Can Affect Any Catalyst Type

- Erosion Risk Varies as Ratio of Flow to 3rd or 4th Power
- Exposed Plate Stainless Steel Provides No Activity and Available for SO_2 to SO_3 Conversion
- Managed by Limiting Face Velocity
  - Minimize Catalyst Pluggage

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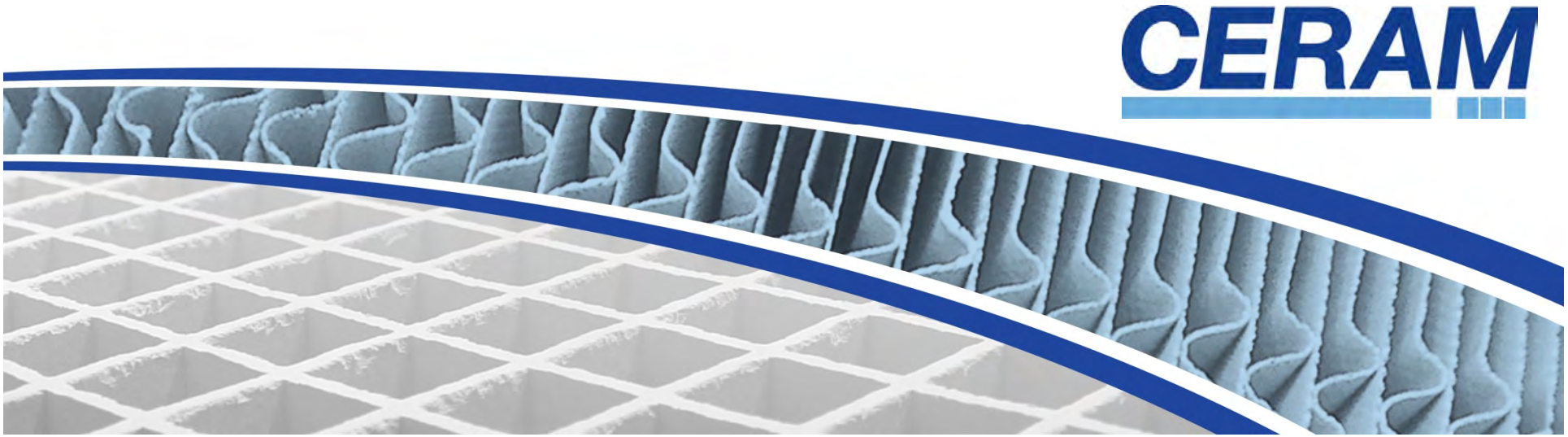
Online Cleaning Devices



Sootblowers – More O&M Cost Than Sonic Horns, But Are They Working?

Sootblower Set to Improper Pressure (Compressed Air Setting Instead of Steam Setting) Ineffective at Cleaning Catalyst

- Lessons Learned
  - Sootblowers Effective If Ash Fluidized; No Cleaning Device Effective with Poor Flow Distribution
  - Increase Frequency Based on Pressure Drop
  - Check Operation Daily

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Sonic Horns – Look Good Outside, But Are They Working?

- Lessons Learned
  - Sonic Horn Effective If Ash Fluidized; No Cleaning Device Effective with Poor Flow Distribution
  - Insulate Outside to Minimize Corrosion in Throat/Bell
  - Check Operation Daily

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Ash Sweepers

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Photo courtesy of Integrated Global Services

Ash Sweepers

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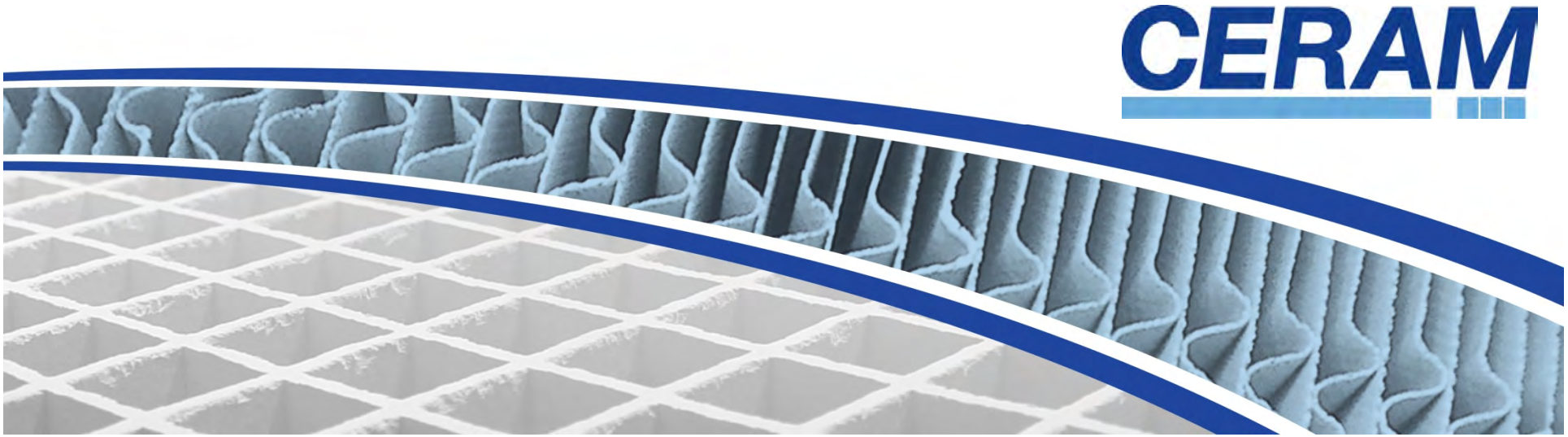
Photo courtesy of Integrated Global Services

In-situ Cleaning



Example of “Mechanical” Cleaning Not Recommended

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Vacuuming and Pneumatic Cleaning

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Vibrational Cleaning

Video courtesy of Michael Ware SCR Solutions, Inc.
& Thompson Industrial Services, LLC

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Sponge Blasting

Patent Pending ***Sponge Blasting*** *Process* utilizes polyurethane foam media to **Safely Remove Hardened Ash from the Surface and Within the Catalyst Modules.**

Before Sponge Blasting

After Sponge Blasting

Photos courtesy of Michael Ware SCR Solutions, Inc. & Thompson Industrial Services, LLC

Sponge Blasting Video

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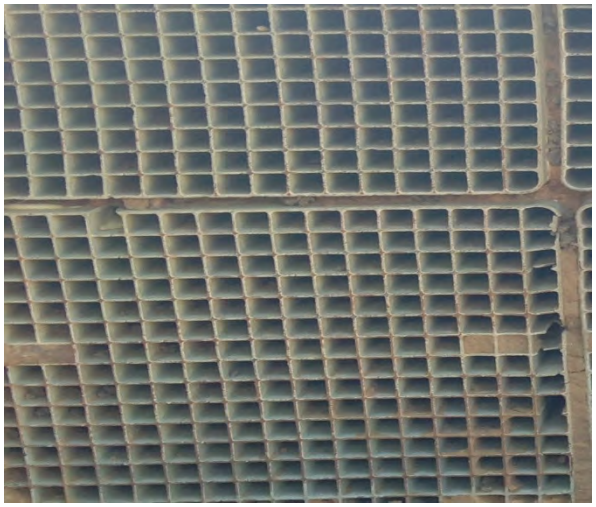
Video courtesy of Michael Ware SCR Solutions, Inc.
& Thompson Industrial Services, LLC

Sponge Blasting

BEFORE

AFTER



This combination of methods **Safely Clears the Catalyst of Potentially Harmful Contaminates that cannot be achieved by traditional methods.**

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Photos courtesy of Michael Ware SCR Solutions, Inc. & Thompson Industrial Services, LLC

Dry Ice Blasting

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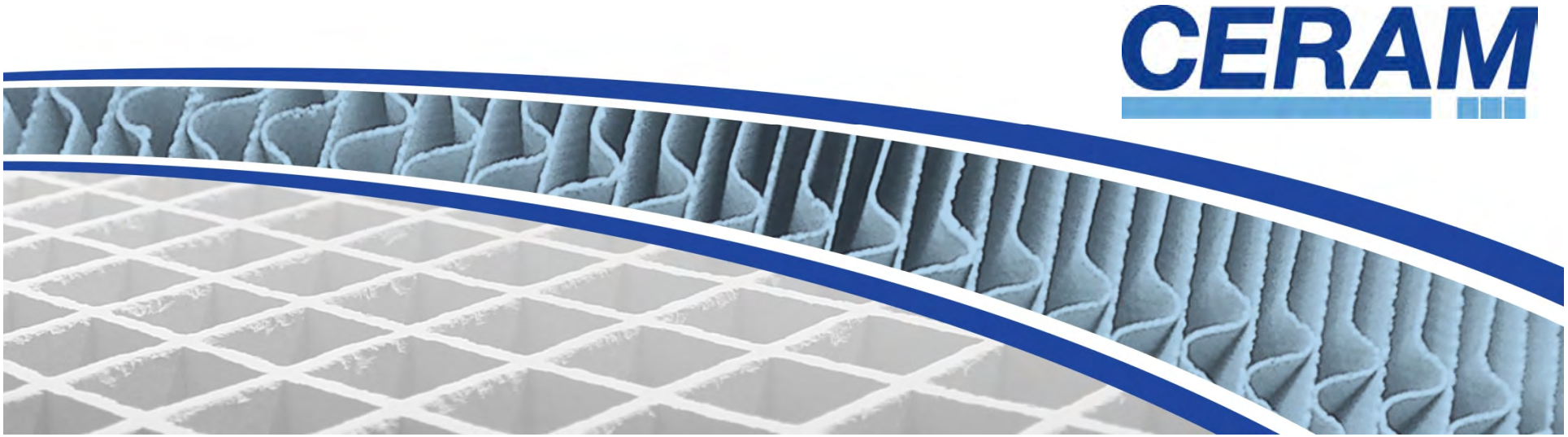
Video courtesy of STEAG SCR-Tech, Inc.

Fix “Root” Cause of Pluggage



Flow Modeling Methods

- CFD (Computational Fluid Dynamics)
- Cold Flow Scale Modeling (dust testing)
- Hot Flow Scale Modeling (real ash)
- Wind Tunnel Testing
  - To determine ash drop-out and re-entrainment aerodynamic behavior
  - Ambient or Hot Wind Tunnel

Slide Courtesy of Airflow Sciences Corporation

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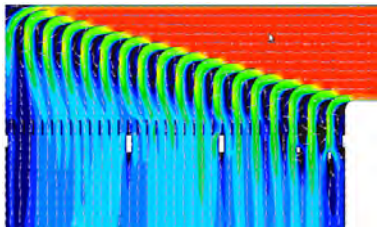
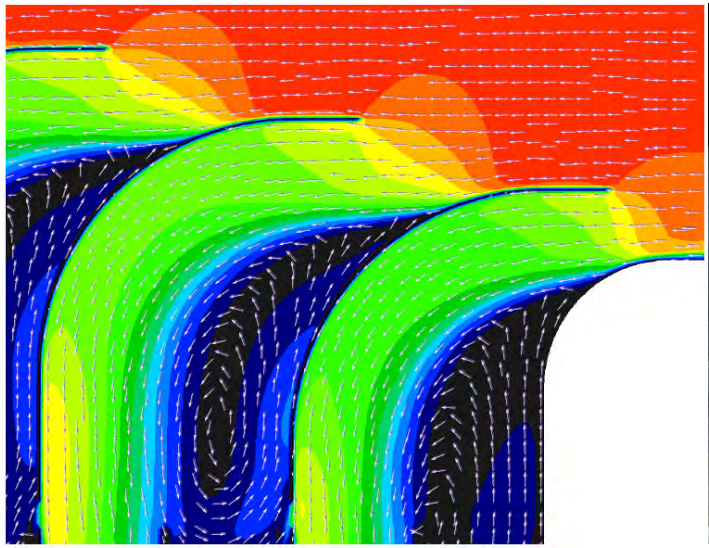
Ash Deposition – Reactor Hood Vanes

- CFD model and field observations show root cause
  - Flow separation and recirculation on vane surface
  - Not *designed correctly*
  - Occasional avalanche can cause catalyst pluggage issue
  - Hood vane redesign required

Hood vanes



Vane detail



(black = recirc zone)

Ash buildup

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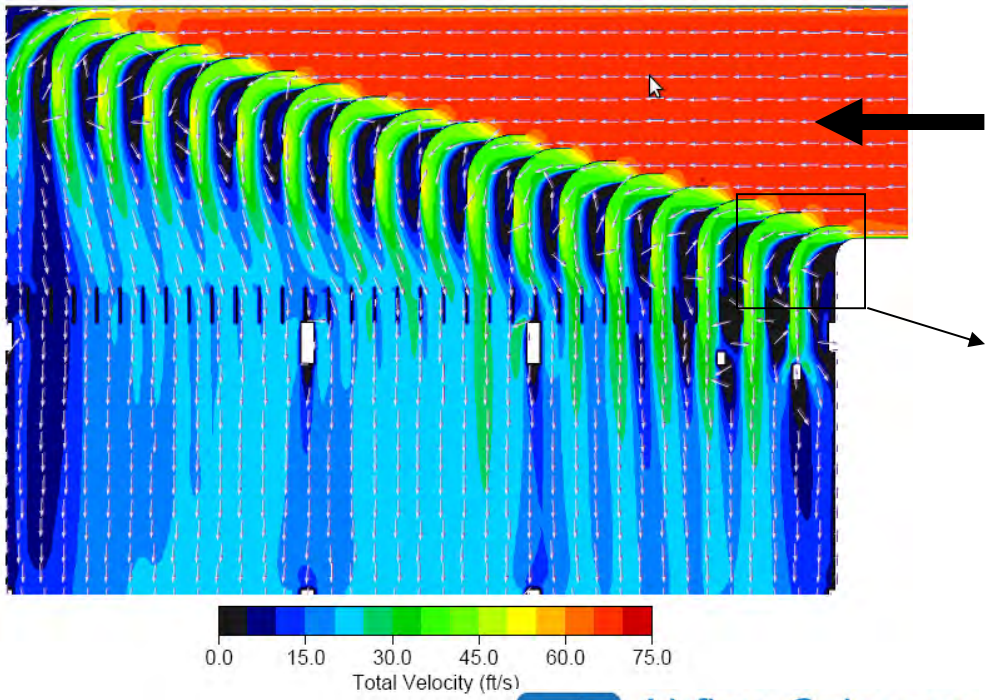
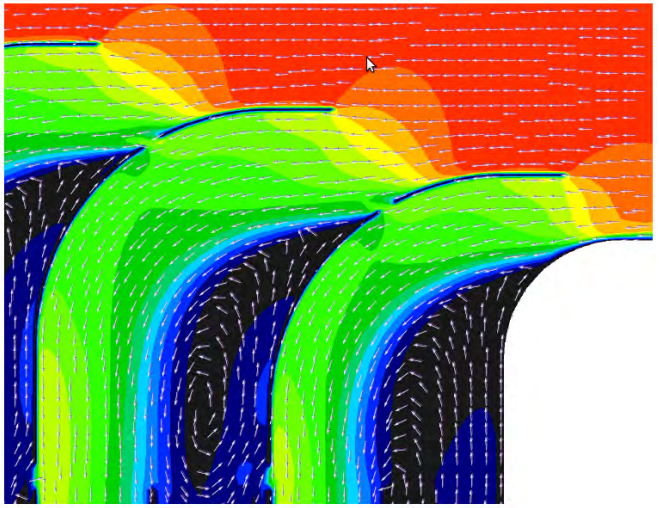
Slide Courtesy of Airflow Sciences Corporation

Ash Deposition – Reactor Hood Vanes

- CFD model used to evaluate design mods
  - Reduce ash accumulation with minimal degradation of velocity uniformity to catalyst
  - "Slots" can be cut in vanes with strategic location and



Close-up at inner corner



CEI Slide Courtesy of Airflow Sciences Corporation

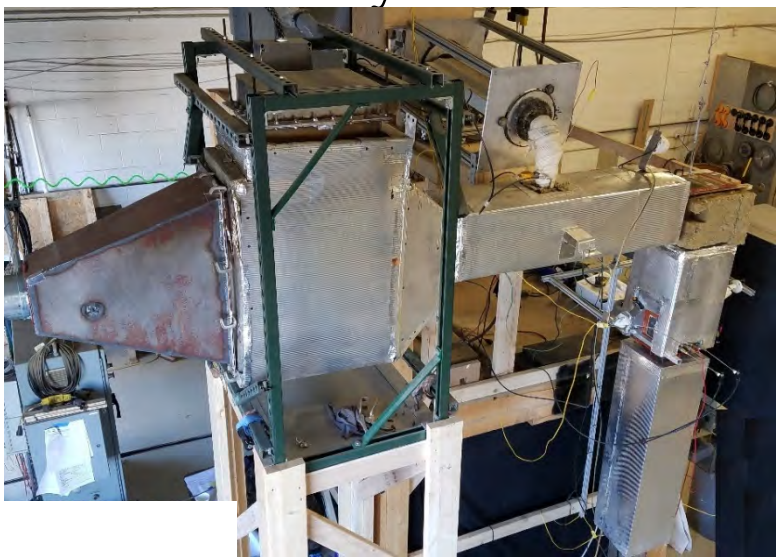
Ash Deposition – Reactor Hood Vanes

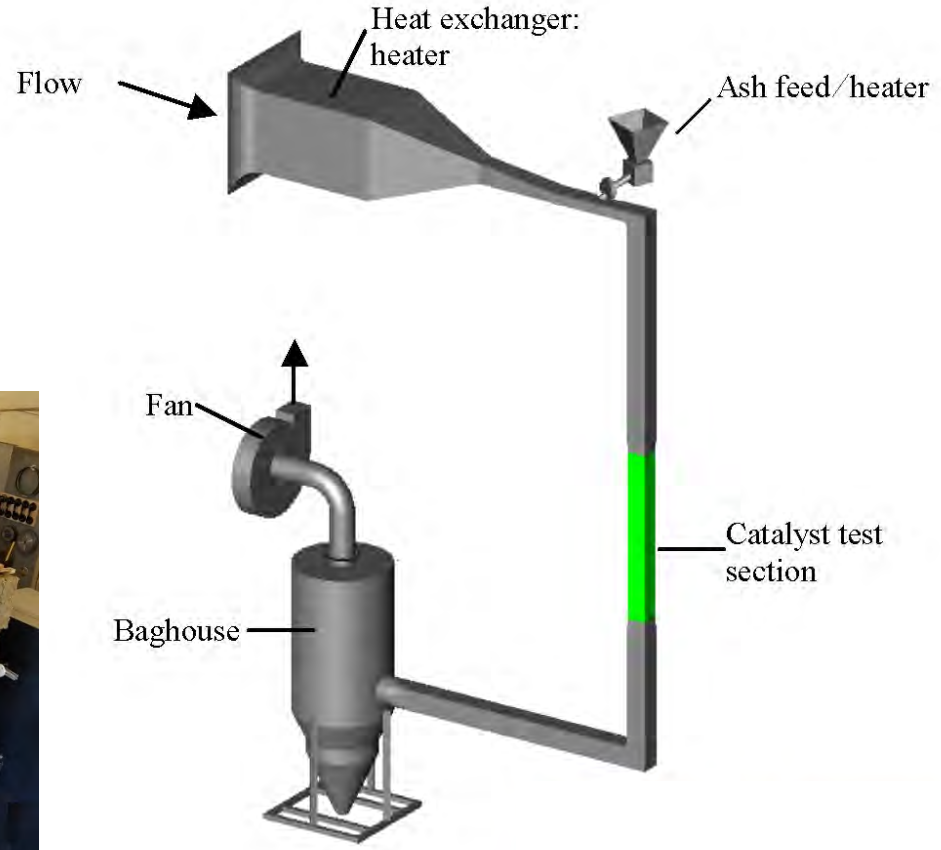
- CFD model used to evaluate design mods
  - Reduce ash accumulation with minimal degradation of velocity uniformity to catalyst
  - "Slots" cut in vanes at strategic location and size

Slide Courtesy of Airflow Sciences Corporation

Ash Deposition – Hot Flow Modeling

- Hot Flow Model
  - Testing under actual temperature conditions
  - Real ash, not laboratory dust





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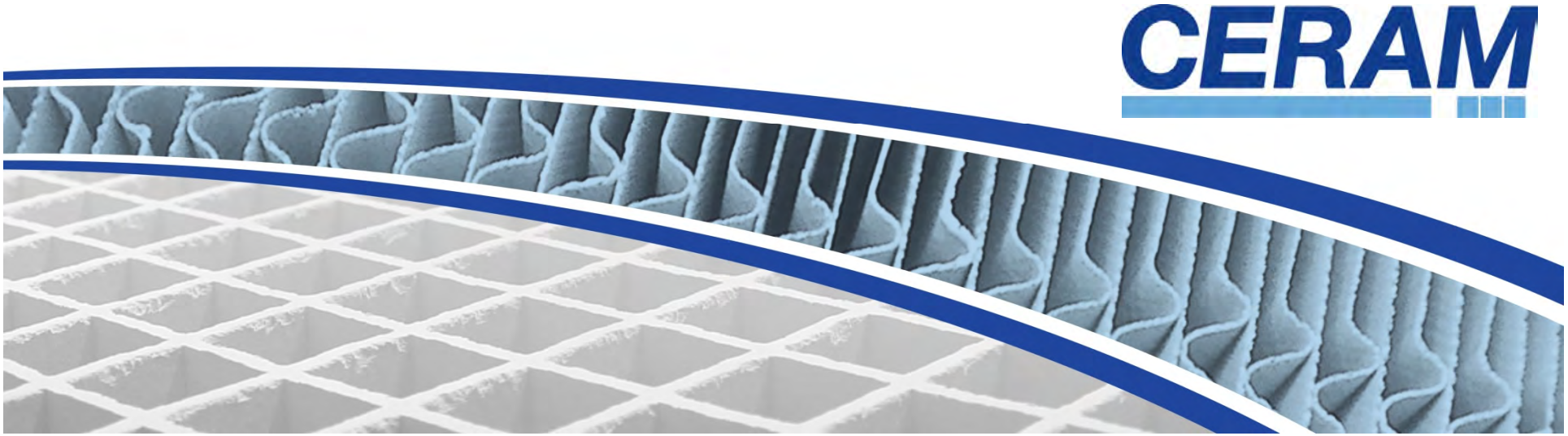
Slide Courtesy of Airflow Sciences Corporation

Summary



Pluggage is Minimized By…

- Pluggage is Minimized by….
  - Proper Pitch and Wall Thickness Selection
  - Proper Cover Grate Selection
  - Proper Gas Velocity in Ductwork and the Reactor (Flow Modeling)
  - Proper Boiler Operation (e.g., LOI, LPA, etc.)
    - LPA Screen Design
  - Proper Maintenance and Operation of Online Cleaning Devices
  - Proper Isolation During Outages (Avoiding Condensation if Possible)
- In-situ Cleaning Technologies
  - Vacuuming/Air Lancing; Vibrational/Sponge; Dry Ice Blasting
  - Cost Considerations
- Flow Modeling Very Effective at “Fixing” Root Cause
  - Rate of Return with Less Pressure Drop & More Surface Area (Longer Time Between Catalyst Events)

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Reinhold Environmental 2017 NOx-Combustion Round Table

Preventative Maintenance: Cleaning Techniques and Catalyst Cleanliness

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IBIDEN

Presented by: Dr. Greg Holscher
IBIDEN CERAM Environmental, Inc.
February 28, 2017

Special Thanks to the Panelist

- ***Jason Bookout**; Senior Engineer; Environmental Systems & Field Support; Catalyst Manager;* Southern Company; 6 years
- ***Dave Browning**; Consulting Engineer: Fleet Combustion & Performance; Technical Engineer; Outage Manager;* FirstEnergy Corporate Technical Services; 14 years
- ***Mike O'Connor**; Engineering Programs Manager;* Dynegy, Inc.; Prior at Duke, Cinergy and CG&E; 28 years
- ***Philp Elliot**; Director of SCR Services;* STEAG SCR-Tech, Inc.; 10 years; Prior at Progress Energy
- ***Robert Mudry**; President;* Air Flow Sciences Corporation; 29 years, started as a summer intern
- ***Jeff Shelton**; Vice President Environmental Solutions;* Integrated Global Services; 2 years; Prior at Martin Engineering for 8 years.

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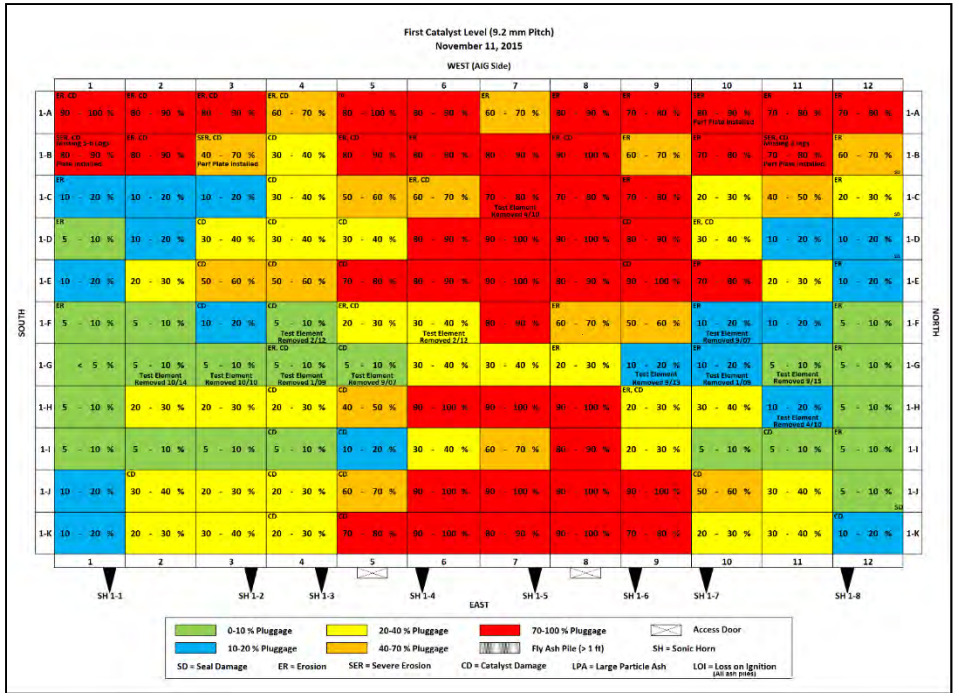
Topics for Panel Discussion

- Pluggage Resistance Catalyst
- Reactor Design & Configuration
- Factors Affecting Pluggage from Operations
- Online Cleaning Devices
- In-Situ Cleaning Technologies
- Fixing the Root Cause of Pluggage

What We Want to Avoid!



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Pluggage Resistance Catalyst?

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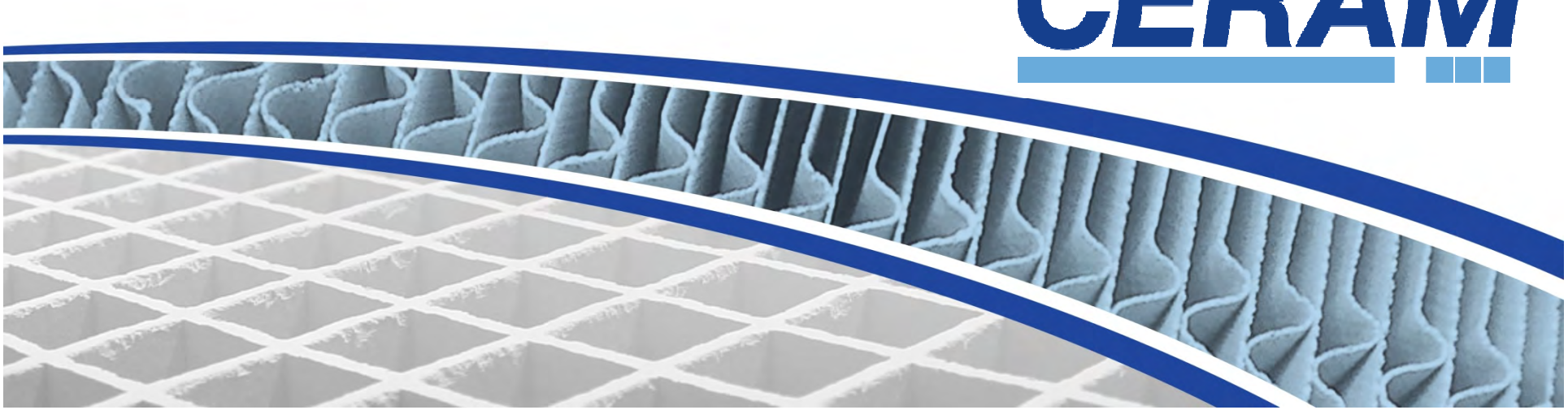
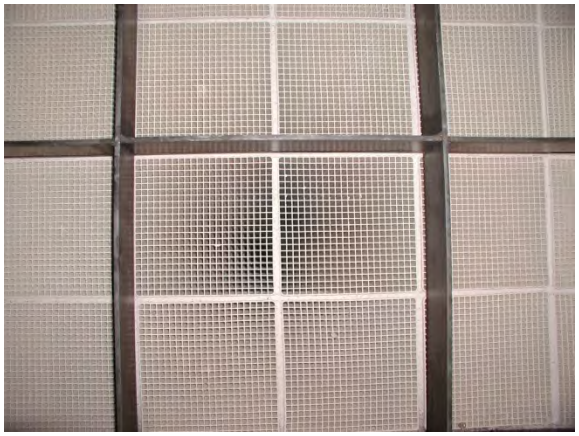
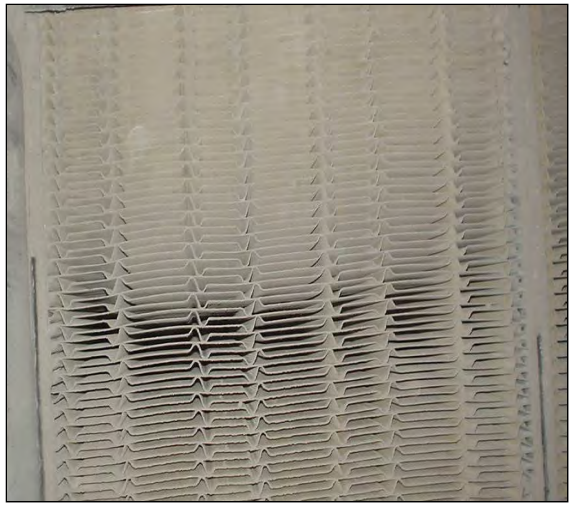


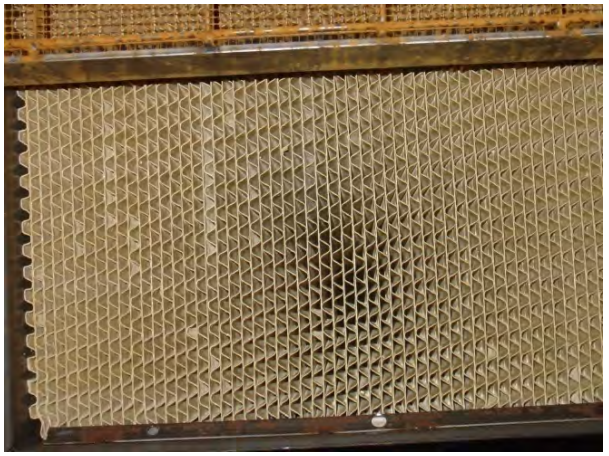
Any Catalyst Can Plug!



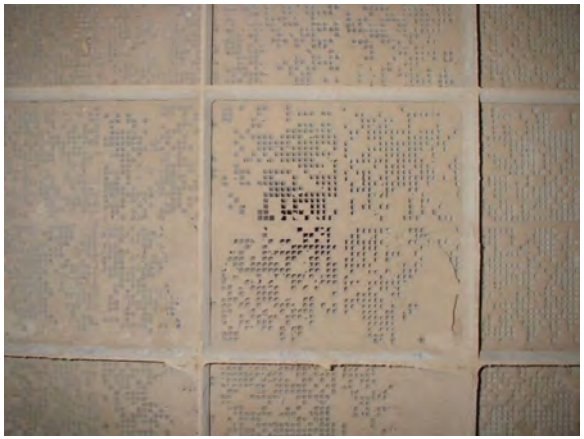
Honeycomb



Plate



Corrugated Fiber



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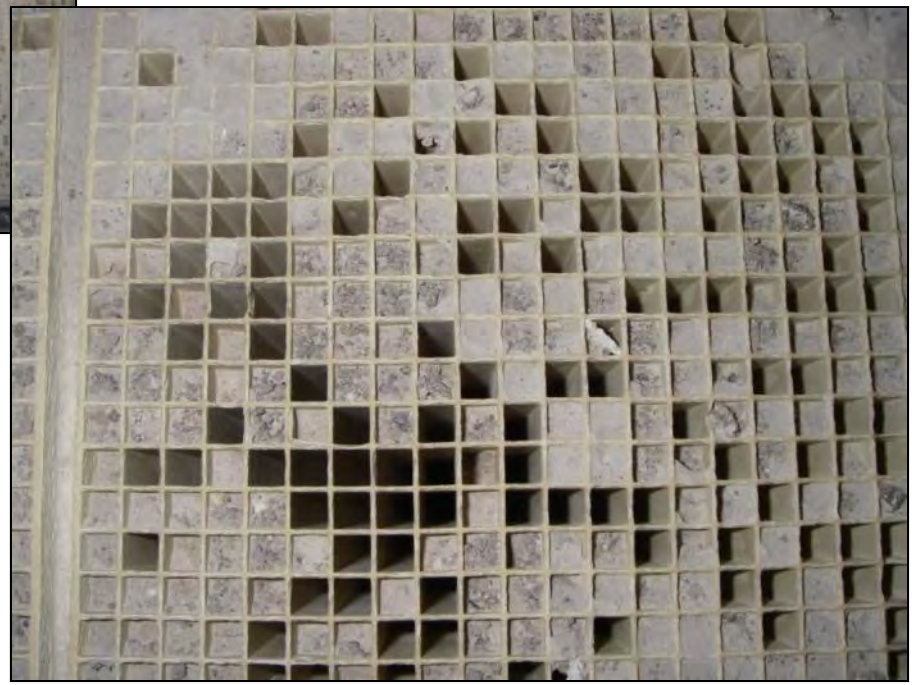
Catalyst Pluggage – LPA and LOI



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Catalyst Pluggage – Plate Catalyst

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Catalyst Pluggage – Plate Catalyst

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Catalyst Pluggage – Corrugated Catalyst

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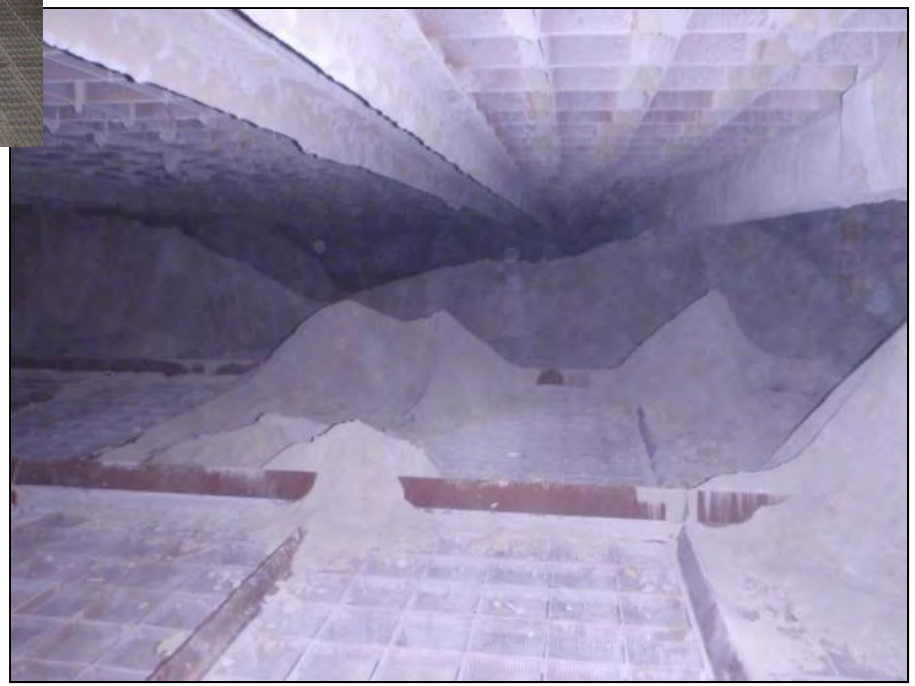
Ash Accumulation



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Ductwork – Ash Dropout

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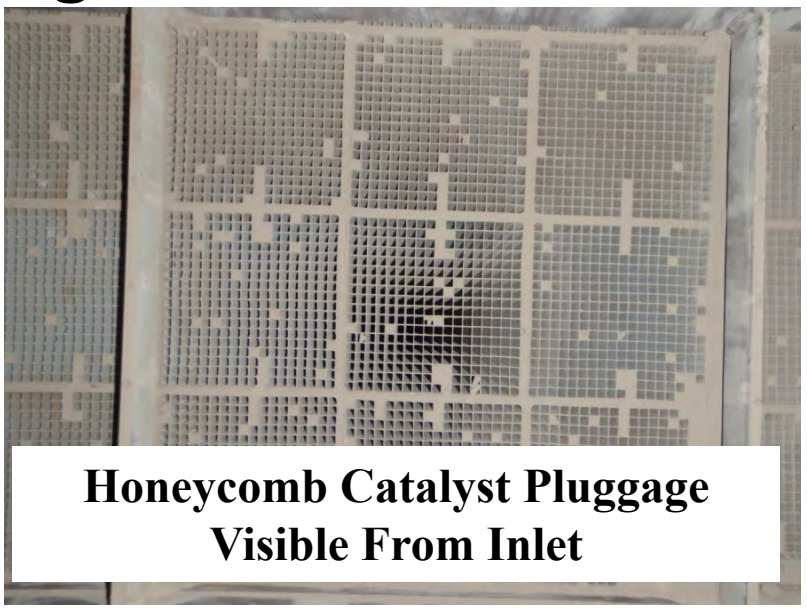
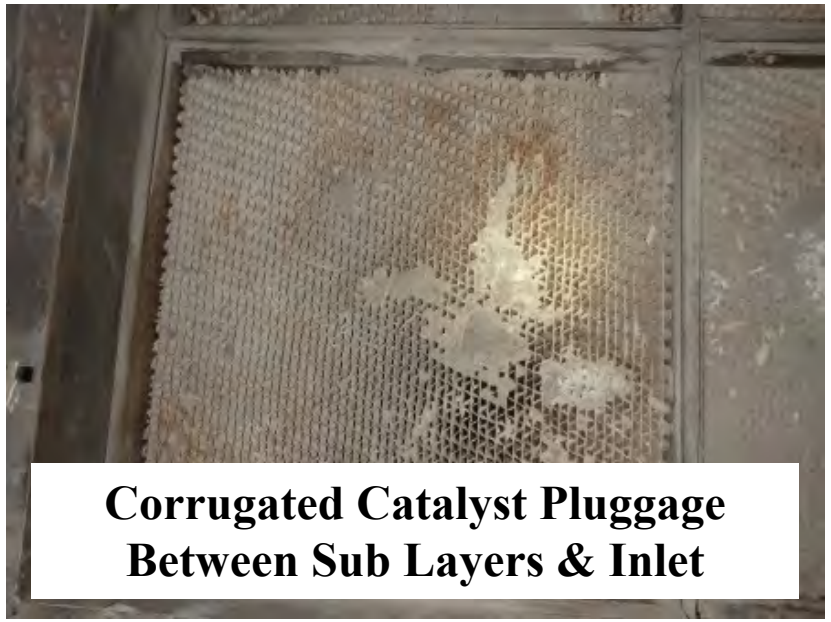
Relative Pluggage Risk

Plate Catalyst Pluggage Accumulates Between Sub Layers & Inlet



Honeycomb Catalyst Pluggage Visible From Inlet

- Pluggage Risk Dependent On…
  - Fuel Ash Loading and Characteristics
  - Flue Gas Flow Conditions Entering Catalyst
  - Catalyst Pitch Selection
- Provided Adequate Pitch & Flow Distributions
- What About Reactor Design or even Cover Grate Design or Varying Pitch Selection?



Corrugated Catalyst Pluggage Between Sub Layers & Inlet

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Cover Grate Design

CERAM Cover Grate in Level 1 (Welded Stainless Steel 1 mm Dia. with 5 mm Opening)

Woven Wire Mesh Cover Grate in Level 4 (4 mm or Less Opening)

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Wygen 3 Cover Grates from IGS

After 1 year of operation

Photos courtesy of Integrated Global Services

Reactor Design & Configuration

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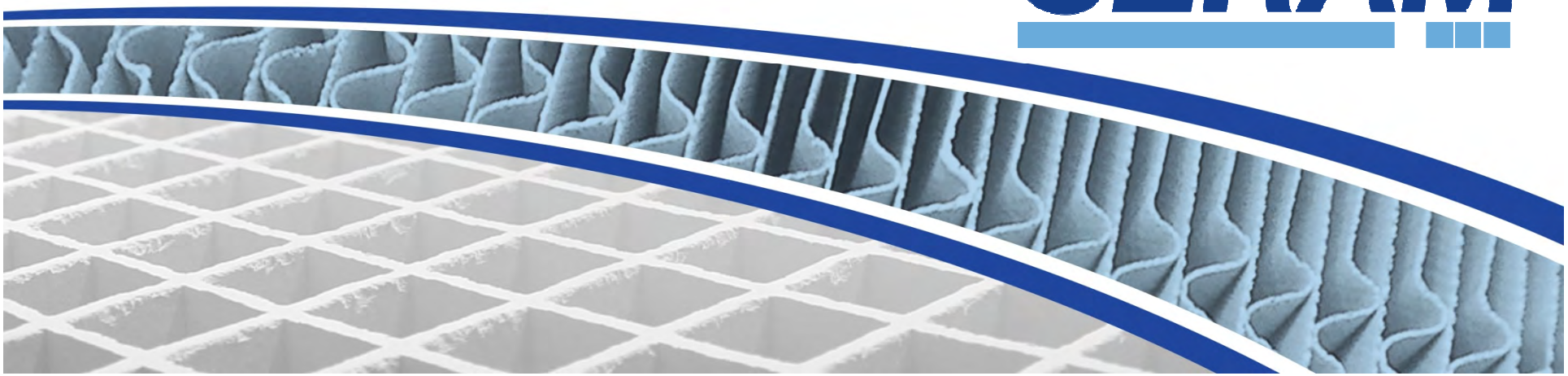

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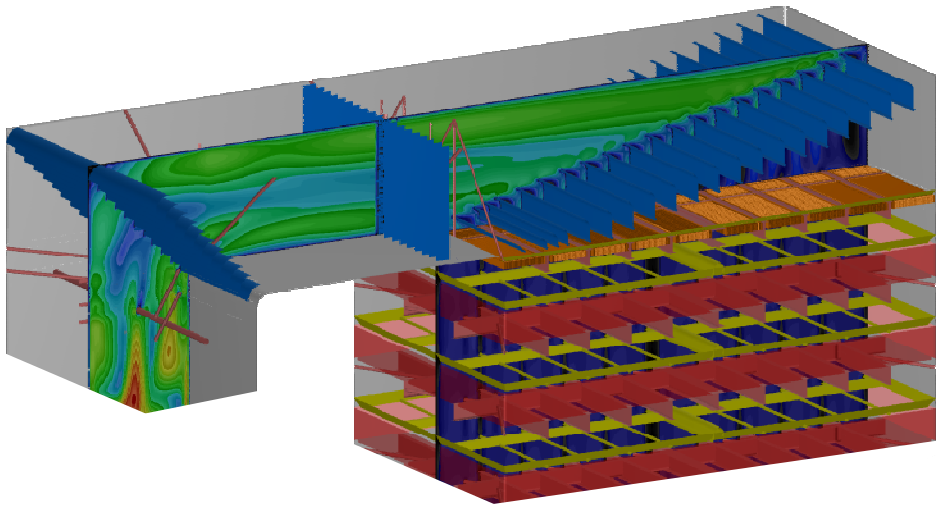

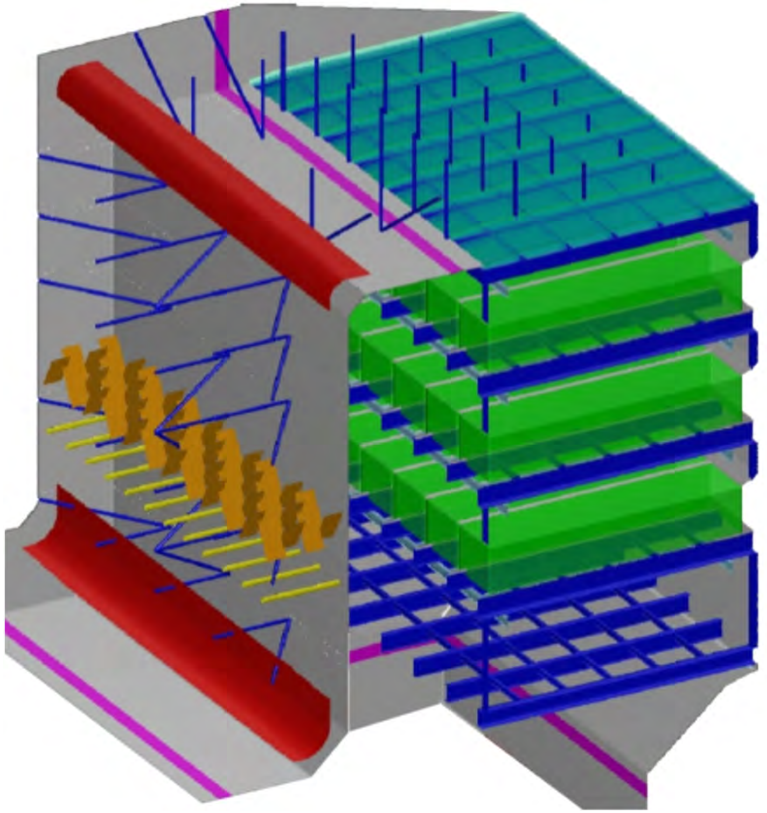

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Slide Courtesy of Airflow Sciences Corporation

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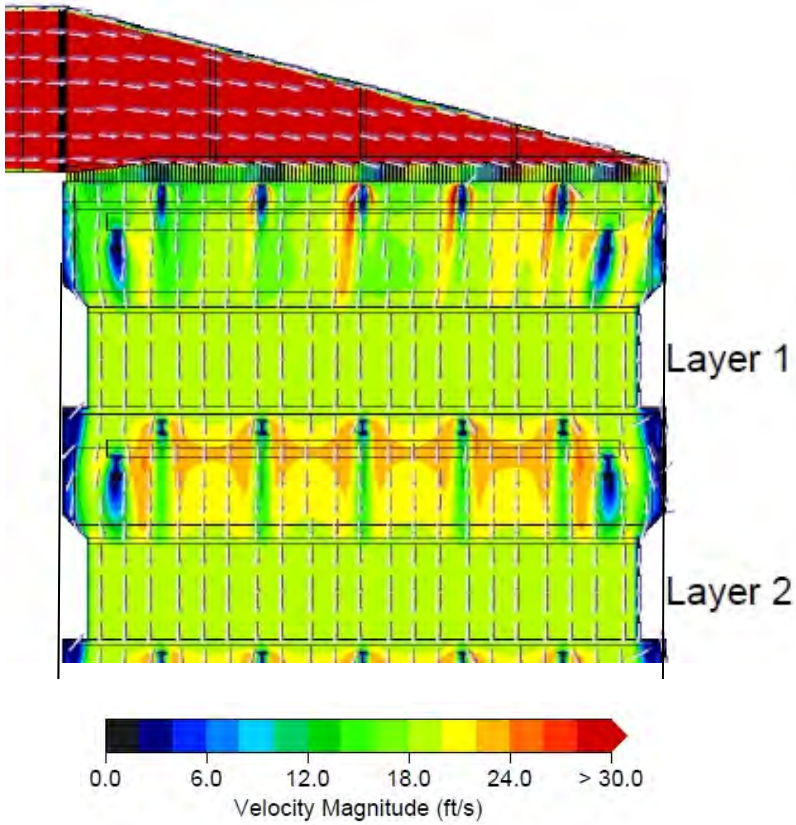
- Sloped hood uses rectifier to turn flow
  - Works well *if designed correctly*



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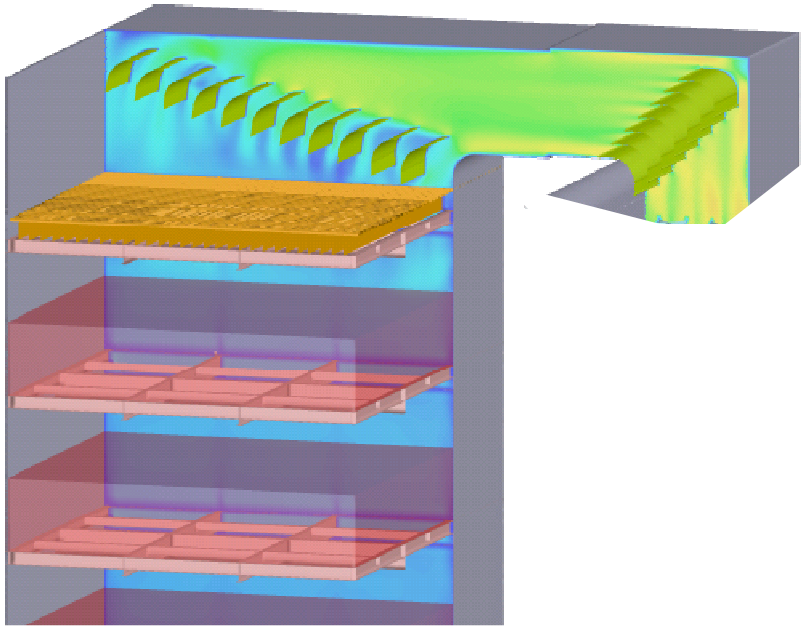

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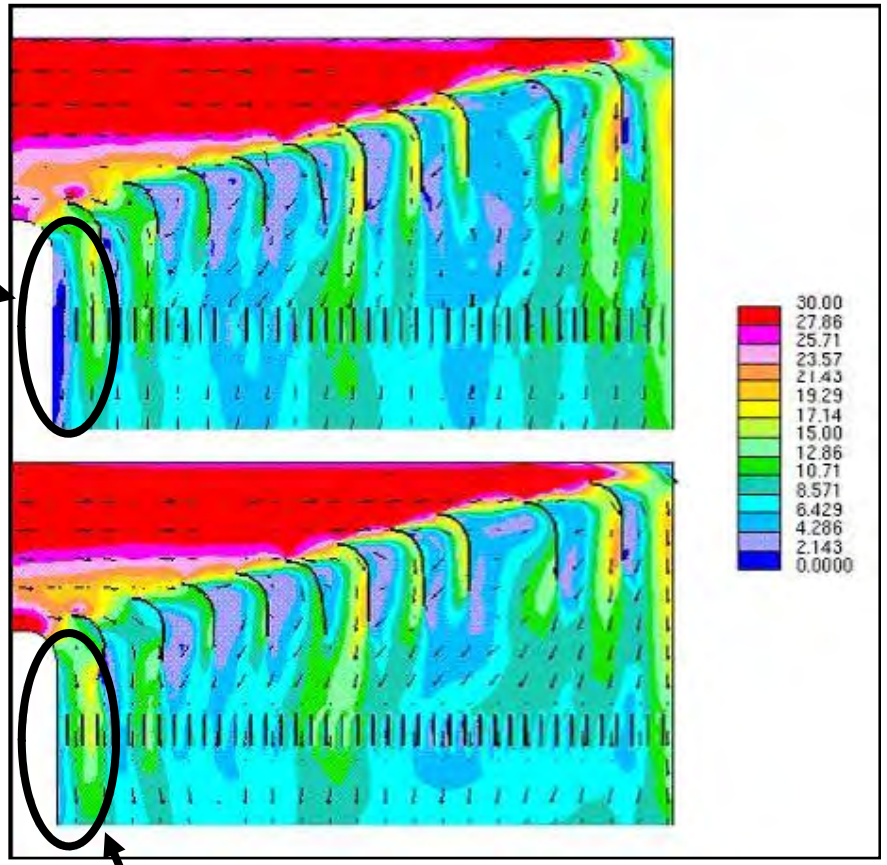

Eliminate Through CFD Modeling

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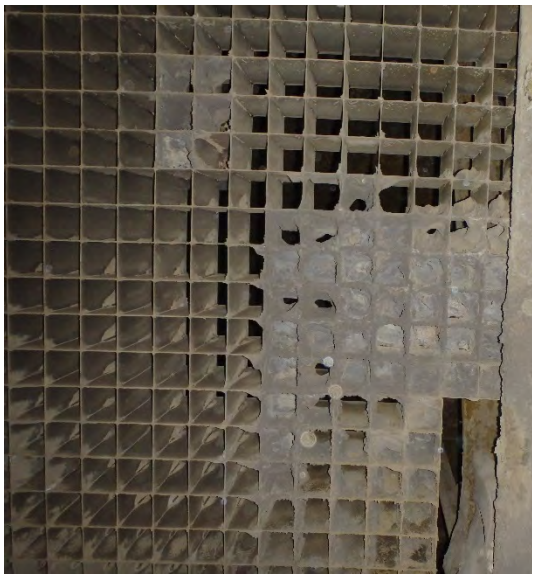
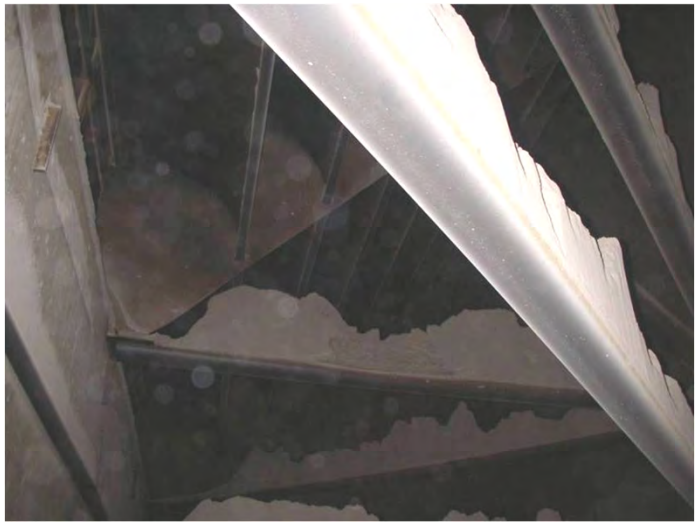
Reactor Configuration – Flow Modeling



Fly ash pile located below gusset plate due to ash shear

- Lessons Learned – Real World Buildup Sometimes Does Not Appear During Modeling
- Locations of Trusses and Gusset Plate Configurations



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Flow Distribution Device Design

- Lessons Learned – Ash Buildup on Vanes and Internal Structural Members
- Locations of Gusset Plates
- Turning Vane Design

Ash Buildup on Vanes

Affects of Ash Shear

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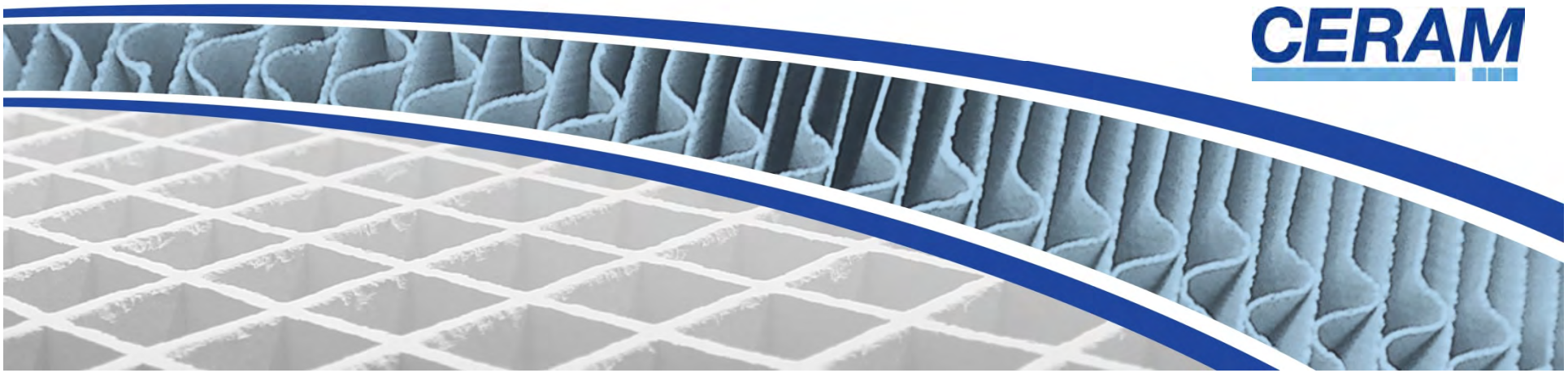
Factors Affecting Pluggage From Operations



Eliminate LPA Prior to Catalyst

Large Particle Ash (LPA)

STEAG LPA Screen

- **L**arge **P**article **A**sh Can Be Present and Should be Controlled as Part of System Design
- LPA Pluggage of Catalyst Leads to…
  - High Pressure Drops
  - Mechanical Damage
  - Reduced Performance Potential
- Effective and Durable Screen Designs are Required
  - Located With Ash Removal
  - Located at Proper Velocity
  - Simple and Advanced Designs Have Both Succeeded and Also Had Problems
- Flow Modeling and Physical Changes are Likely Necessary

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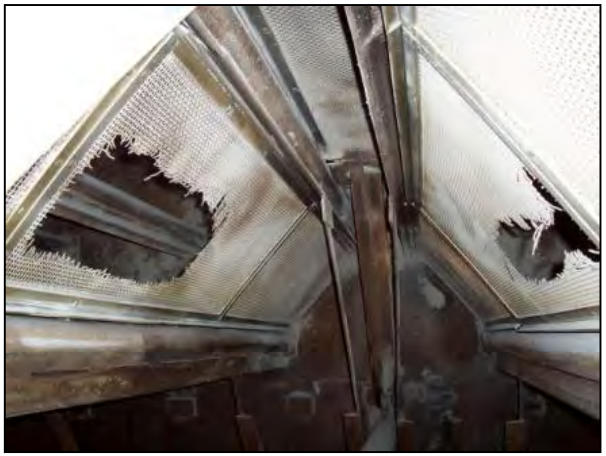
Simple & Advanced LPA Screens Can Succeed or Fail

- Proper Choices of LPA Screen Design are Site Specific
- Ensure Proper Velocity at LPA Screen
- Remove Material From Hoppers
- Cleaning Device (Sonic Horn, Rapper, etc.)

Coated & Non-Coated Screens Failed (High Velocity)

Stainless Steel Screen Failed at Fasteners (High Velocity)

Damaged LPA Screen Material



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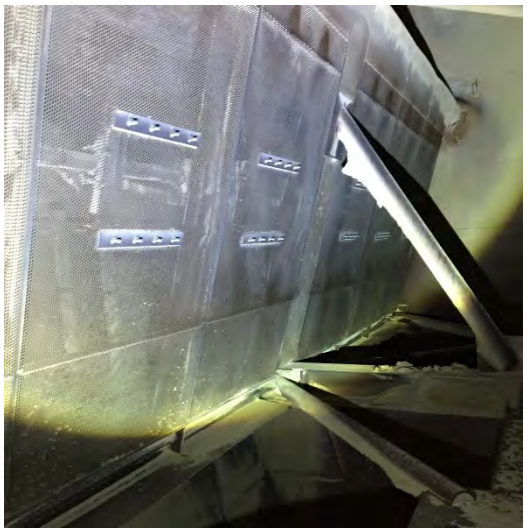
Pluggage Due to LPA

Before LPA Screen

After Install of LPA Screen



Photos courtesy of Integrated Global Services

Minimize Carbon Carryover

Reactor Accumulation of Unburned Carbon

Plate Catalyst With Accumulated Unburned Carbon

- The Control of Unburned Carbon is Important for Reliable DeNOx Operation
- All DeNOx Catalyst Has Oxidizing Properties and Will Tend to Oxidize Unburned Carbon
- Oxidized Carbon Sticks to Catalyst and Can Result in Pluggage
- Accumulation on Catalyst Increases Risk of Pluggage and Fires
- Increased Potential for Needing Offline, Out of Reactor Cleaning
- Homogeneous Honeycomb Catalyst Consists of Fully Oxidized Material
- Metal Substrates Can Lead to Increased Potential for Fires

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Pluggage Leads to Erosion Which Can Affect Any Catalyst Type

- Erosion Risk Varies as Ratio of Flow to 3rd or 4th Power
- Exposed Plate Stainless Steel Provides No Activity and Available for SO_2 to SO_3 Conversion
- Managed by Limiting Face Velocity
  - Minimize Catalyst Pluggage

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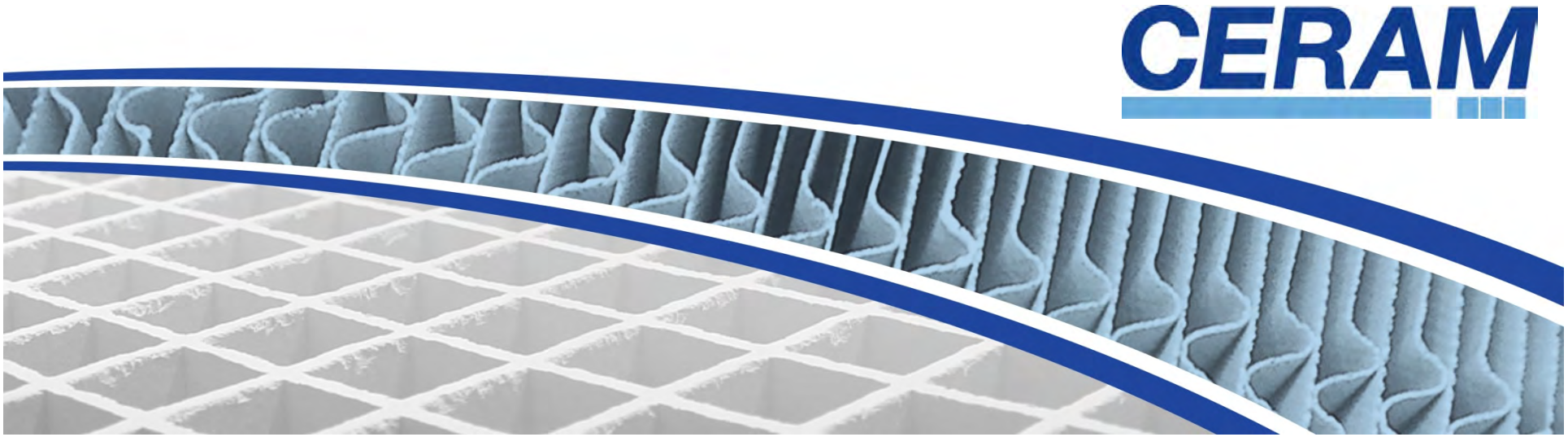
Online Cleaning Devices



Sootblowers – More O&M Cost Than Sonic Horns, But Are They Working?

Sootblower Set to Improper Pressure (Compressed Air Setting Instead of Steam Setting) Ineffective at Cleaning Catalyst

- Lessons Learned
  - Sootblowers Effective If Ash Fluidized; No Cleaning Device Effective with Poor Flow Distribution
  - Increase Frequency Based on Pressure Drop
  - Check Operation Daily

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Sonic Horns – Look Good Outside, But Are They Working?

- Lessons Learned
  - Sonic Horn Effective If Ash Fluidized; No Cleaning Device Effective with Poor Flow Distribution
  - Insulate Outside to Minimize Corrosion in Throat/Bell
  - Check Operation Daily

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Ash Sweepers

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Photo courtesy of Integrated Global Services

Ash Sweepers

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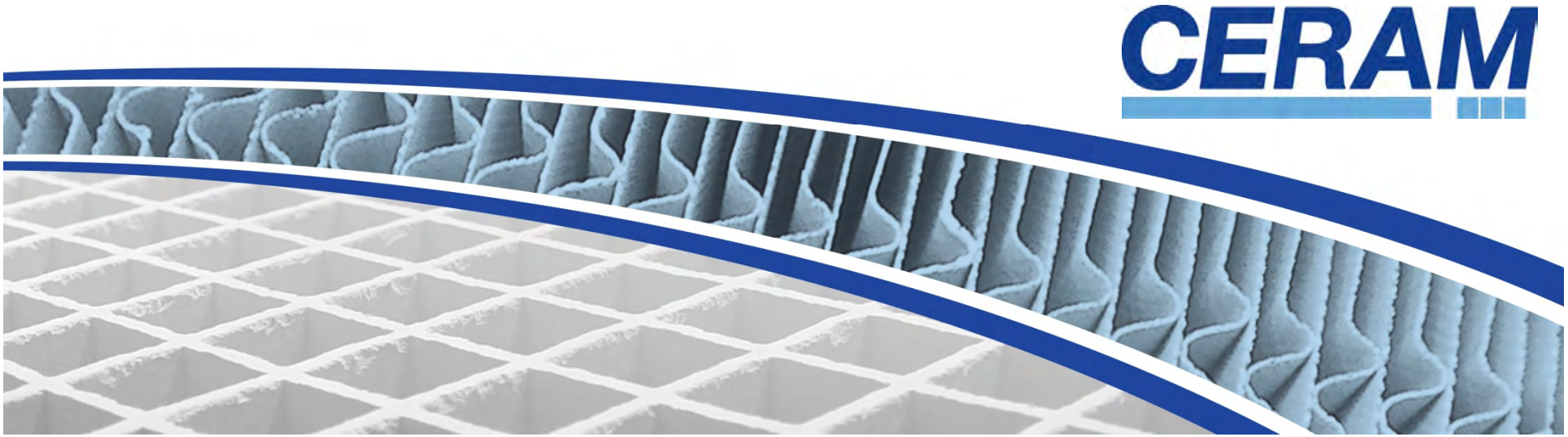
Photo courtesy of Integrated Global Services

In-situ Cleaning



Example of “Mechanical” Cleaning Not Recommended

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Vacuuming and Pneumatic Cleaning

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Vibrational Cleaning

Video courtesy of Michael Ware SCR Solutions, Inc.
& Thompson Industrial Services, LLC

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Sponge Blasting

Patent Pending ***Sponge Blasting*** *Process* utilizes polyurethane foam media to **Safely Remove Hardened Ash from the Surface and Within the Catalyst Modules.**

Before Sponge Blasting

After Sponge Blasting

Photos courtesy of Michael Ware SCR Solutions, Inc. & Thompson Industrial Services, LLC

Sponge Blasting Video

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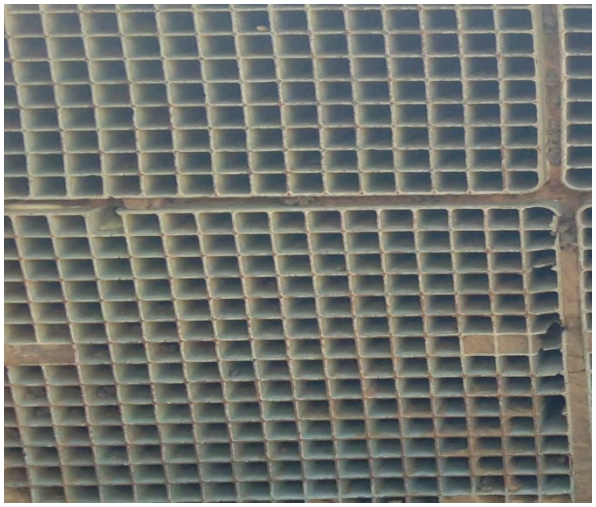
Video courtesy of Michael Ware SCR Solutions, Inc.
& Thompson Industrial Services, LLC

Sponge Blasting

BEFORE

AFTER



This combination of methods **Safely Clears the Catalyst of Potentially Harmful Contaminates that cannot be achieved by traditional methods.**

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Photos courtesy of Michael Ware SCR Solutions, Inc. & Thompson Industrial Services, LLC

Dry Ice Blasting

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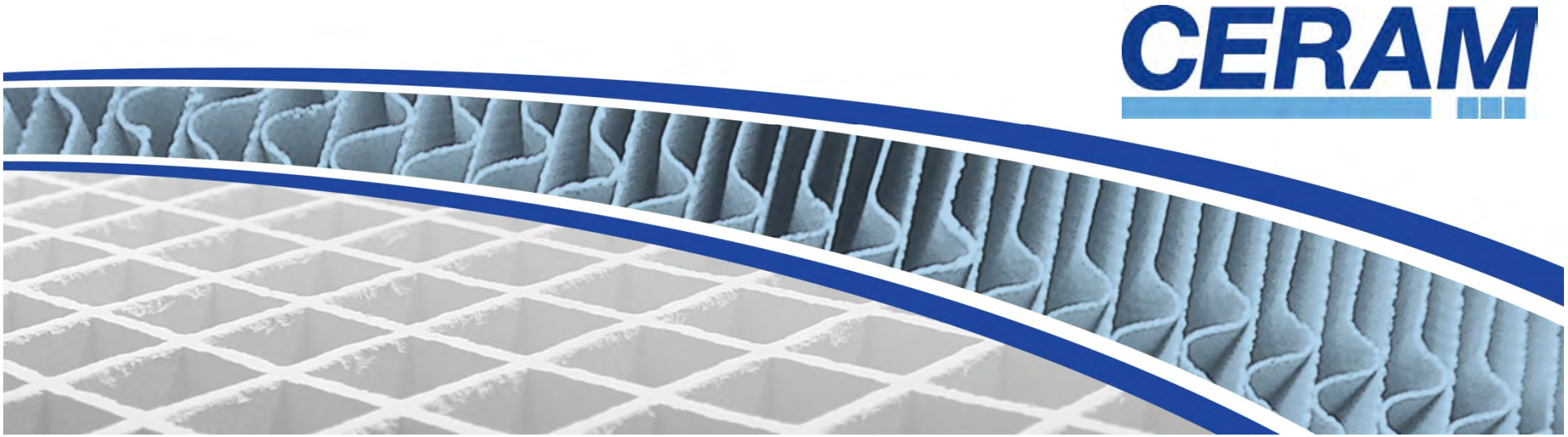
Video courtesy of STEAG SCR-Tech, Inc.

Fix “Root” Cause of Pluggage



Flow Modeling Methods

- CFD (Computational Fluid Dynamics)
- Cold Flow Scale Modeling (dust testing)
- Hot Flow Scale Modeling (real ash)
- Wind Tunnel Testing
  - To determine ash drop-out and re-entrainment aerodynamic behavior
  - Ambient or Hot Wind Tunnel

Slide Courtesy of Airflow Sciences Corporation

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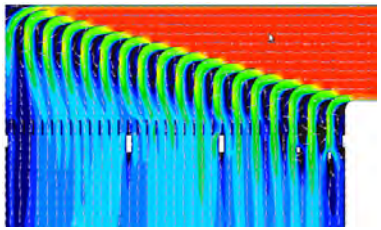
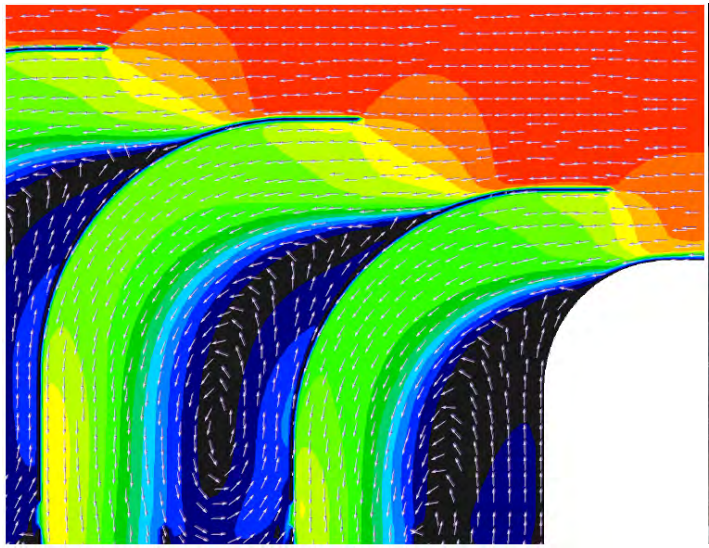
Ash Deposition – Reactor Hood Vanes

- CFD model and field observations show root cause
  - Flow separation and recirculation on vane surface
  - Not *designed correctly*
  - Occasional avalanche can cause catalyst pluggage issue
  - Hood vane redesign required

Hood vanes



Vane detail



(black = recirc zone)

Ash buildup

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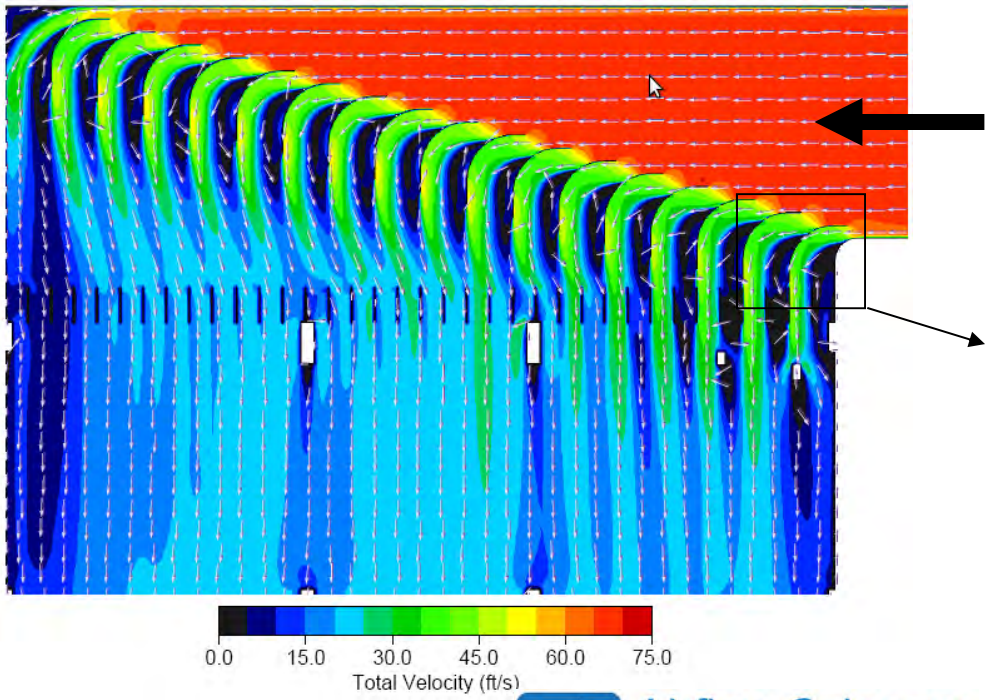
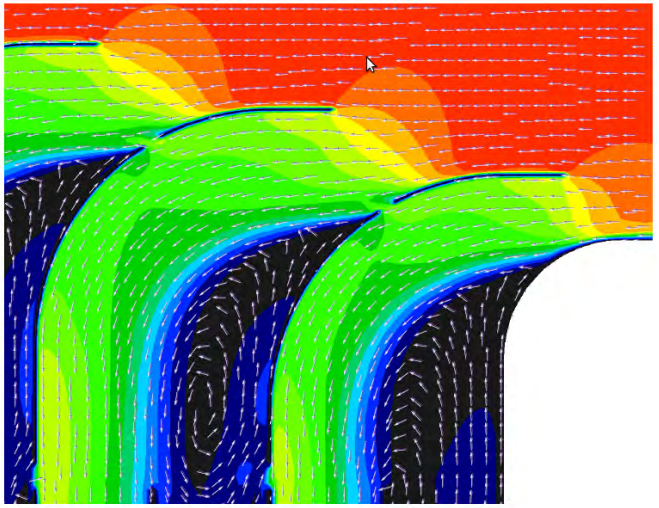
Slide Courtesy of Airflow Sciences Corporation

Ash Deposition – Reactor Hood Vanes

- CFD model used to evaluate design mods
  - Reduce ash accumulation with minimal degradation of velocity uniformity to catalyst
  - "Slots" can be cut in vanes with strategic location and



Close-up at inner corner



CEI Slide Courtesy of Airflow Sciences Corporation

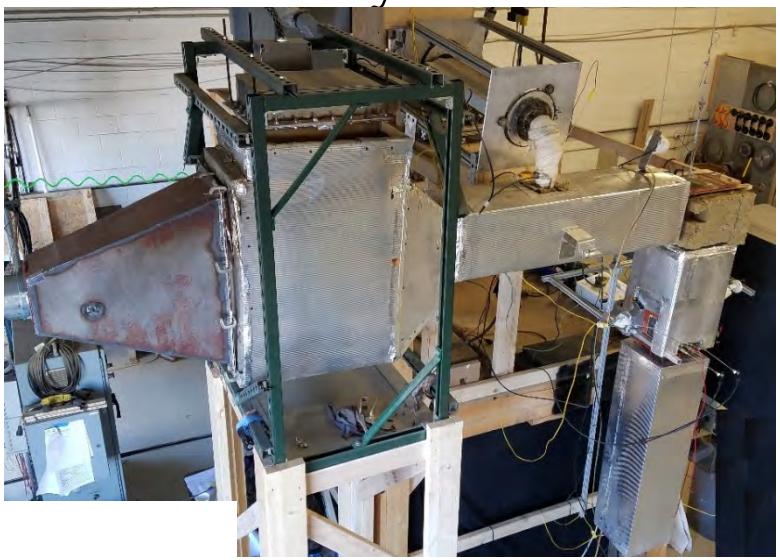
Ash Deposition – Reactor Hood Vanes

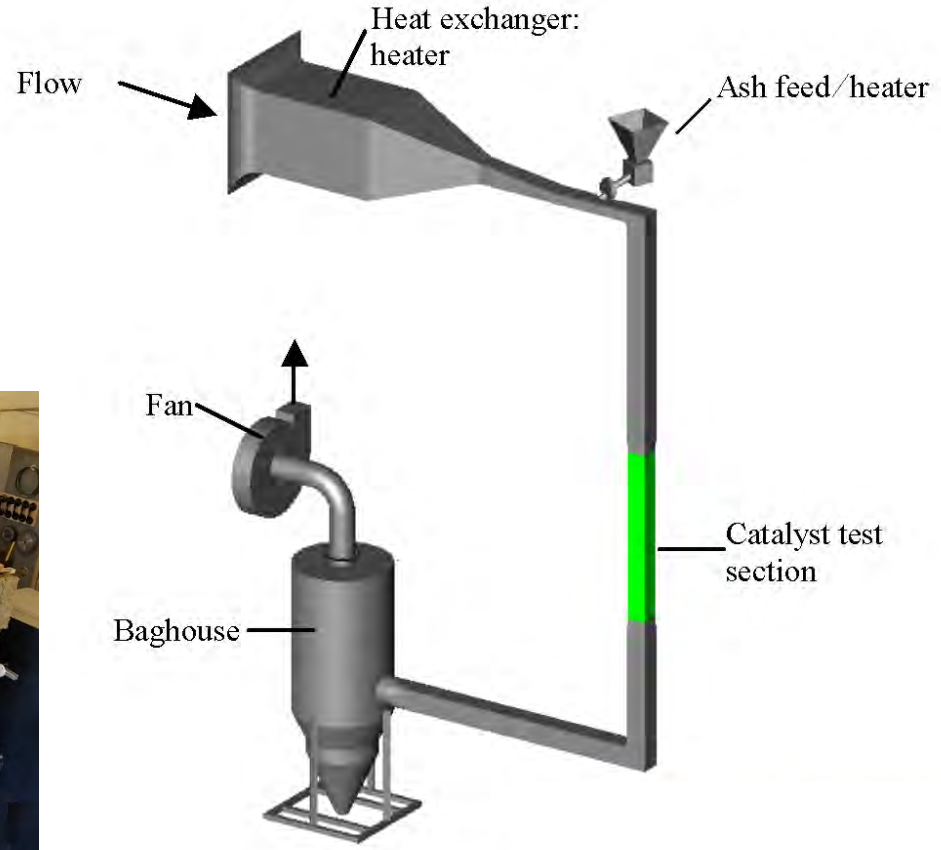
- CFD model used to evaluate design mods
  - Reduce ash accumulation with minimal degradation of velocity uniformity to catalyst
  - "Slots" cut in vanes at strategic location and size

Slide Courtesy of Airflow Sciences Corporation

Ash Deposition – Hot Flow Modeling

- Hot Flow Model
  - Testing under actual temperature conditions
  - Real ash, not laboratory dust





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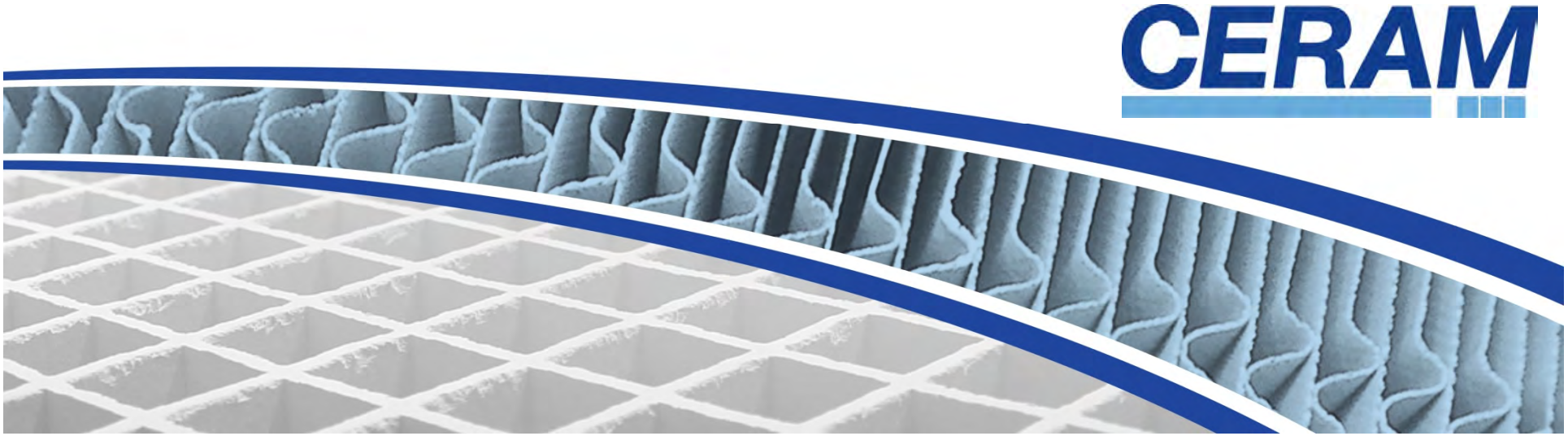
Summary



Pluggage is Minimized By…

- Pluggage is Minimized by….
  - Proper Pitch and Wall Thickness Selection
  - Proper Cover Grate Selection
  - Proper Gas Velocity in Ductwork and the Reactor (Flow Modeling)
  - Proper Boiler Operation (e.g., LOI, LPA, etc.)
    - LPA Screen Design
  - Proper Maintenance and Operation of Online Cleaning Devices
  - Proper Isolation During Outages (Avoiding Condensation if Possible)
- In-situ Cleaning Technologies
  - Vacuuming/Air Lancing; Vibrational/Sponge; Dry Ice Blasting
  - Cost Considerations
- Flow Modeling Very Effective at “Fixing” Root Cause
  - Rate of Return with Less Pressure Drop & More Surface Area (Longer Time Between Catalyst Events)

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