Ammonia Mixing Issues and Lessons Learned

2017 NOx-Combustion-CCR Round Table
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Agenda

- Intro
- Coal Fired SCR
- Gas Turbine SCR
- Videos
- Summary

- Audience participation encouraged

From Webster's Dictionary

Mix (verb):

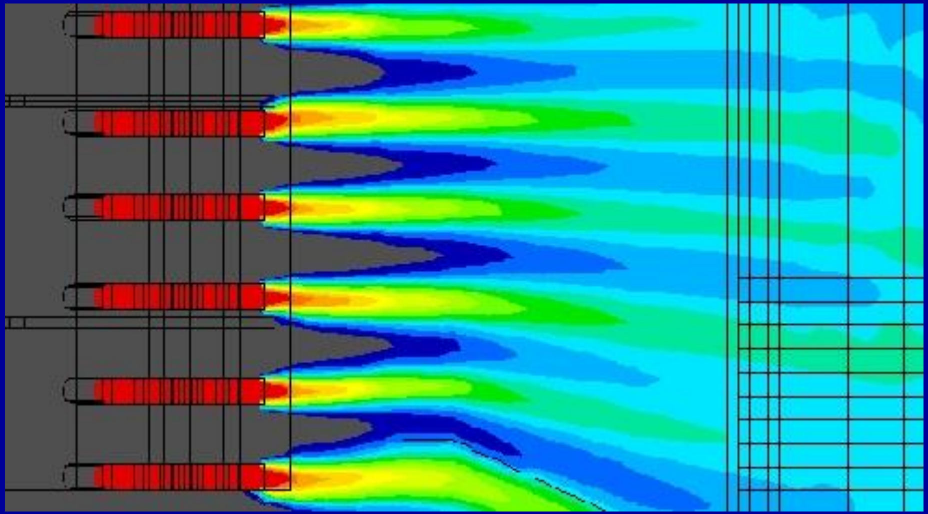
(1) : to combine or blend into one mass
(2) : to combine with another
(3) : to bring into close association
(4) : to form by mixing components
(5) : to confuse -- often used with *up*

What Do You Mix for SCRs?

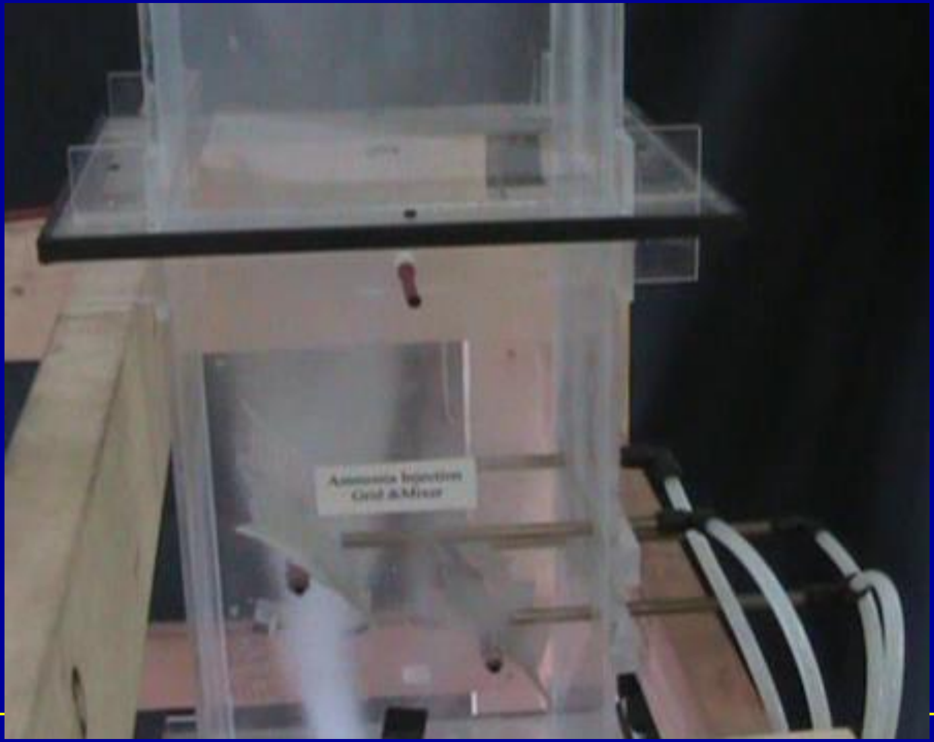
- Ammonia
- NOx
- (Ammonia-to-NOx ratio)
- Temperature

- Sorbents (ACI, DSI)

How Do You Mix?

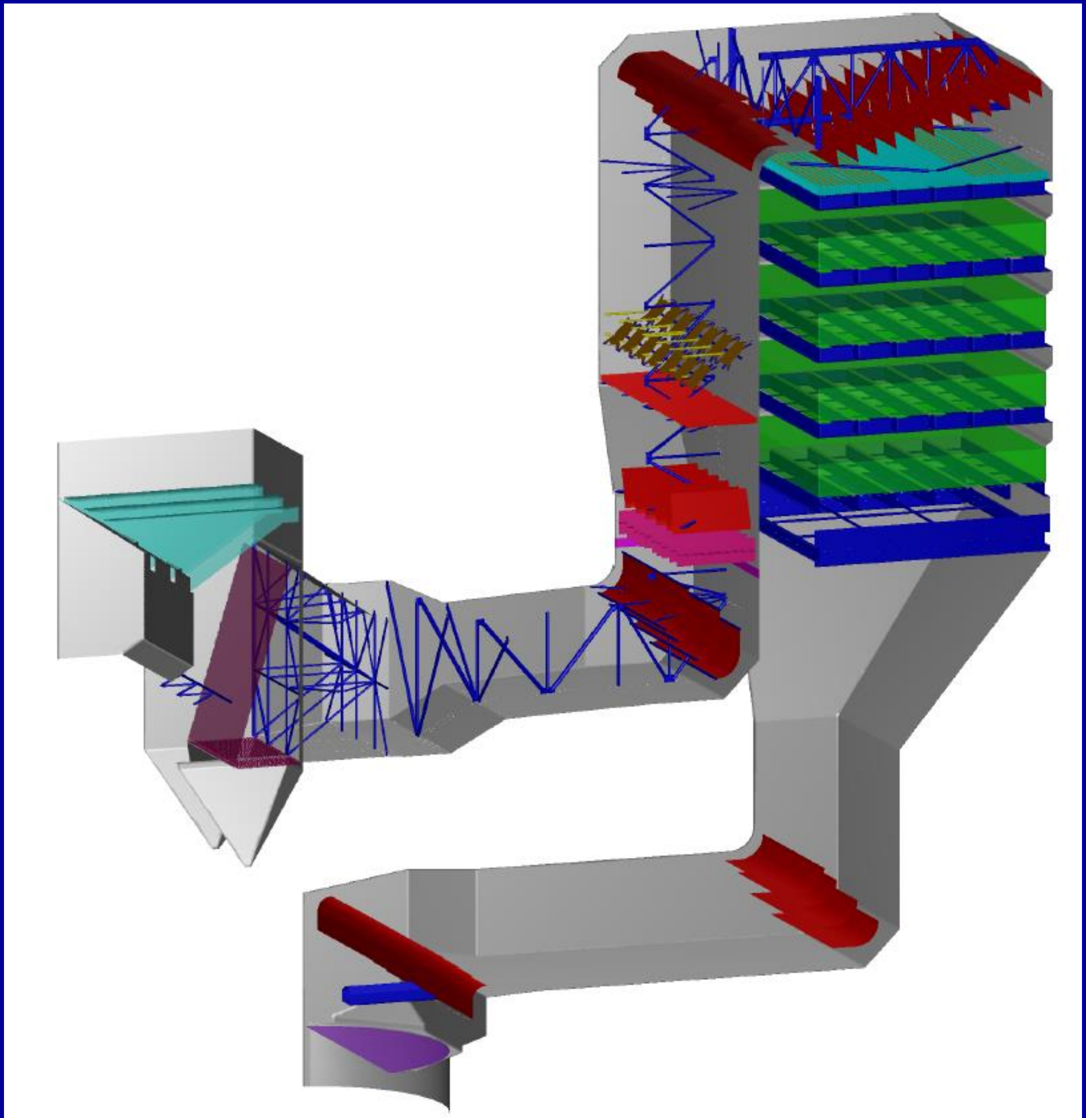


- Control the flow streams at the merger location
  - Multi-point injection
  - Layered injection
  - Diffusion + turbulence
- Churn up the flow after the merger
  - Induce high turbulence
  - Create shear forces
  - Generate swirl or vortices



Where do you mix?

- Coal Fired SCR
  - NOx, temperature –
    - upstream AIG
    - “Premixer”
  - NH3 – at or after AIG



Where do you mix?

- Gas Turbine SCR
  - NOx – uniform?
  - Temperature
    - Upstream CO catalyst
  - NH_3 – at or after AIG

Coal Fired SCR

- Typical performance goals compete with each other
  - Uniform ammonia-to-NOx ratio
  - Uniform velocity at AIG and catalyst
  - Vertical flow entering catalyst
  - Uniform temperature at catalyst
  - Capture LPA with screen/baffles
  - Minimize pressure loss
  - Minimize erosion potential
  - Minimze pluggage potential

Ammonia-to-NOx Ratio

- Ammonia-to-NOx ratio at the catalyst inlet plane should be "uniform"
- Allows optimal NOx reduction with minimum ammonia slip
- Typical goal is %RMS < 5% or

  deviation within +/-5% of mean
- Can be highly influence by velocity patterns

NOx Stratification

- NOx is not necessarily uniform at the boiler exit; it is a function of
  - Boiler design
  - Burner air flow balance
  - Coal pipe balance
  - Mills out-of-service
- Solutions
  - Mix the NOx prior to the NH3 injection – “Pre-mixer”
  - Mix the NOx and the NH3
  - Tune the NH3 to the NOx profile
    - Consistency over load range important

Ammonia Injection

- Two basic strategies are used for ammonia injection in SCRs
  - Dense grid of injection pipes
  - Coarse grid of injection pipes with mixers

Dense Grid Ammonia Injection

- Many injection lances with multiple nozzles per lance
  - Depending on SCR size, could have 50-100 lances per reactor inlet duct
  - Typically 6-10 nozzles per lance
  - Hundreds of discrete injection points
- Lances grouped into zones for tuning
- Often no mixer or only a “local” mixer

Dense Grid AIG Benefits

- More tunable for maximum NOx reduction
  - Is this true?
  - More levers does mean more complexity
- No negative influence on velocity or flyash distribution at catalyst
- Lower pressure drop

Dense Grid AIG Issues

- Requires very good velocity profile at AIG location
- Pluggage of nozzles
- Tuning not as predictable as sometimes envisioned
  - Velocity distribution issues
  - Unequal flow per nozzle
  - Low resolution of reactor outlet sample grid
- Valve issues over time

- What has the audience experienced?

Coarse Grid Ammonia Injection

- Fewer injection lances compared to dense grid by factor of 5-10
  - Depending on SCR size, could have 5, 10, 20 lances per reactor
  - Some systems have just 1 injection point per lance
  - Others have multiple nozzles per lance (2 to 10)
- Lances located immediately upstream of a static mixer
- Often multiple stages of static mixers

Coarse Grid AIG Benefits

- Fewer nozzles and larger openings less prone to pluggage
- Mixing and high turbulence reduces sensitivity of gradients
  - Does not need as much tuning?
  - More consistent performance over the load range?

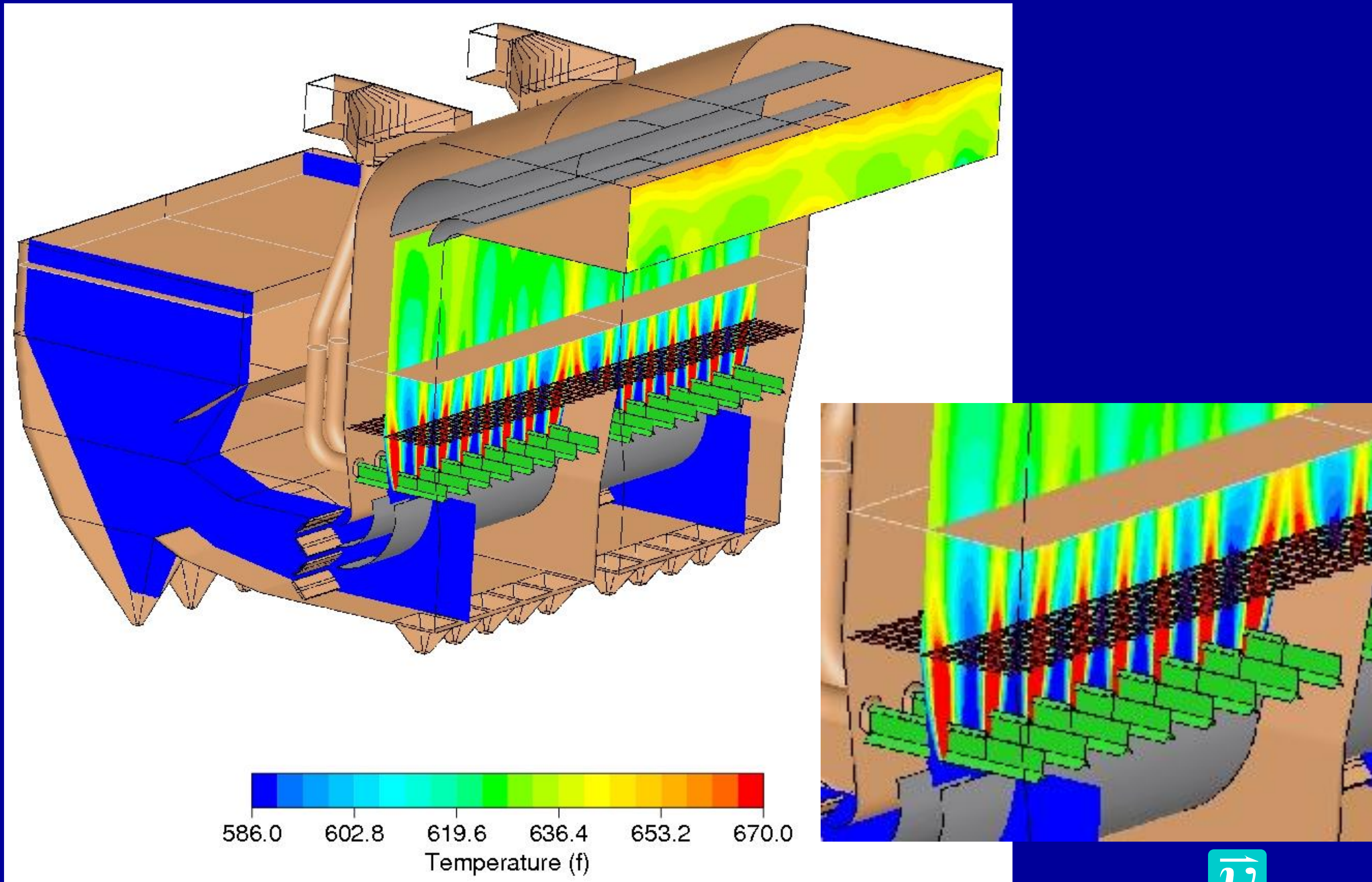
Coarse Grid AIG Issues

- Tuning not as straight-forward due to purposeful creation of turbulence
- Duct wall and internal structure erosion
- Higher pressure loss
- Ash accumulation on mixers

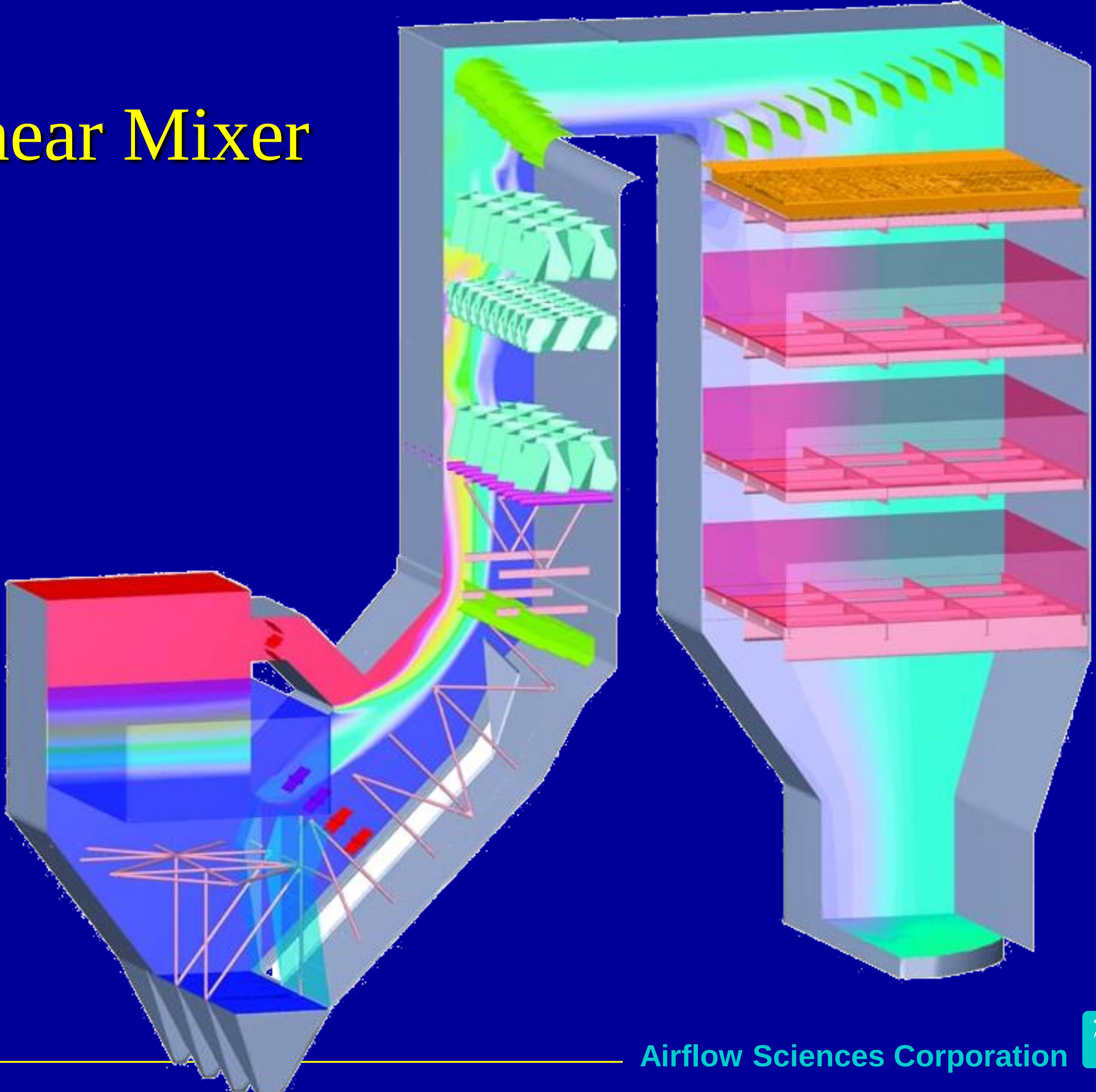
- What has the audience experienced?

Shear Mixer

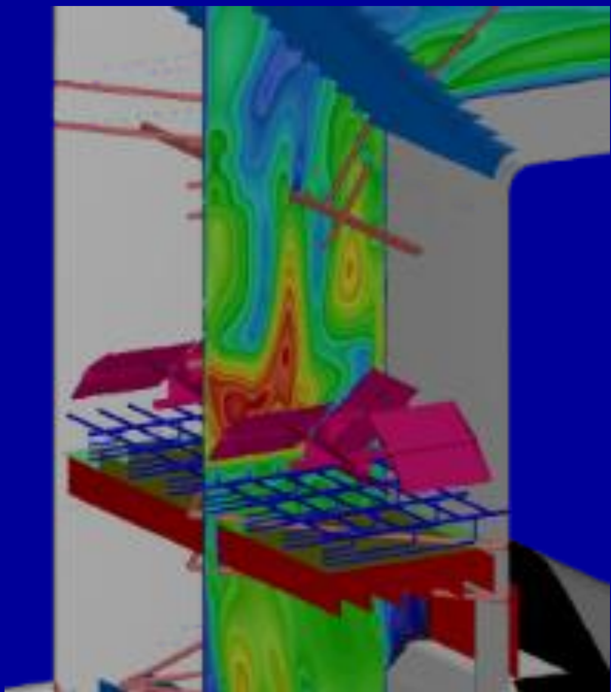
Shear Mixer

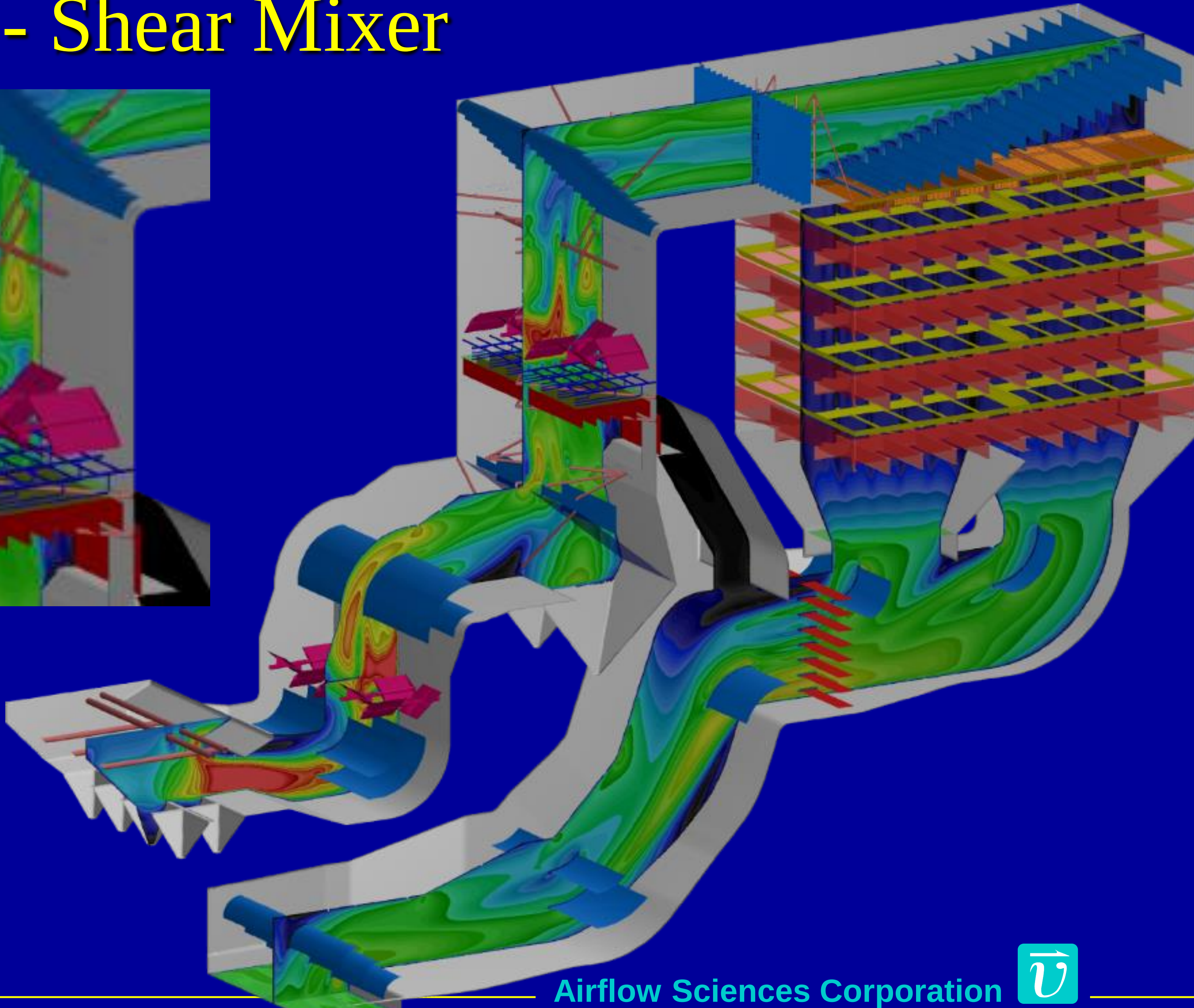


Shear Mixer

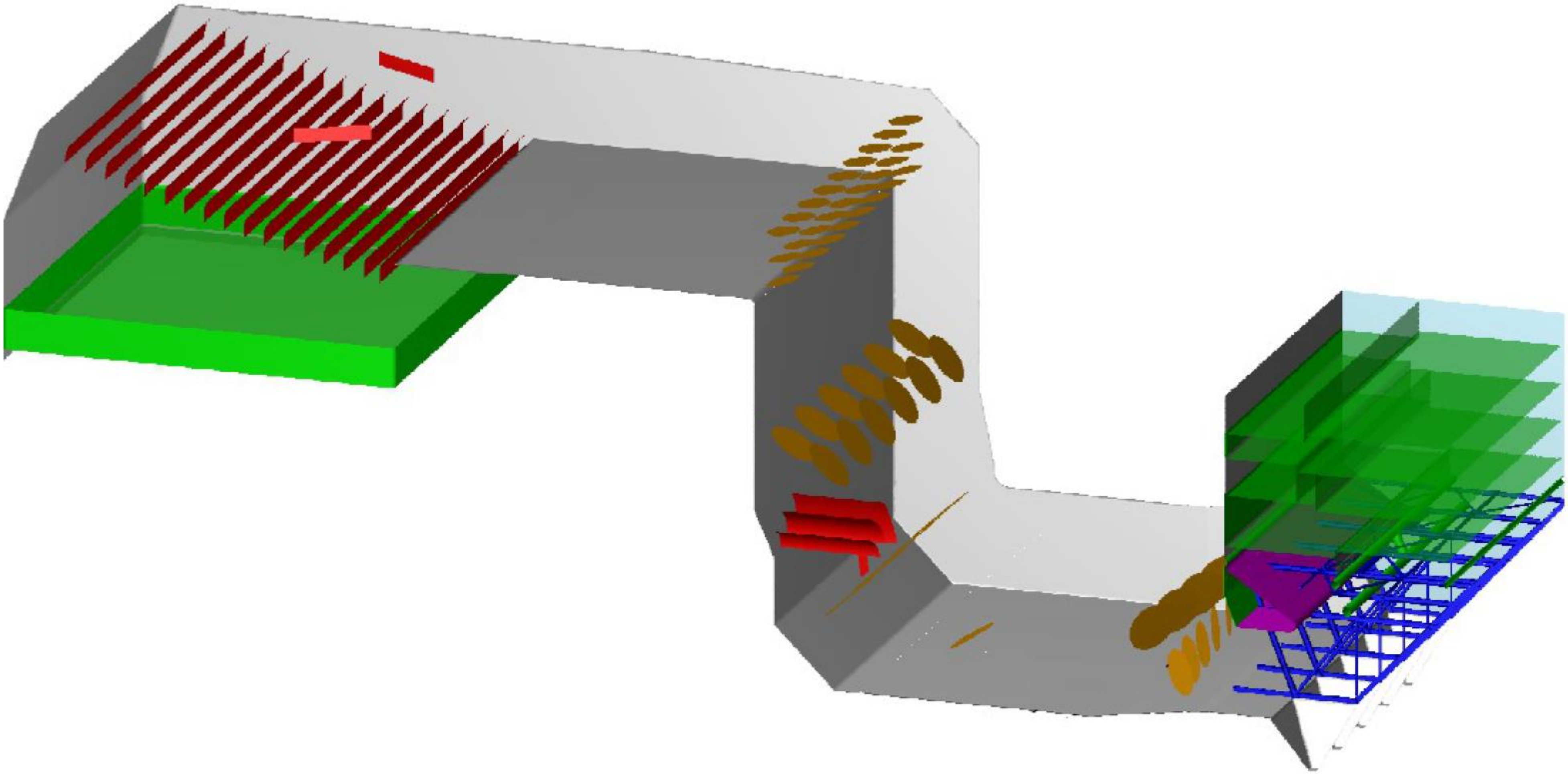


Swirl - Shear Mixer

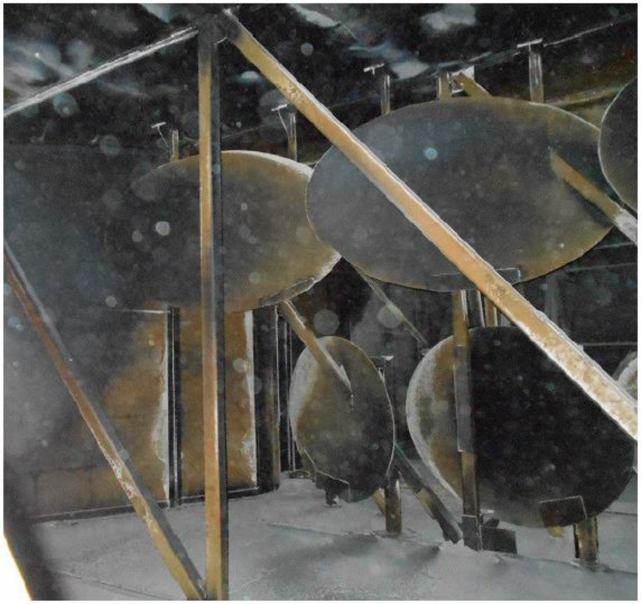




Vortex Mixer

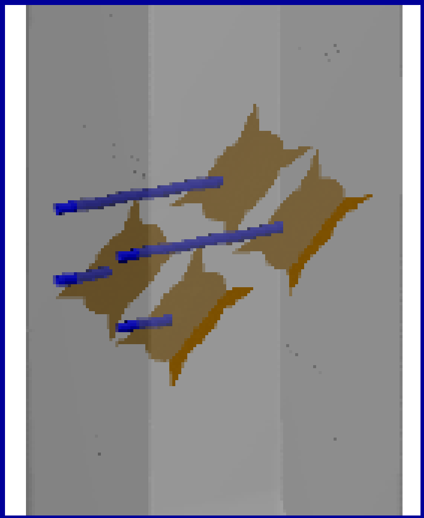


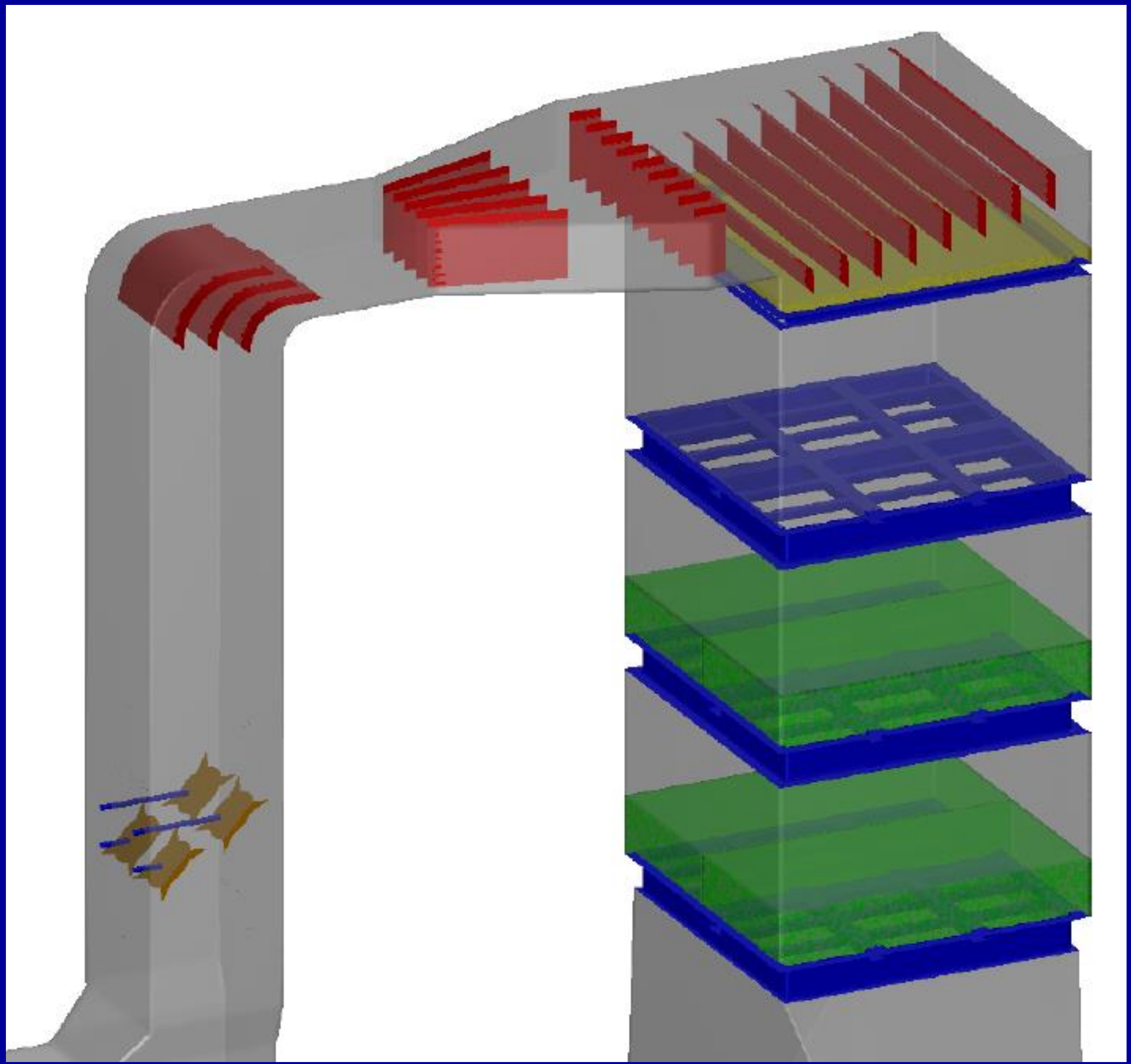
Vortex Mixer



Economizer outlet,
compilation photo of mixer plates
(flow is into page)

Vortex Mixer





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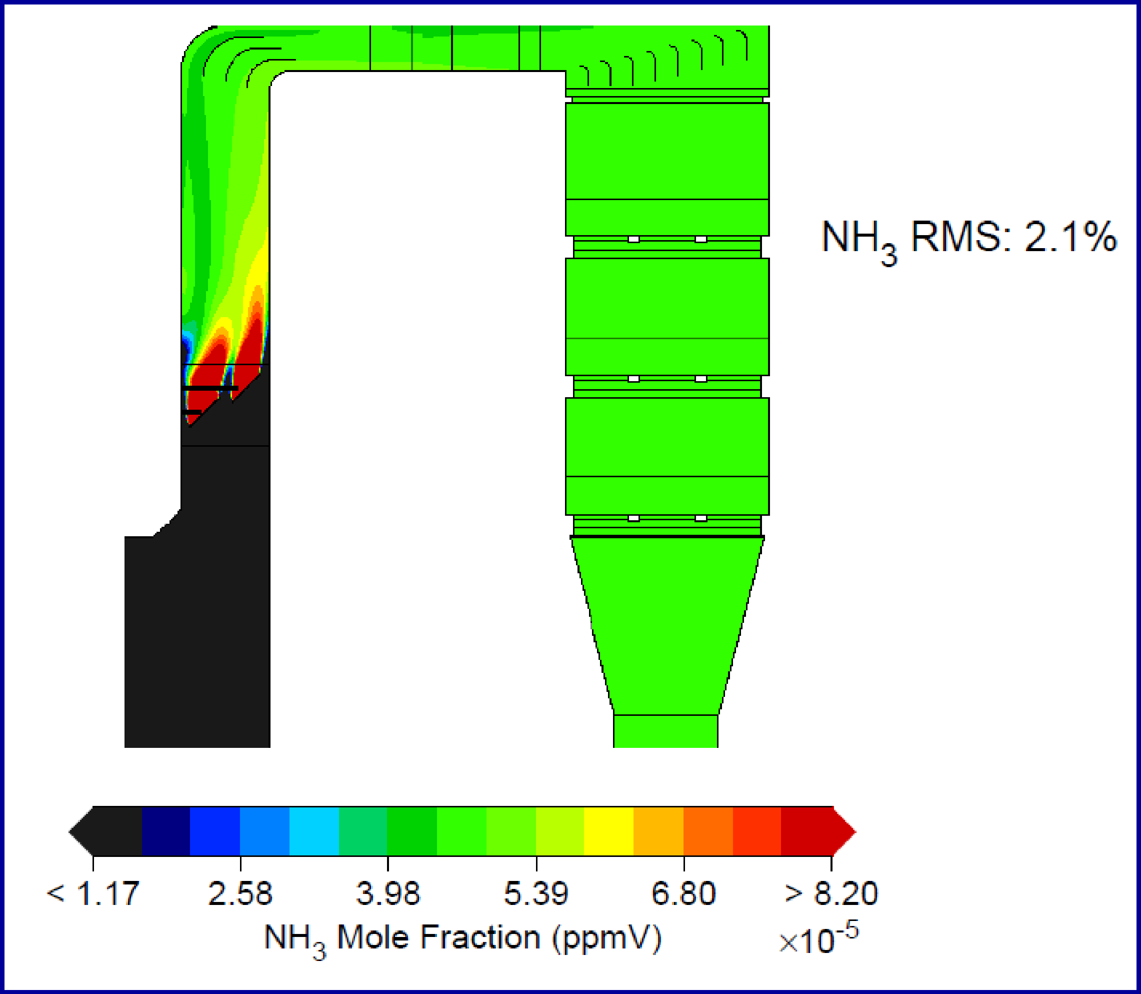

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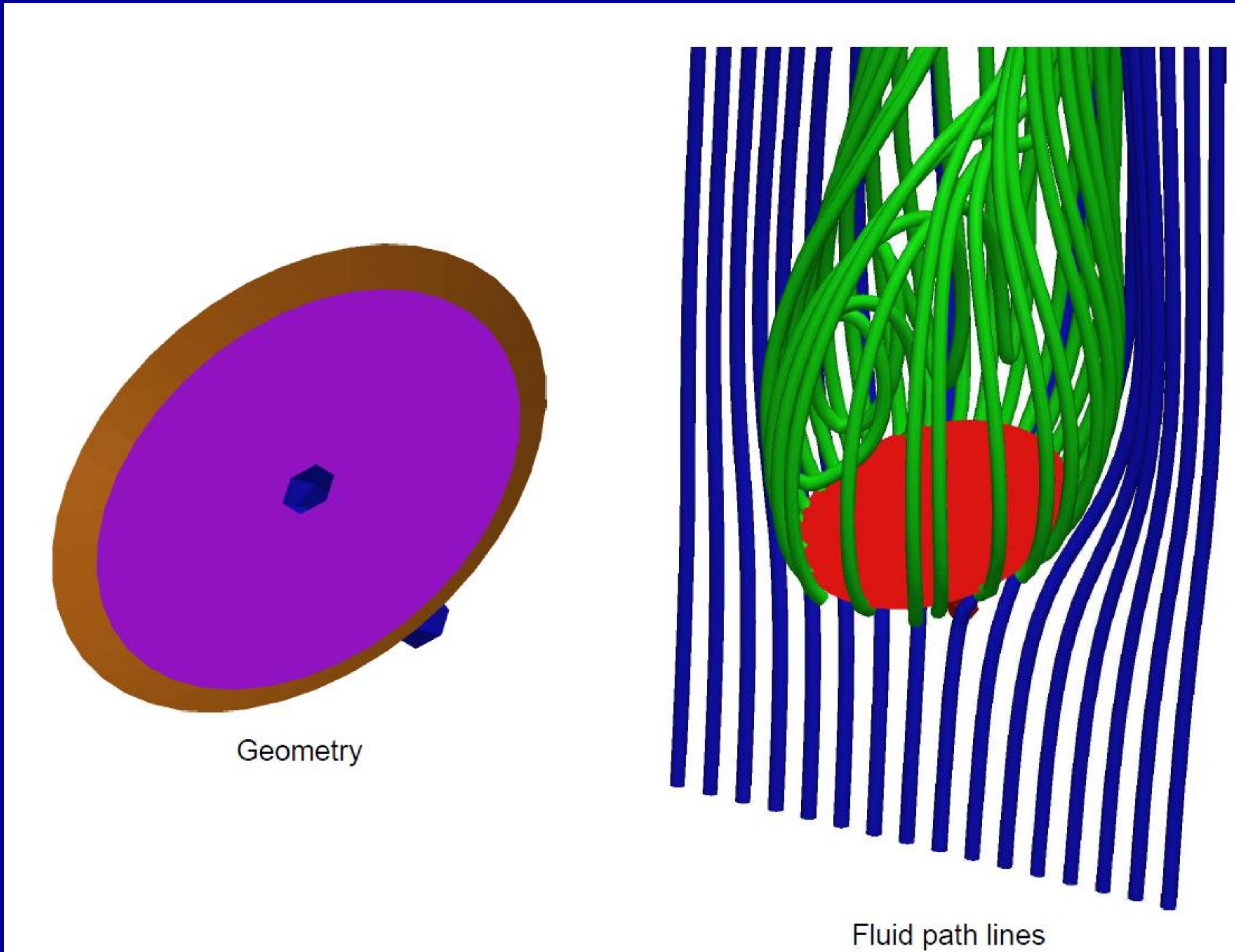
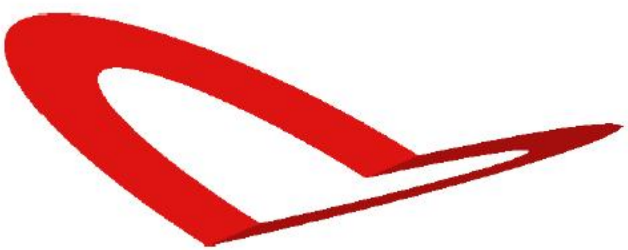
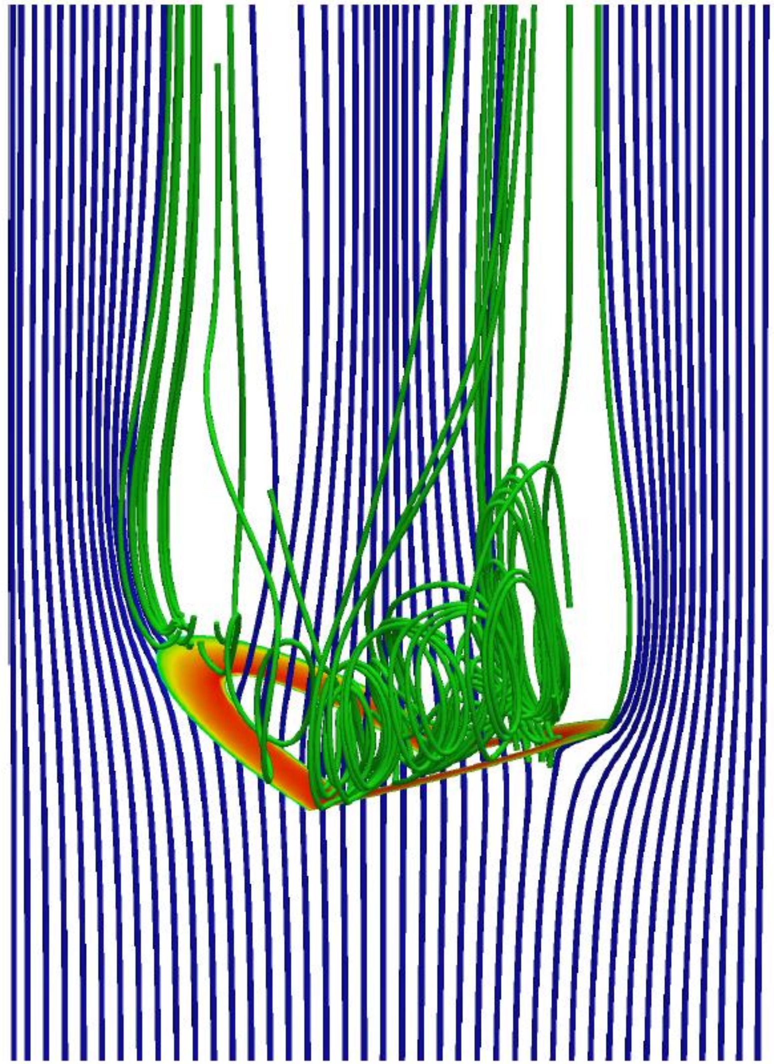


Vortex Mixer

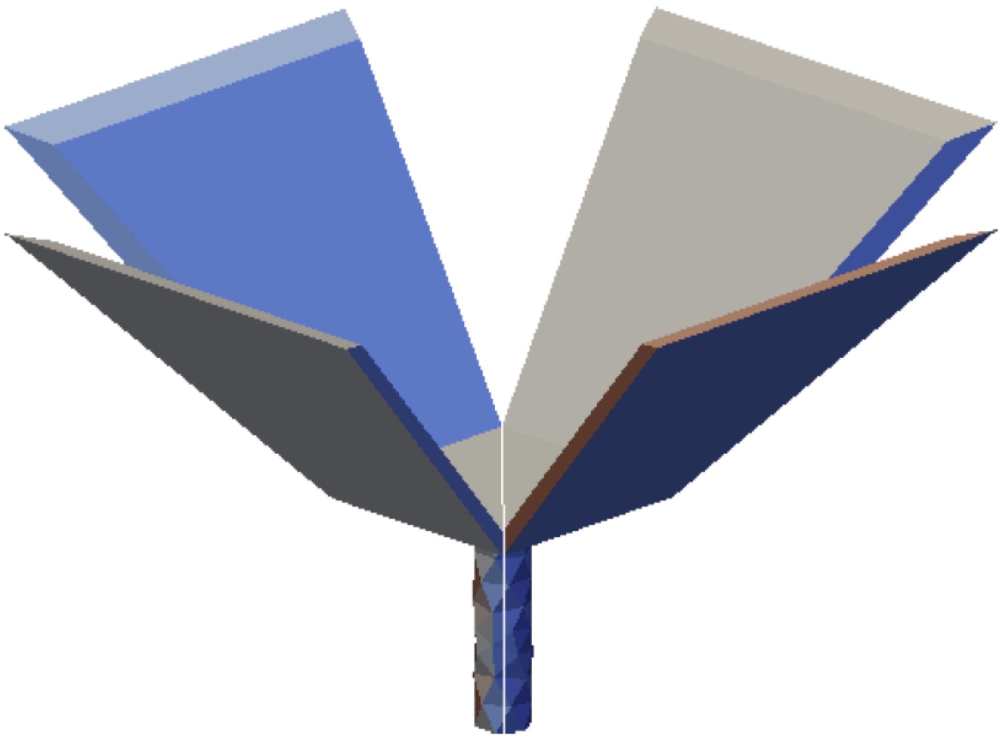


Geometry



Fluid path lines

Vortex Mixer



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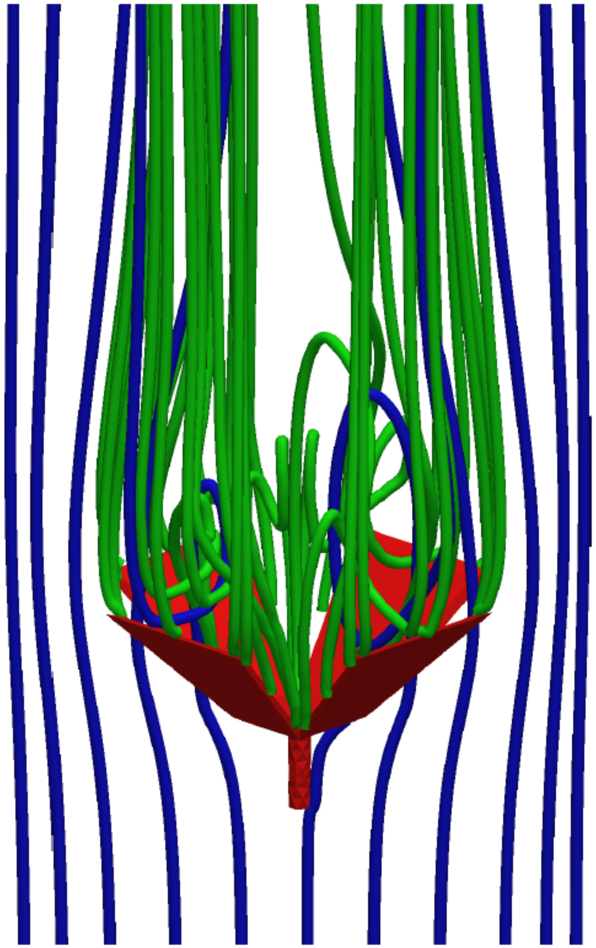
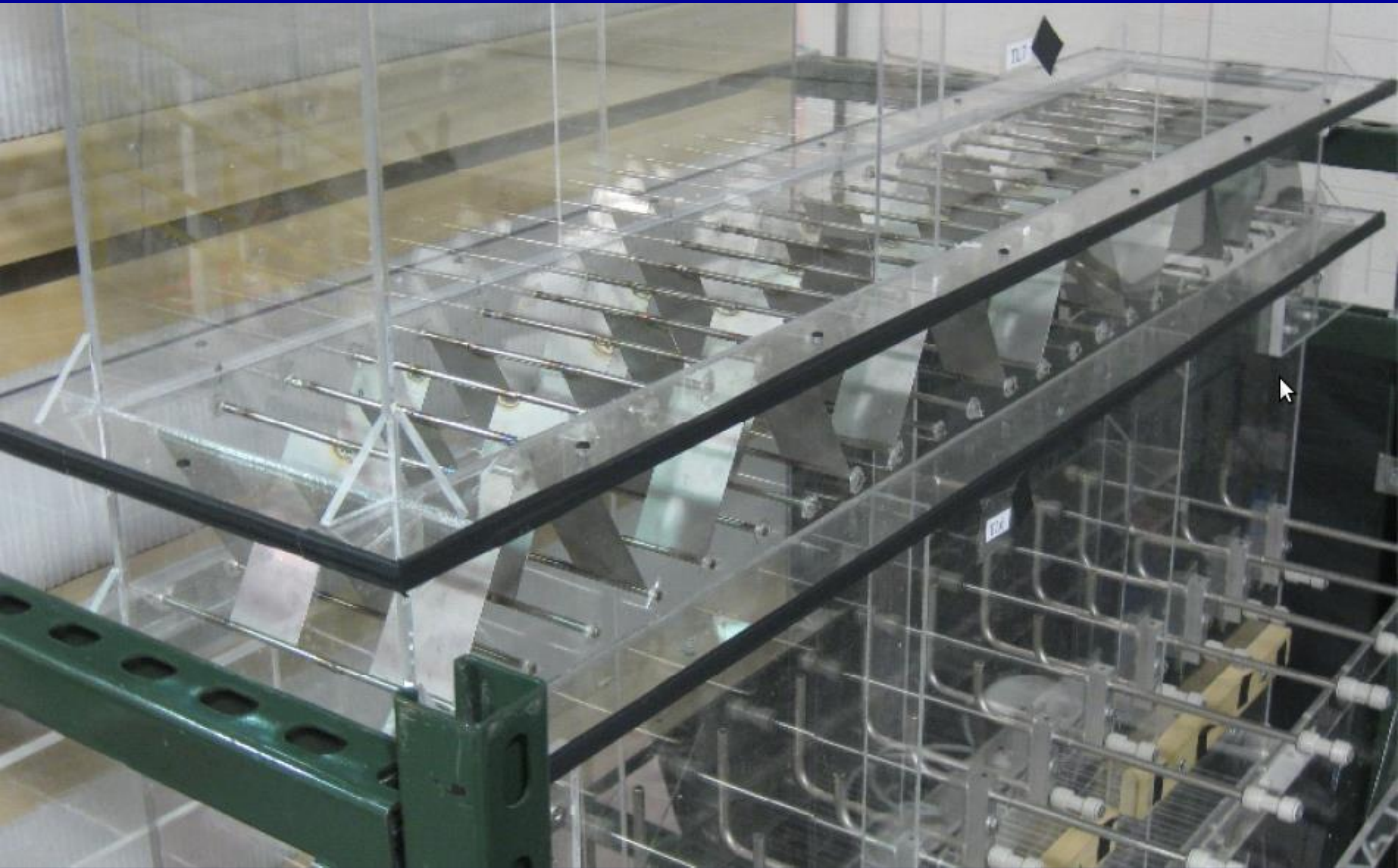
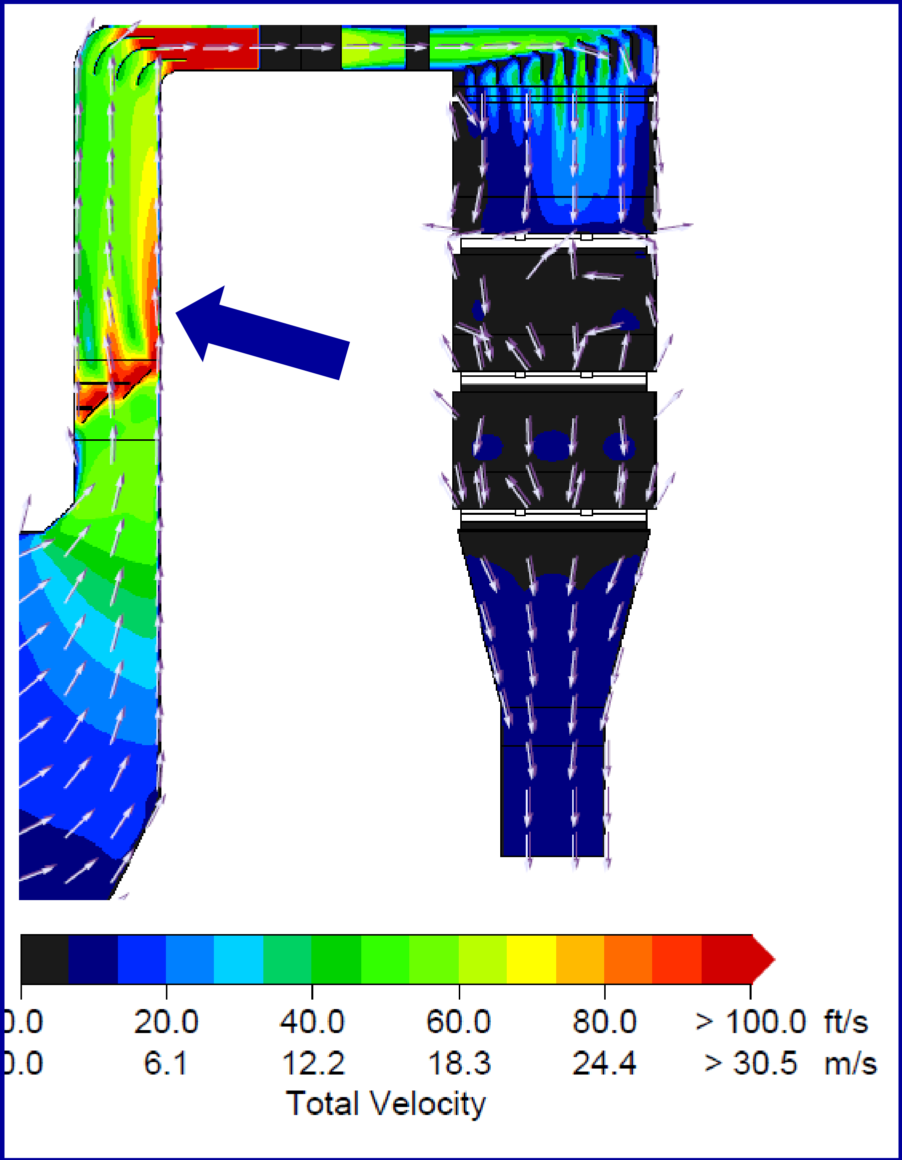


Fluid path lines

Vortex - Shear Mixer



Mixer Issues - Erosion



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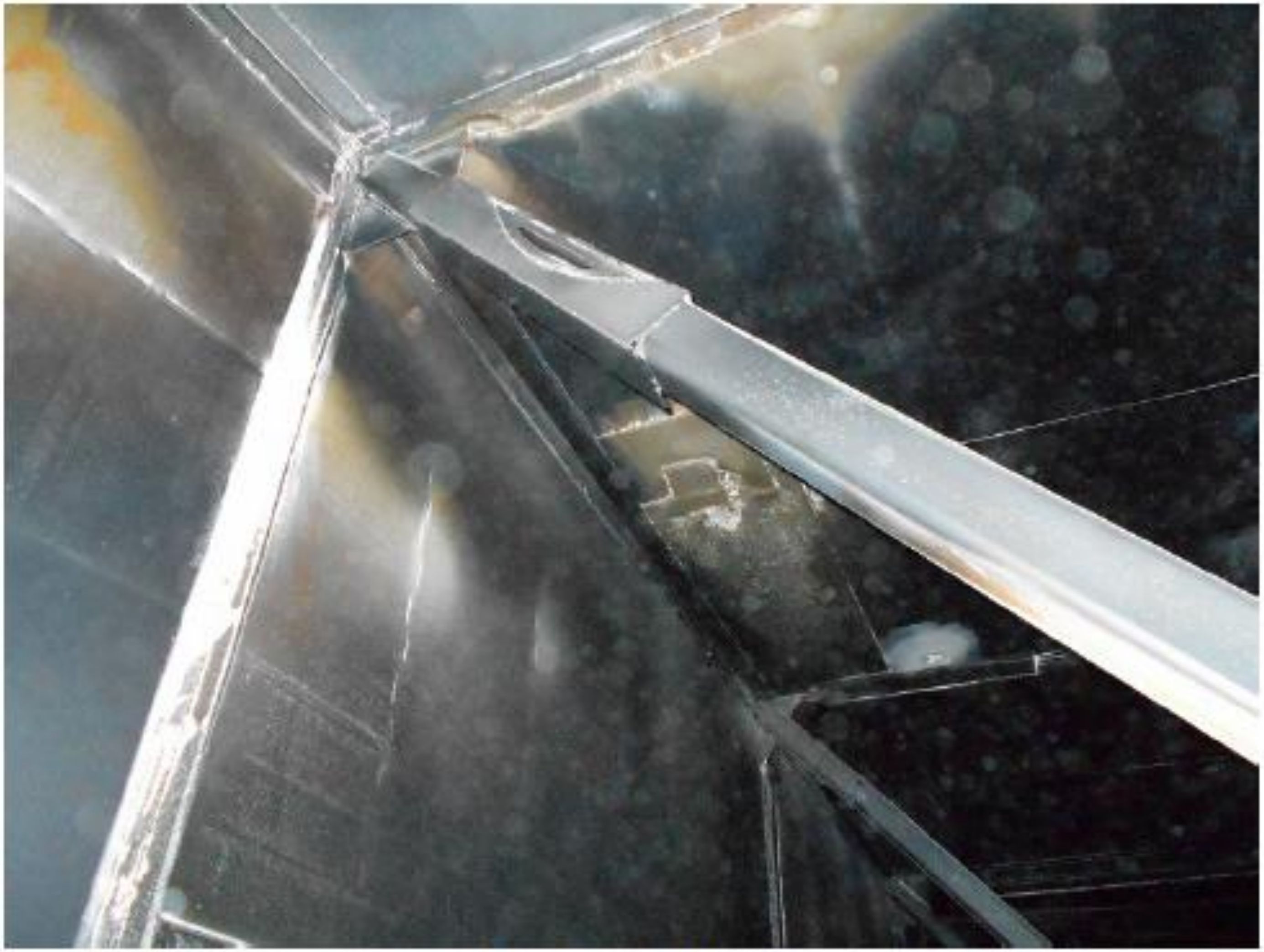
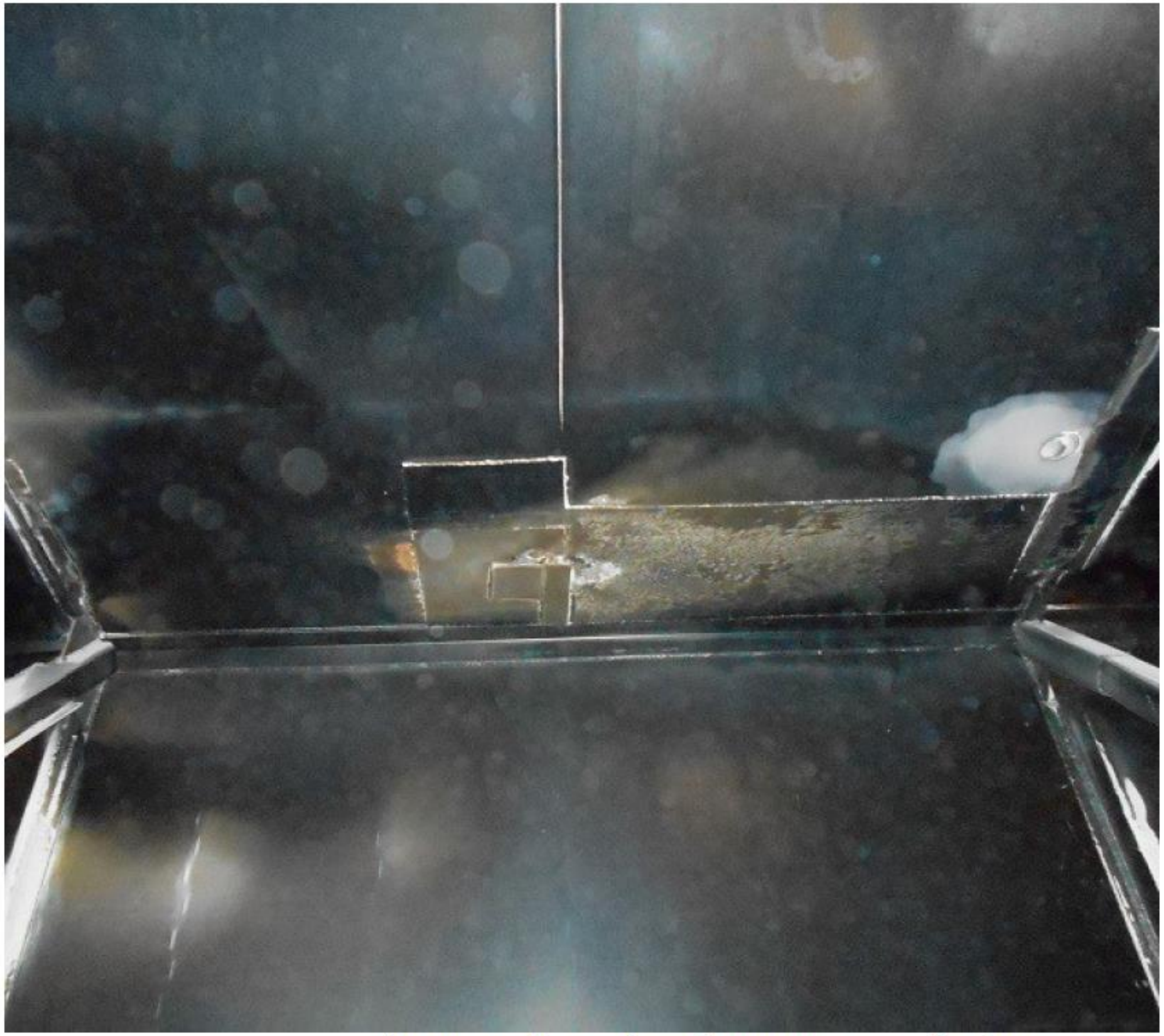
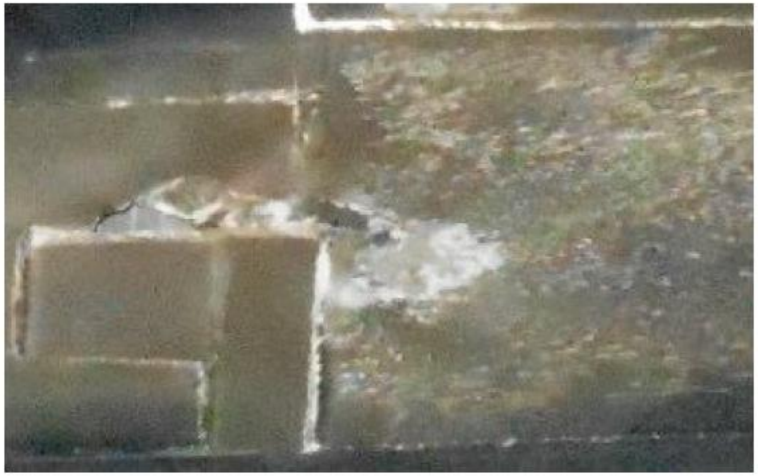


Internal truss erosion downstream of mixers
(zoomed view at right)

Mixer Issues - Erosion

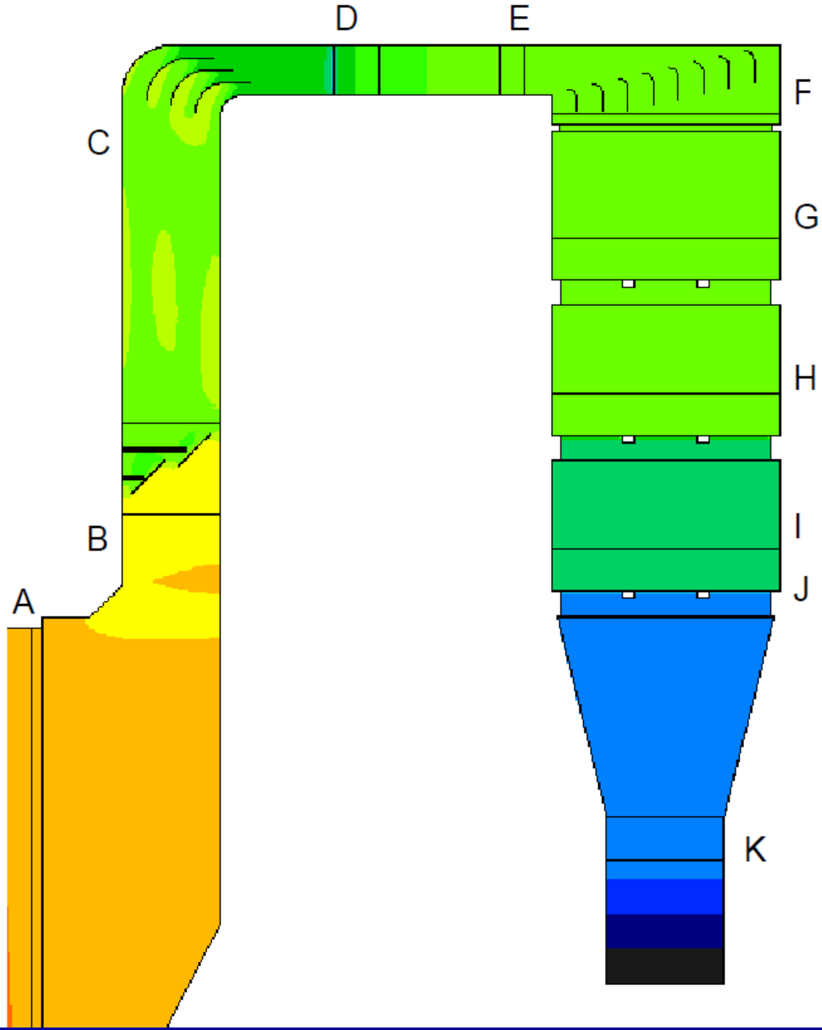




Duct roof erosion downstream of mixers, near unit centerline (flow is left to right)
(zoomed view at right; repair patches evident)

Mixers– Pressure Drop

	Location	Total Pressure Loss (inH2O)	Total Pressure Loss (mmH2O)
A	Evaporator Outlet	0	0
B	Upstream AIG	-0.03	-0.8
C	Downstream AIG	-0.75	-19.1
D	Upstream SCR Duct Expansion	-0.95	-24.1
E	Downstream SCR Duct Expansion	-1.07	-27.1
F	Upstream Flow Rectifier	-1.23	-31.2
G	Upstream (Future) 1st Catalyst Layer	-1.26	-32.1
H	Upstream 2nd Catalyst Layer	-1.29	-32.7
I	Upstream 3rd Catalyst Layer	-2.30	-58.3
J	Downstream 3rd Catalyst Layer	-3.29	-83.7
K	Economizer Inlet	-3.31	-84.0
A-K	**Total DP, Evaporator Outlet to Economizer Inlet**	**3.31**	84.0
A-K	**Total DP, Excluding Catalyst Layers**	**1.27**	32.3



DP = 0.72 IWC

Typical mixer stage
DP = 0.3 to 0.8 IWC

Summary – Coal Fired SCR

- The NH_3, NO_x, and temperature distributions are key players in SCR performance
- Pre-mixer often used for NO_x and temperature at boiler outlet
- Dense Grid AIG generally no mixer or "local" mixer
- Coarse Grid AIG will have 1 or more high turbulence mixer layers
- AIG and mixer design involves many competing criteria which must be understood and optimized

Videos

Gas Turbine SCR

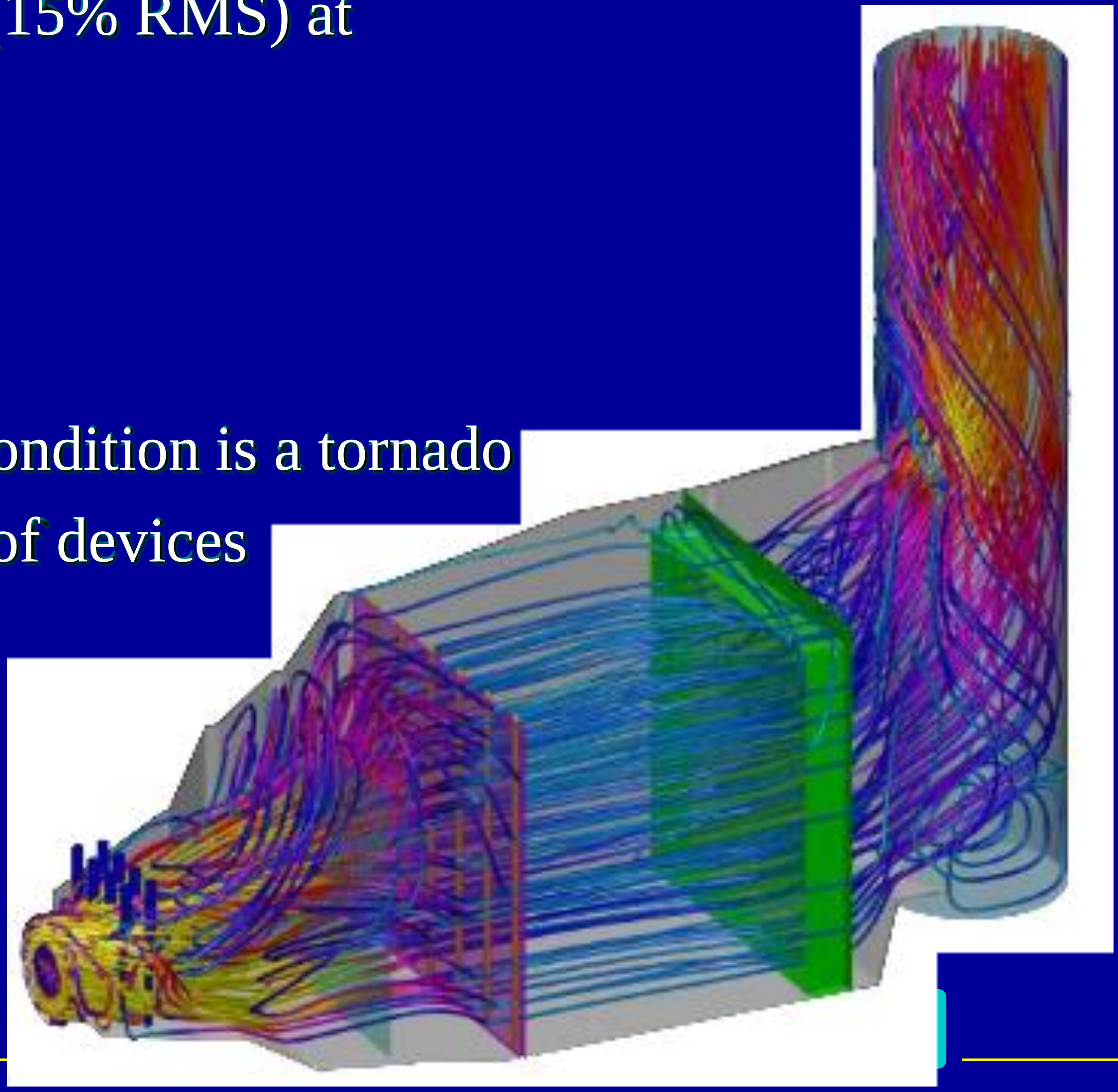
- Gas turbines come in many sizes and flavors
  - Simple cycle
  - Combined cycle / HRSG
  - With / without CO catalyst
  - With / without tempering air

Gas Turbine SCR

- Typical performance goals compete with each other
  - Uniform ammonia-to-NOx ratio
  - Uniform velocity at AIG and catalyst
  - Uniform temperature at catalyst
  - Minimize pressure loss
  - Uniform velocity at CO catalyst
  - CO catalyst influence on SCR

GT Design Objectives

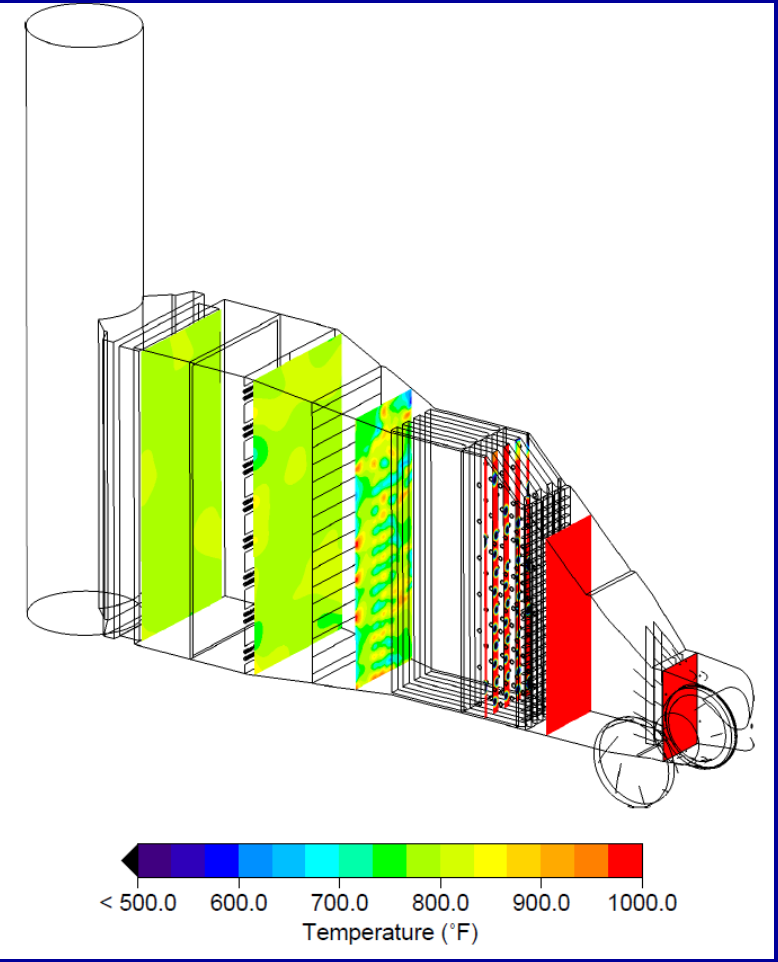
- Flow
  - Uniform velocity profile (15% RMS) at
    - CO catalyst
    - AIG
    - SCR catalyst
    - Tube banks
    - Stack CEMs
  - Not easy given the inlet condition is a tornado
  - Requires intricate design of devices
    - Baffles
    - Straighteners
    - Perforated plates



GT Design Objectives

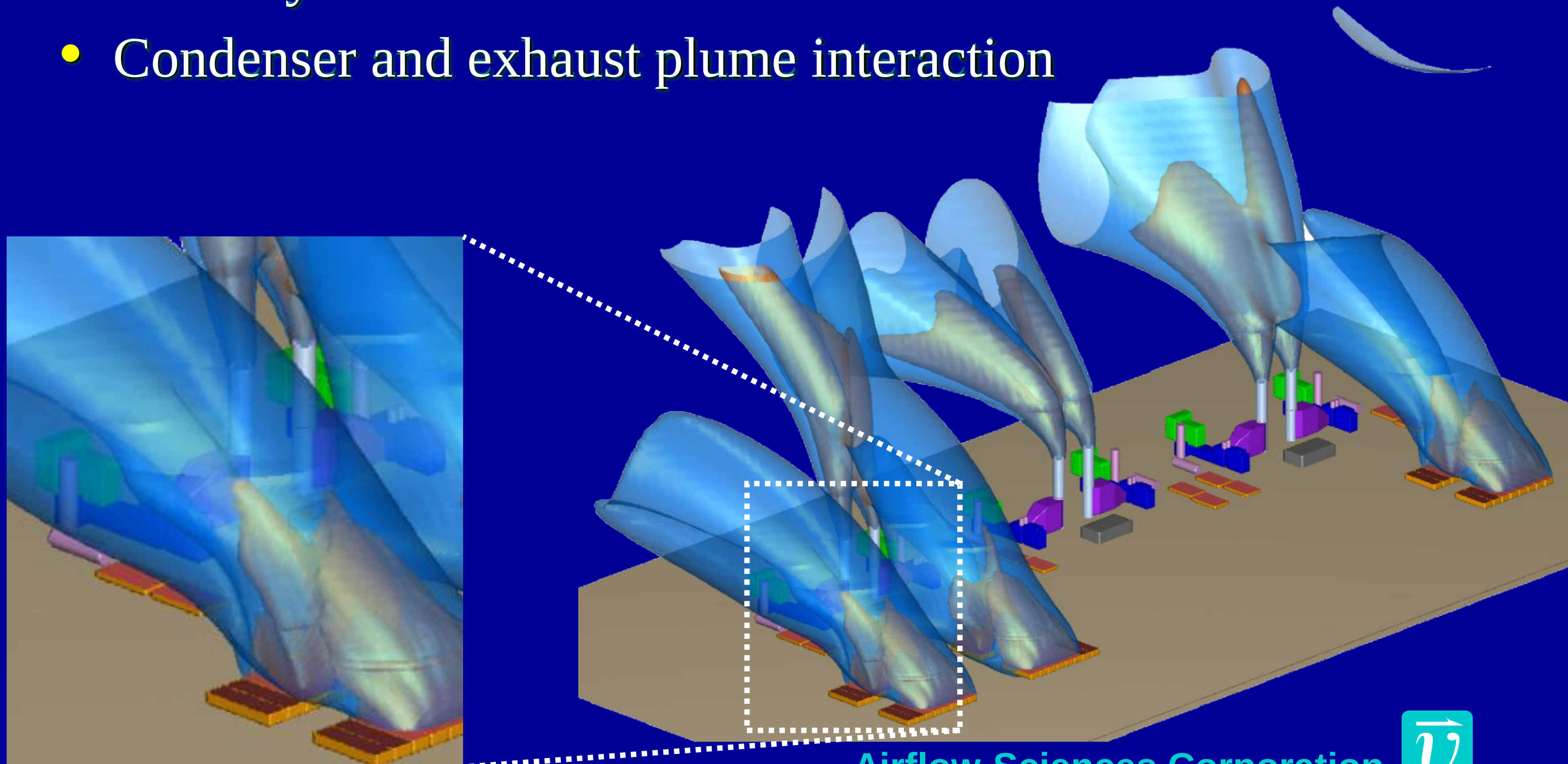
- Gas Temperature
  - Heat transfer to tube banks / HRSG important
  - Uniformity at catalyst (CO, NOx) affects performance
    - Typical goal +/-50 F
    - Can be challenging if significant amount of tempering air
    - Temperature is not necessarily uniform exiting the turbine

Tempering air case



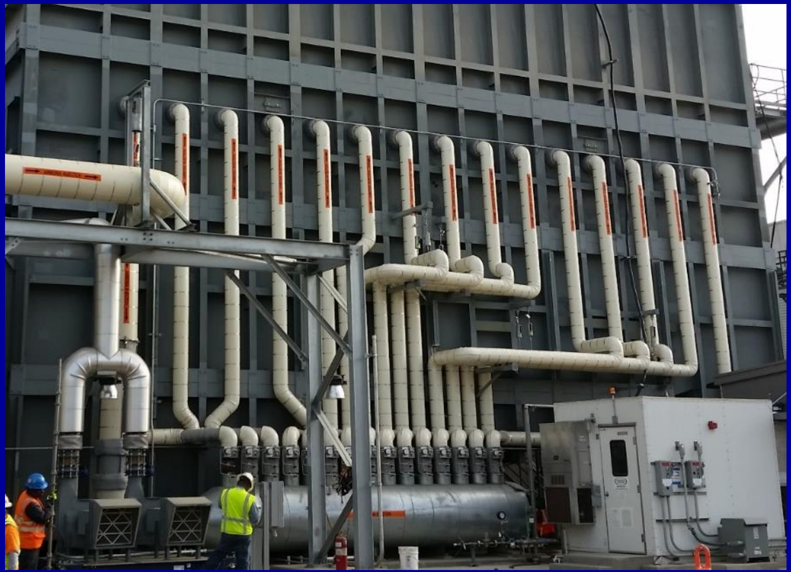
GT Design Objectives

- Turbine Inlet Conditions
  - Can have inlet cooling systems
  - Plant layout can affect turbine inlet conditions
  - Condenser and exhaust plume interaction



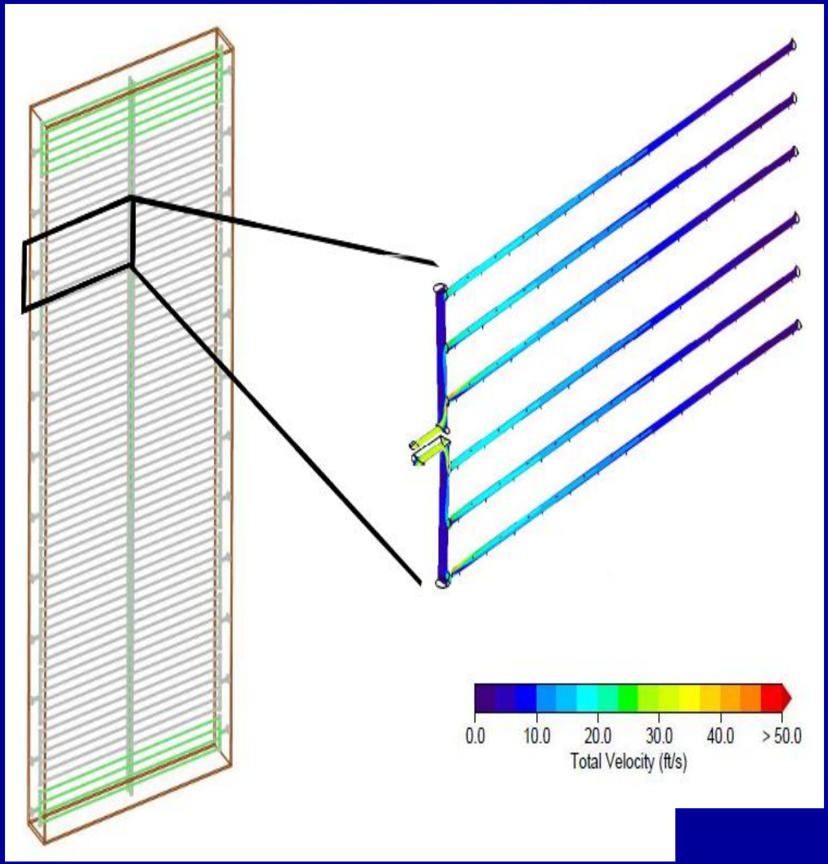
GT Design Objectives

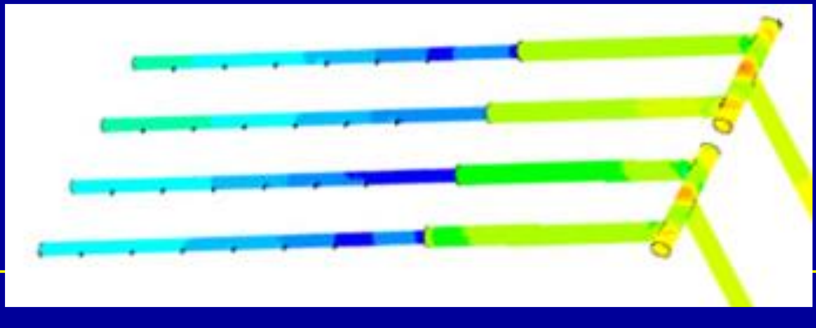
- Ammonia Injection
  - The key factor in deNOx performance and ammonia slip
  - Goal is uniform concentration (ammonia-to-NOx ratio) at SCR catalyst
  - General target is 5% RMS or better
  - Optimization requires balance of competing goals
    - Velocity profile at AIG
    - Uniform injection from AIG nozzles
    - Mixing effectiveness
    - Pressure drop
  - AIG design is not straight-forward
    - Mixing can be limited
    - Temperature heat up can affect distribution
    - Updated design practices have led to advances
    - Older systems likely have room for improvement



GT Design Objectives

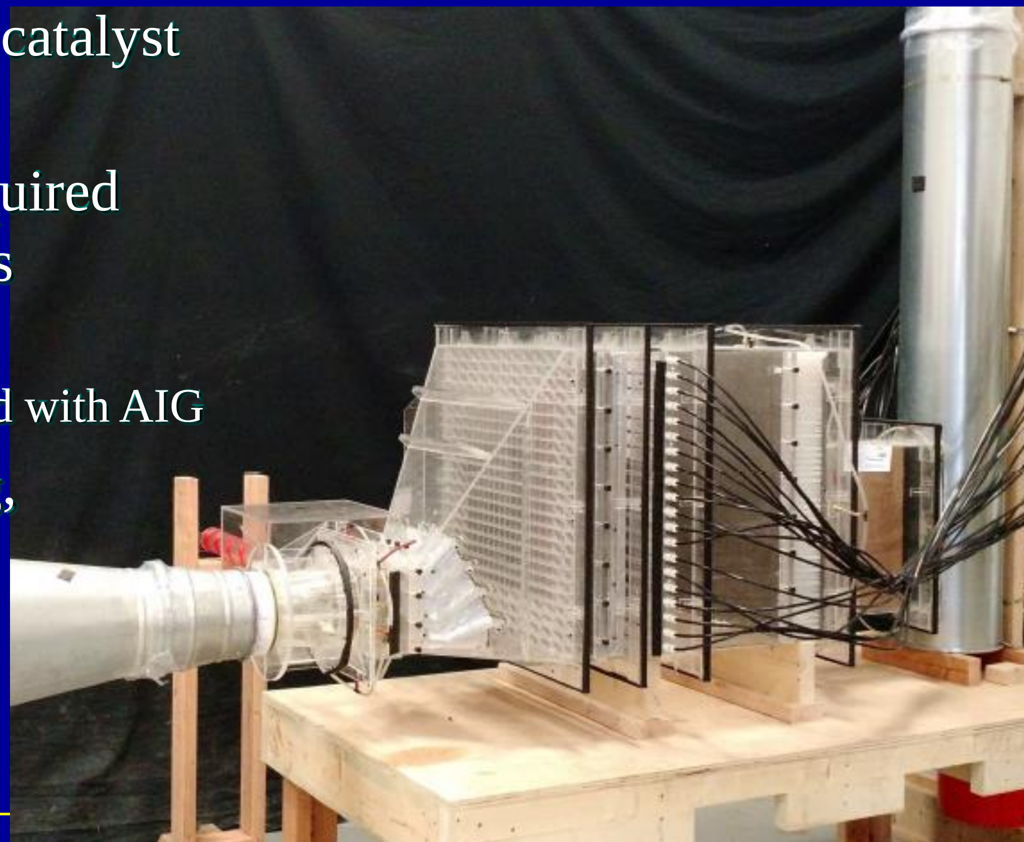
- Ammonia Injection Grid
  - General goal is to inject equal ammonia from each nozzle to within 2% or better
  - Correct sizing of header ID, lance ID, and nozzle diameters is important
  - May need to consider heat transfer from gas side to the internal pipe flow; this can influence the balance between nozzles
  - The presence of tuning valves cannot always fix a poor design





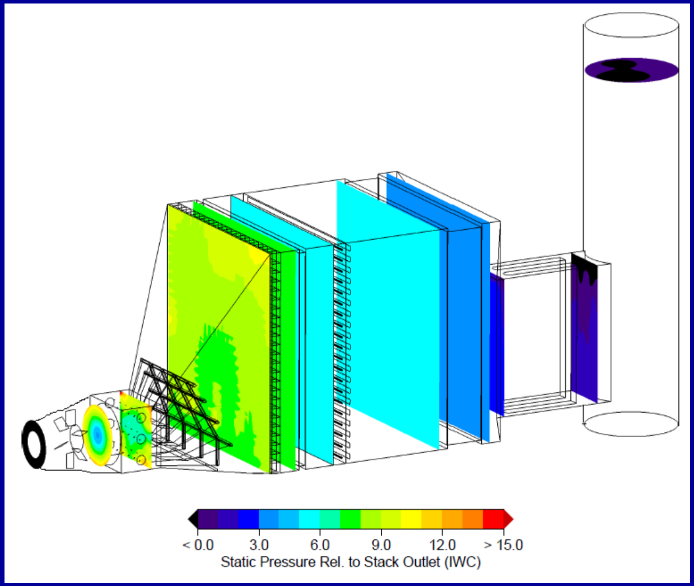
GT Design Objectives

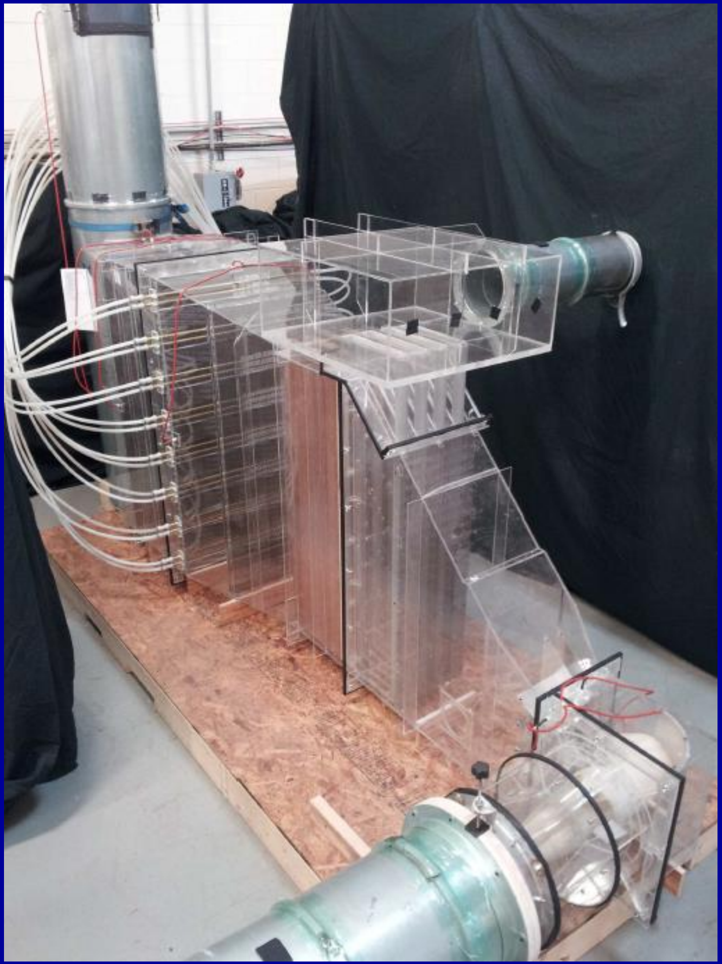
- Ammonia Distribution at SCR
  - Need to ensure sufficient number of lances/nozzles to cover the cross section
  - Depends on residence time to catalyst and turbulence intensity
  - Additional mixing may be required depending on geometry details
    - Static mixer after AIG
    - Turbulence generators integrated with AIG
  - Determined through modeling, validated via testing



GT Design Objectives

- Pressure Drop
  - Minimize
  - This goal competes with all the other goals
  - Balancing act is needed





GT Conclusions

- There are many parameters that affect gas turbine and SCR performance
- Need optimized design at beginning, and design improvements over time
- AIG design and mixing play a critical role
- Cost-effective enhancements are possible to existing systems

Questions