REINHOLD ENVIRONMENTAL Ltd.

2012 NOx-Combustion Round Table & Expo Presentation

February 13-14, 2012, in Columbus, OH / Hosted by AEP

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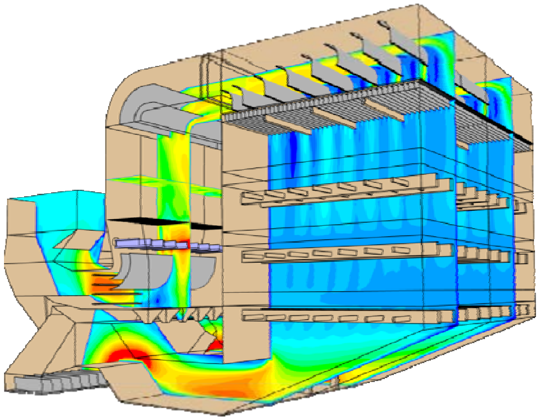

SCR Gas Flow Modeling

Presentation for

Reinhold Environmental

2012 NOx Combustion Round Table

Columbus, OH

February 14, 2012

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Overview

- SCR Flow Modeling Methods
- Pros and Cons
- Typical Objectives and Techniques
- Model Accuracy
- Flow Visualization
- Conclusions
- Q&A

The Need for Flow Modeling…

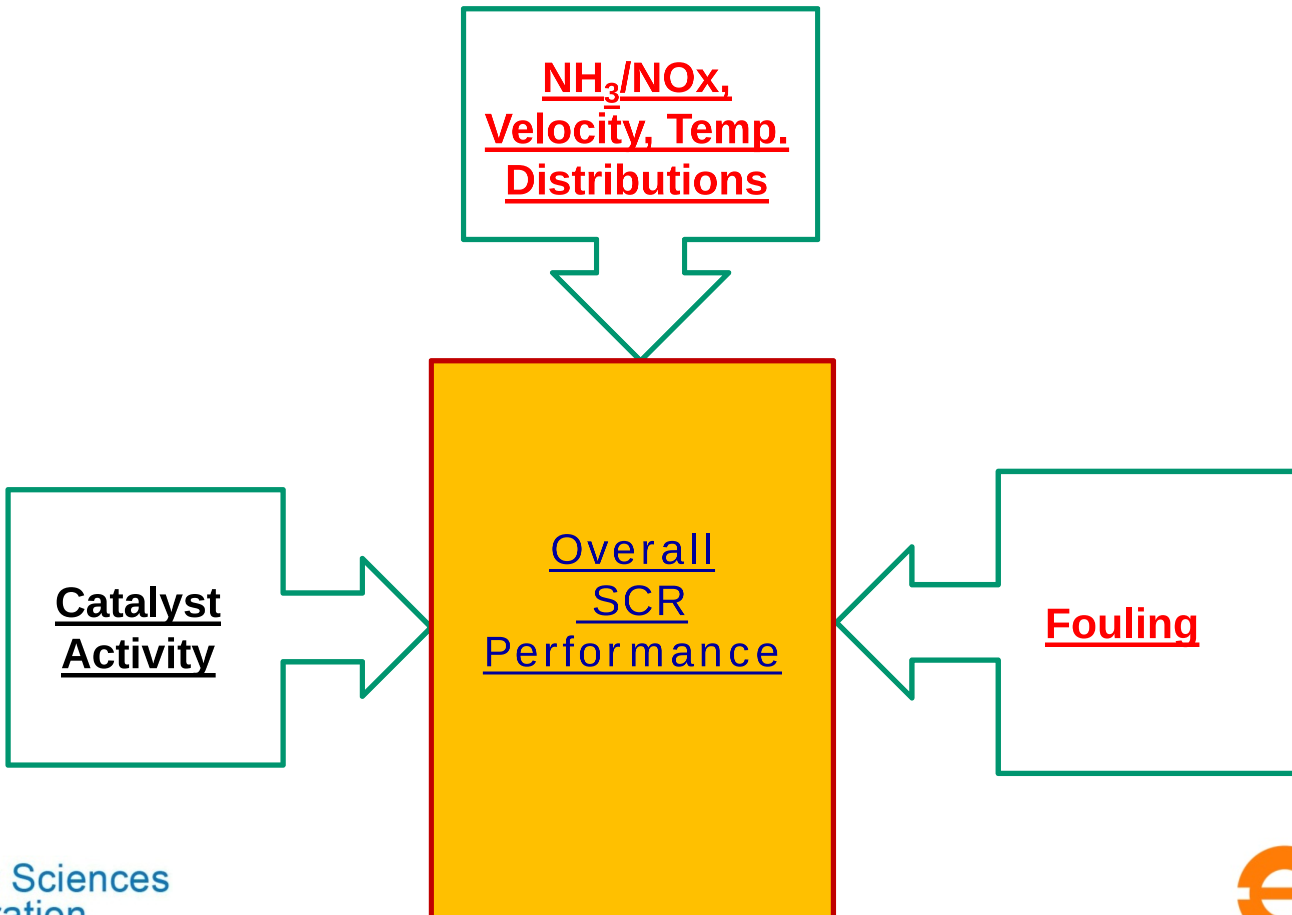
- Performance Optimization
  - Flow Distribution…Ash Distribution
  - NH_3/NOx Mixing/Distribution
  - Thermal Mixing
- O&M
  - Pressure Drop
  - Ash Accumulation
  - LPA Screen Capture
  - Erosion

The Need for Flow Modeling…

- Trial and Error without modeling can work but…
  - Fixes can be costly
  - Results not as expected
  - New problems could develop
- Modeling can save time and $$ in the long run
- Can directly impact Catalyst Management
  - Poor distribution and/or ash buildup in reactor can significantly alter catalyst management strategies

The Need for Flow Modeling…

CATALYST ACTIVITY IS ONLY ONE PIECE OF THE PUZZLE !



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SCR Modeling…Physical & CFD

- Physical Modeling
  - Utilizes a scale model (plexiglas)
  - Geometrically identical to full-scale
  - Ambient air as test gas
  - Flow visualization
  - Ash deposition
  - Two-fluid mixing
  - Allows for accurate simulations of complex phenomena

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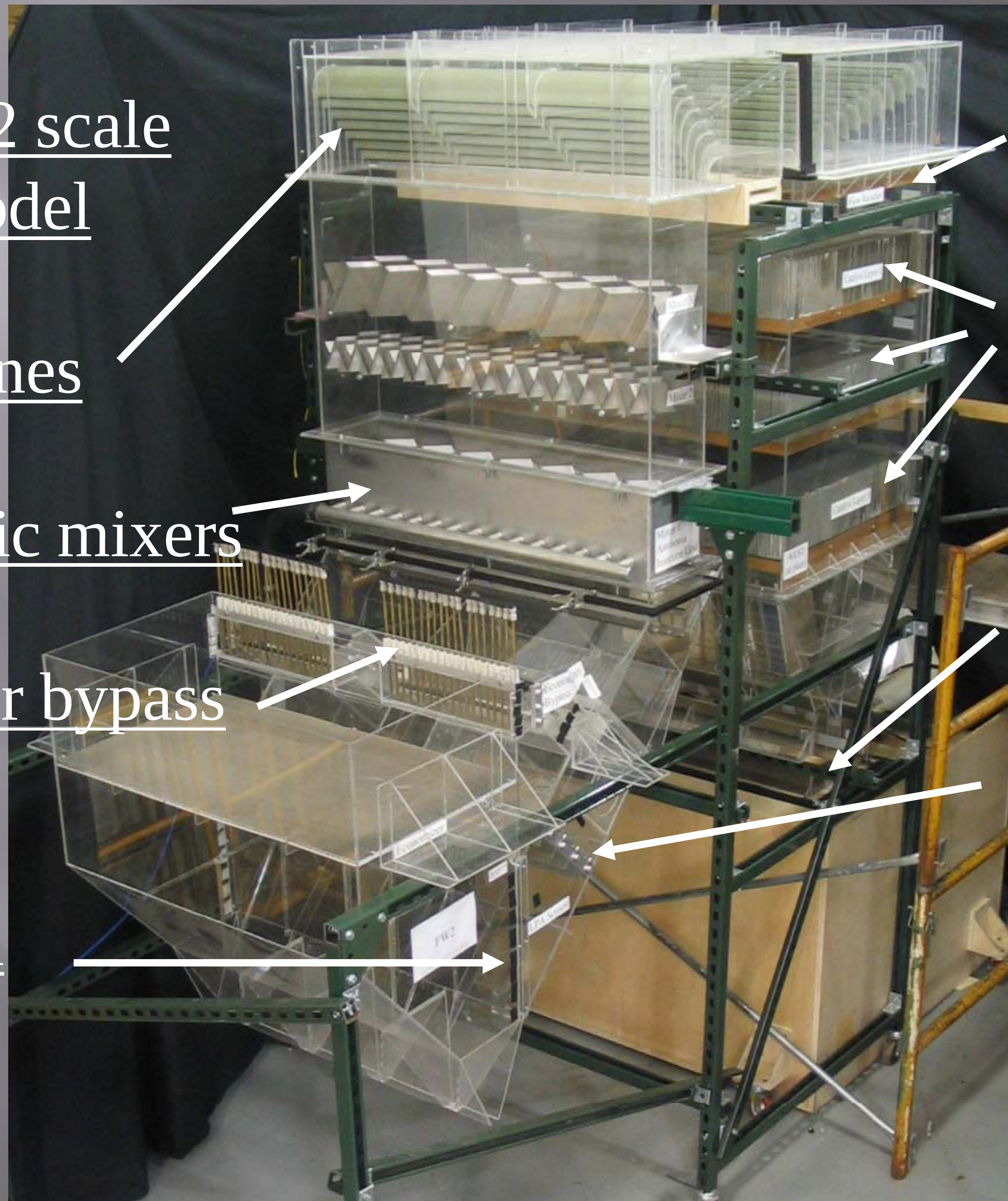
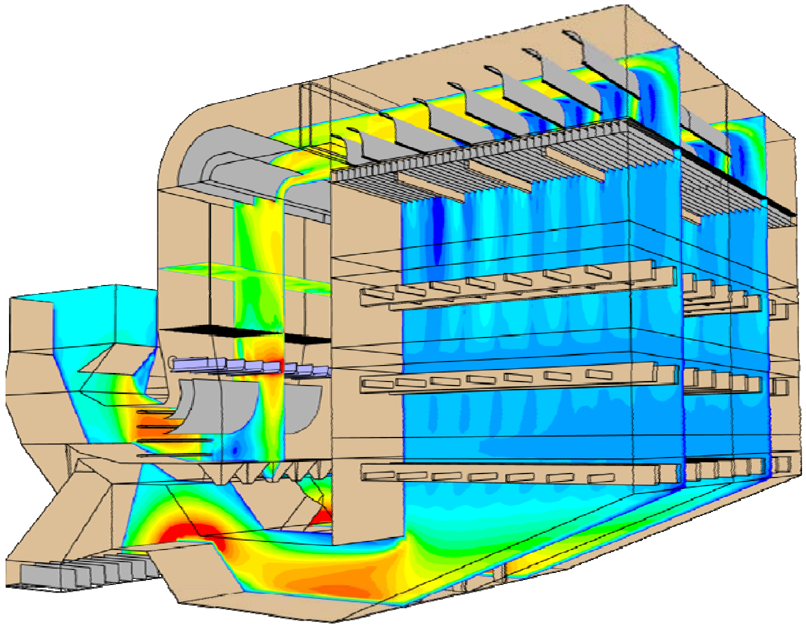
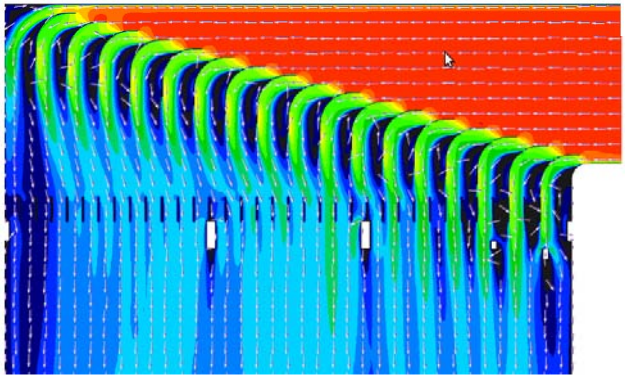

Typical 1/12 scale physical model
Turning vanes
AIG w/static mixers
Economizer bypass
LPA screen
Rectifier
Catalyst layers
Air heater
Dampers

SCR Modeling…Physical & CFD

- Computational Fluid Dynamics (CFD)
  - o Numerical simulation
  - o All predictions performed with high-speed computers
  - o Full-scale conditions
  - o Complex geometries can be modeled
  - o Detailed outputs





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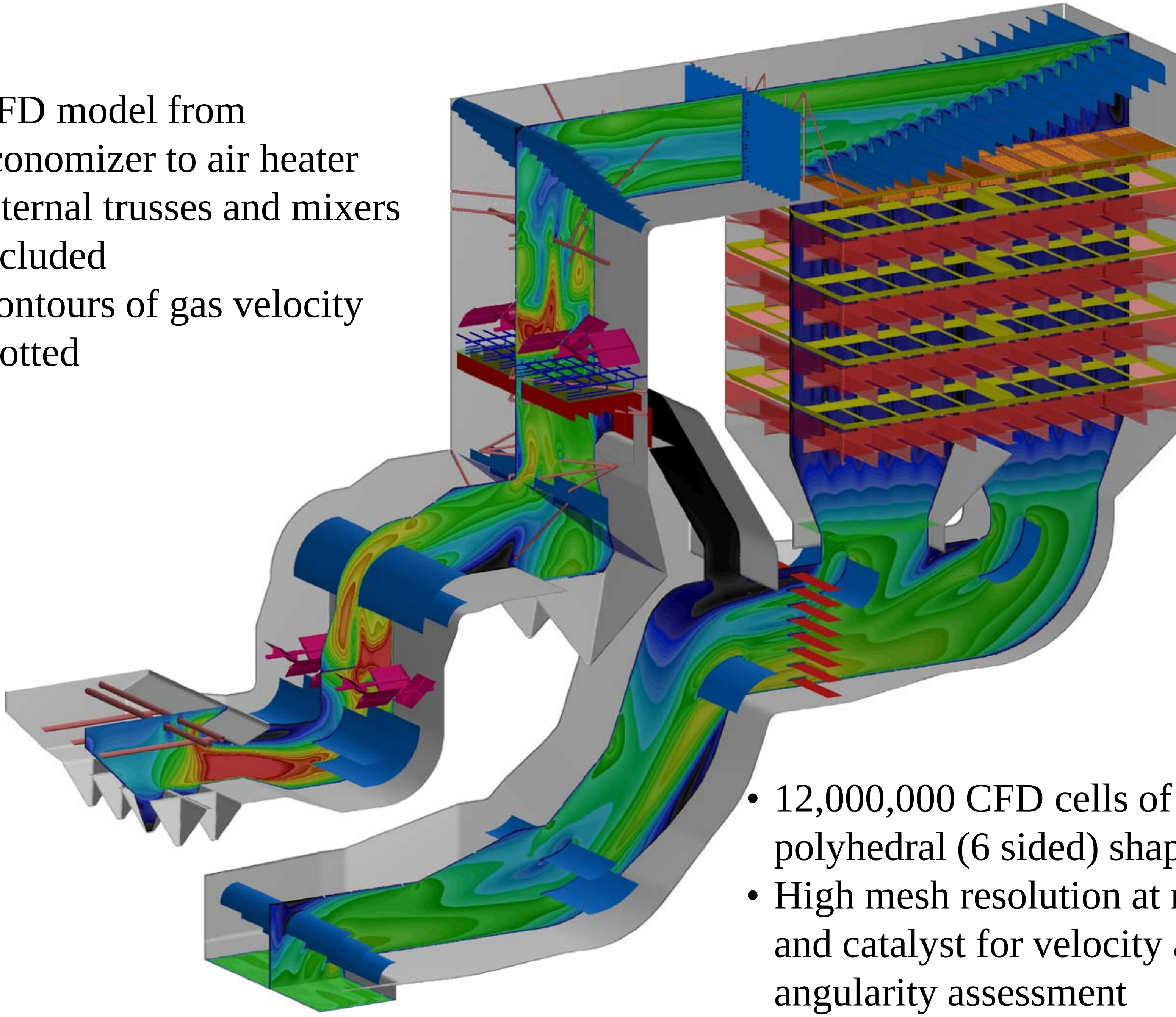
- CFD model from economizer to air heater
- Internal trusses and mixers included
- Contours of gas velocity plotted



- 12,000,000 CFD cells of primarily polyhedral (6 sided) shape
- High mesh resolution at rectifier and catalyst for velocity and angularity assessment

Physical & CFD…Pros and Cons

- Physical Modeling - Pros
  - Proven Technique
  - Complex flow simulations and solutions
  - NH_3 distribution modeling
  - Ash dropout / re-entrainment
  - Visualization
- Physical Modeling - Cons
  - Iterations can be time consuming
  - Thermal mixing difficult
  - Measurement points limited

Physical & CFD…Pros and Cons

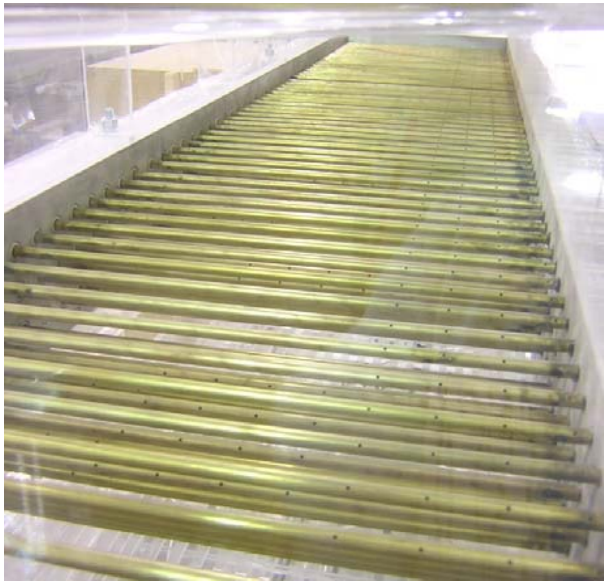
- CFD Modeling - Pros
  - Iterations can be done quickly*
  - Detailed representation of flow and mixing patterns
  - “Infinite” number of test points
  - Output can be very informative
  - Can track particulate in flight
- CFD Modeling - Cons
  - * Large and complex models can be time consuming
  - Particulate dropout/re-entrainment modeling limited
  - NH_3 distribution modeling requires detailed mesh

Typical Modeling Objectives

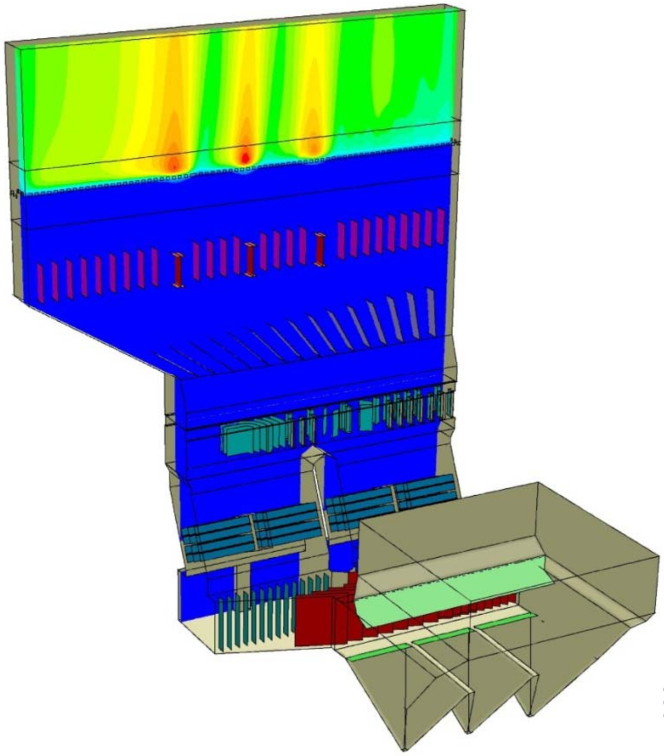
- NH3/NOx Distribution
- Velocity Distribution
  - AIG Inlet
  - Catalyst Inlet/Outlet
  - Angularity at Catalyst
- Thermal Mixing
- Minimize Ash Buildup on Horizontal Surfaces
- Minimize Pressure Drop
- Optimize LPA Capture

SCR Ammonia Injection

- Physical model
  - o Tracer gas injection
  - o Measure concentration gradient at catalyst

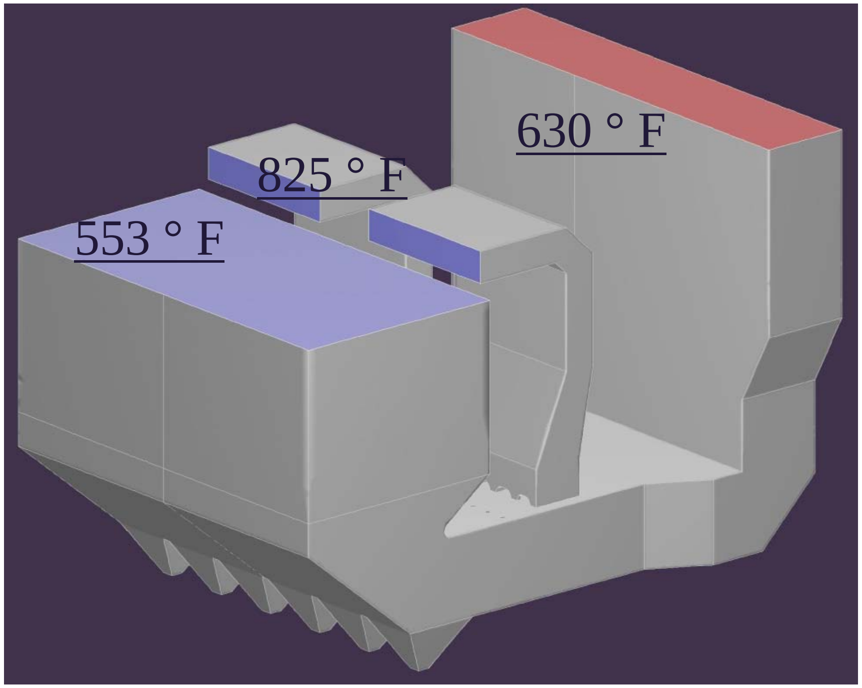


- CFD model
  - o Gaseous or liquid NH3 injection
  - o Track species through ducts to the catalyst inlet



SCR Thermal Mixing

- Economizer gas bypass used to boost SCR inlet gas temperature under low load operation
- Extract hot gas at econ inlet
- Inject into cooler econ outlet stream
- Need to mix the flows smoothly to obtain uniform temperature at catalyst with minimum DP
- Sounds simple enough, but there are many options and competing design elements



Without mixer, ΔT = ±83 °F

With mixer, ΔT = ±15 °F

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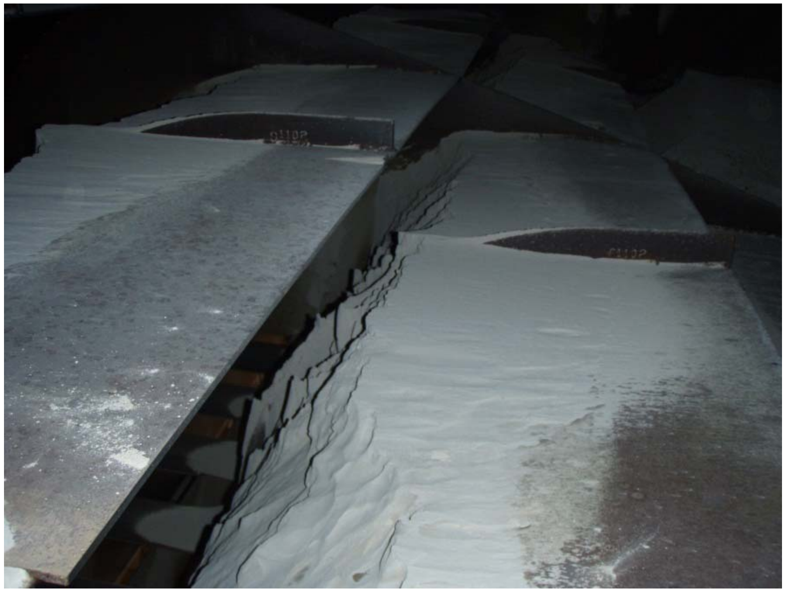
Ash Deposition

- Flues
- Turning vanes
- Catalyst



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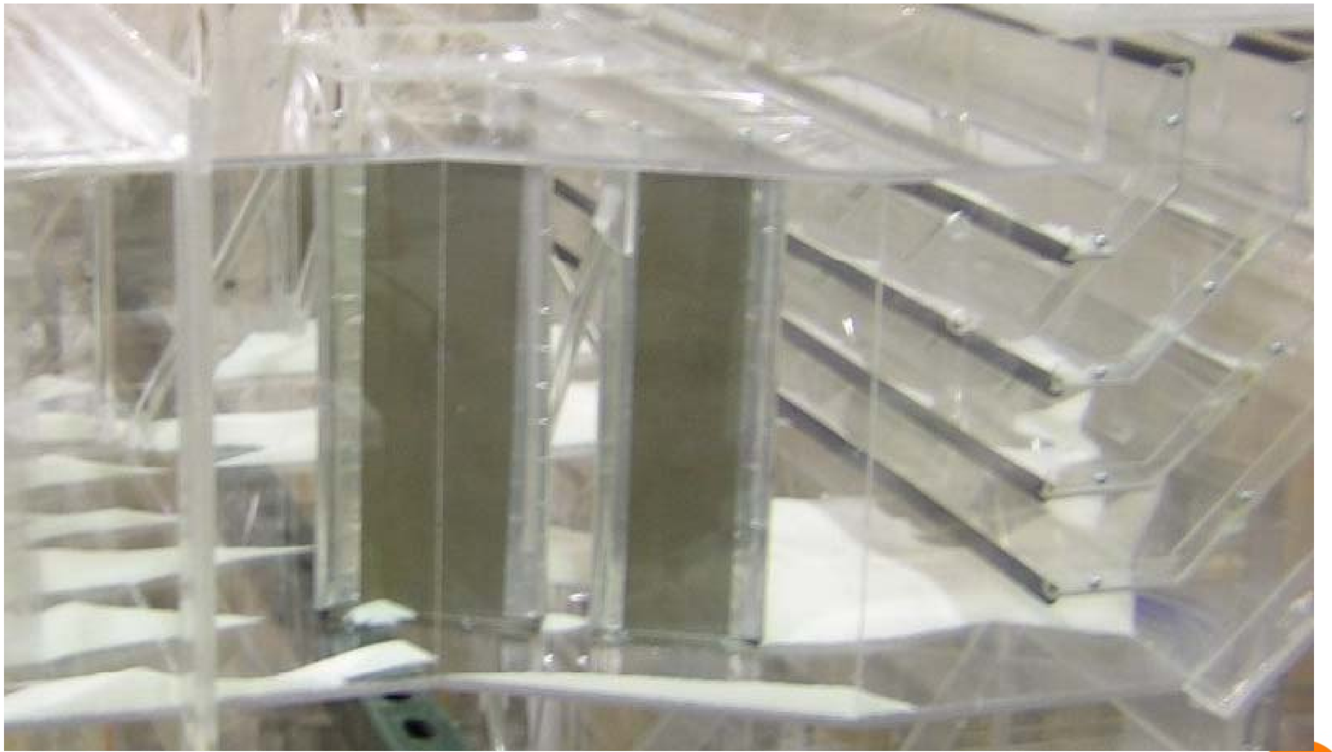
Ash Deposition – Model Testing

- Drop out
- Re-entrainment



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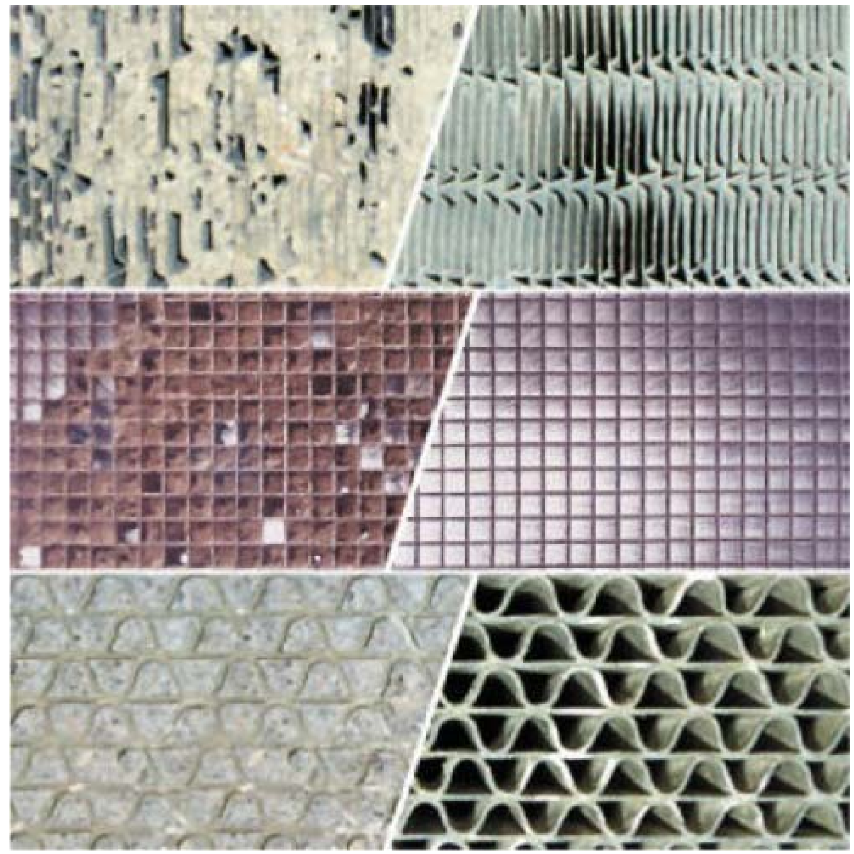
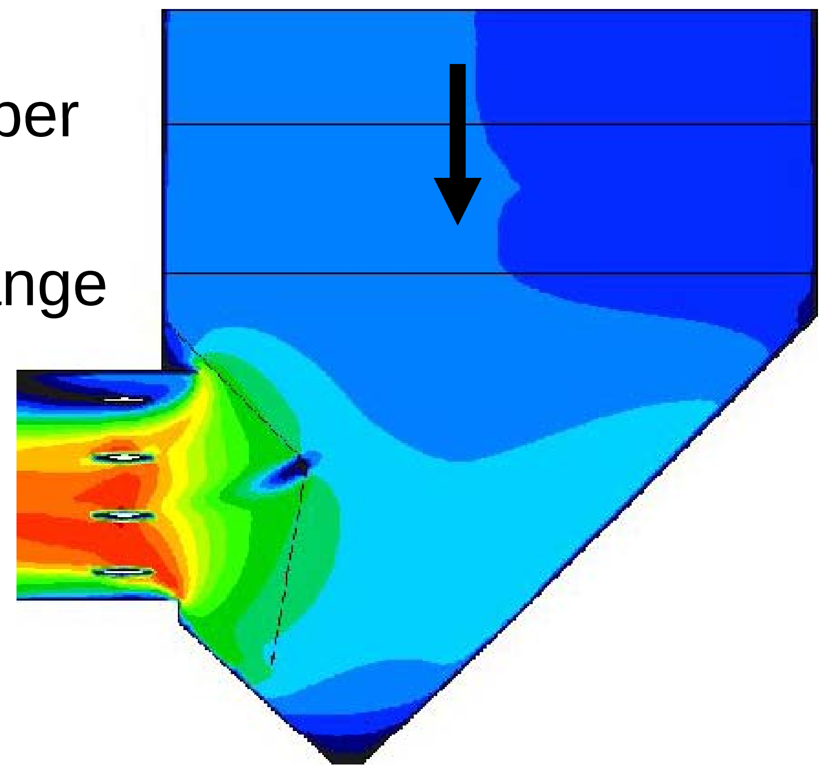
SCR Large Particle Ash

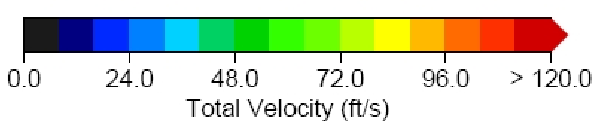
- SCR system design needs to effectively capture all LPA prior to the catalyst



LPA Modeling via CFD

- Examine gas flow patterns and peak velocities through the system
- Track ash particles in flight through the ductwork and hopper regions
- Use model to evaluate wide range of design options





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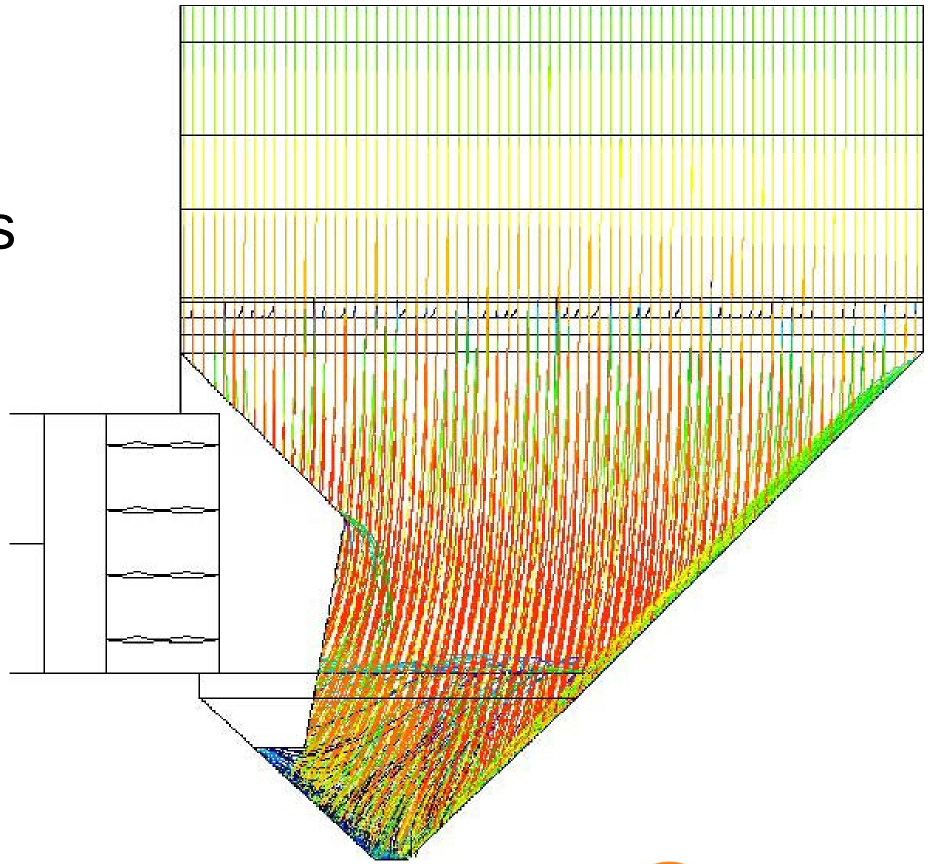
LPA Tracking

- Examine numerous particle sizes (3-7mm typical)
- Calculate particle paths
  - Rebound off surfaces
  - Impact on screen
  - Capture in hopper



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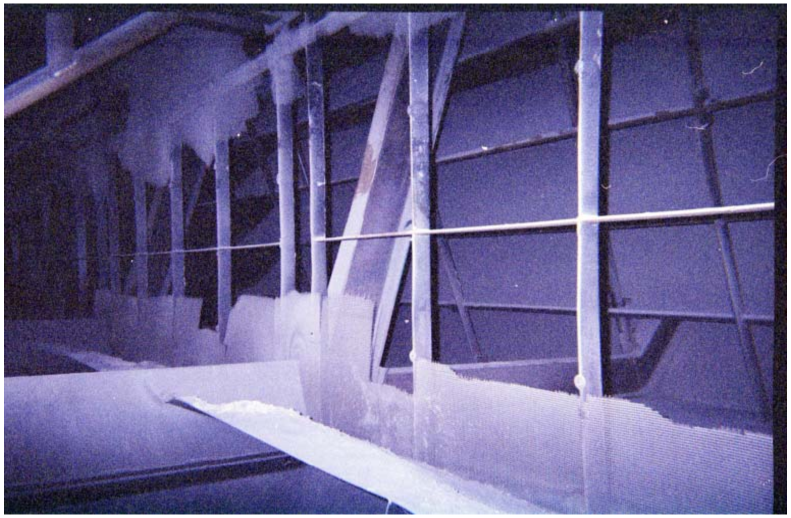
LPA Modeling and Design – Key Points

- Ash capture statistics in hoppers
- LPA screen pluggage potential
- LPA screen erosion
- Pressure drop



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Model Accuracy

- Do physical and CFD models match field test data?
  - Field data is unfortunately limited
  - Tend to go by industry experience and whether catalyst performance goals are met
- Do CFD and physical models match each other?
  - For velocity and pressure drop predictions, correlation is quite good
  - For NH3 injection correlation has improved steadily over time
    - Better CFD meshes (= mesh quality and level of detail)
    - Faster computers (= larger CFD meshes)

Model Comparisons – Velocity

Velocity at catalyst inlet (% RMS)				
Case	**Load**	**Physical**	**CFD**	**Model Date**
1	MCR	14.6	14.3	Jan-2007
1	70	13.5	14.3	Jan-2007
1	40	7.1	14.5	Jan-2007
2	Full	9.6	8.2	Oct-2007
3	100	10.7	5.8	Oct-2008
3	50	10.4	5.9	Oct-2008
3	40	8.6	5.7	Oct-2008
4	Full	10.2	11.4	Apr-2009
5	Full	9.5	9.3	Jul-2009
5	Mid	9	10.6	Jul-2009
5	Low	7.9	7.5	Jul-2009
6	100	7.9	7.2	Feb-2010
6	75	7.6	6.8	Feb-2010
6	37	7	6.5	Feb-2010

Model Comparisons – Pressure Drop

DP (Inches of water, economizer to air heater)				
Case	**Load**	**Physical**	**CFD**	**Model Date**
1	MCR	4.2	5.1	Jan-2007
1	70	1.9	2.3	Jan-2007
1	40	1.3	1.4	Jan-2007
2	Full	6.9	7.3	Apr-2009
3	Full	9.6	10.1	Jul-2009
3	Mid	4.9	4.7	Jul-2009
3	Low	2.4	2.3	Jul-2009
4	100	5.6	5.8	Feb-2010
4	75	2.7	2.9	Feb-2010
4	37	1.3	1.3	Feb-2010

Model Comparisons – NH_3 Distribution

NH3 at catalyst (% RMS)				
Case	Load	Physical	CFD	Model Date
1	MCR	2	5.1	Jan-2007
1	70	2.1	5.1	Jan-2007
1	40	8.6	9.5	Jan-2007
2	Full	3.1	5	Oct-2007
3	100	1.4	3.3	Oct-2008
4	Low	3.8	3.8	Jul-2009
5	100	2.2	3.1	Feb-2010
5	75	2.2	3.3	Feb-2010
5	37	2.4	3.4	Feb-2010

Flow Visualization

- Physical models – smoke flow, string tufts, dust injection/re-entrainment
- CFD models –animations of gas streamlines and particle pathlines

Flow Visualization - Physical

- Video – Smoke flow

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Flow Visualization - CFD

- Video 1 – Streamline tracking

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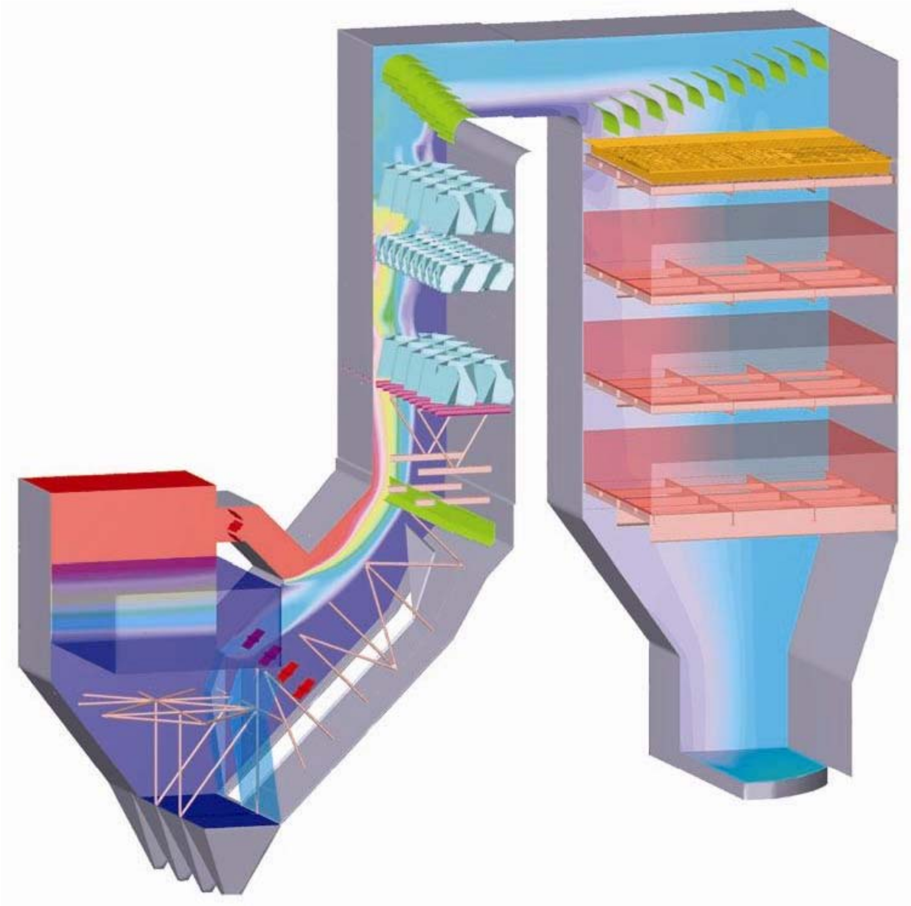
Flow Visualization - CFD

- Video 2 – SCR Fly Through



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Conclusions

- Performance of SCR Systems relies heavily on flow conditions
- Analysis and design tools include physical and CFD flow modeling
- Both tools have their strengths, and can wisely be used to provide significant improvements and extend the life of catalyst

Q&A

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