HRSG HEAT TRANSFER AND SCR PERFORMANCE IMPROVEMENTS THROUGH CFD MODELING AND FIELD TESTING

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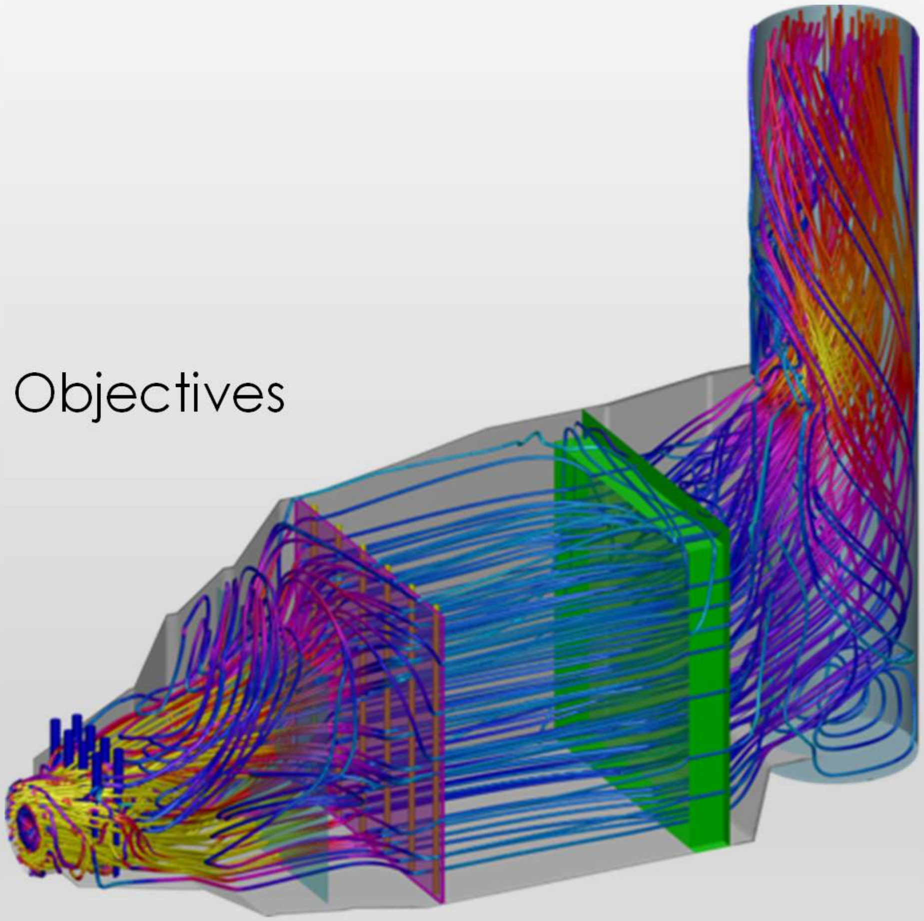
Airflow Sciences Corporation

Azore® Software

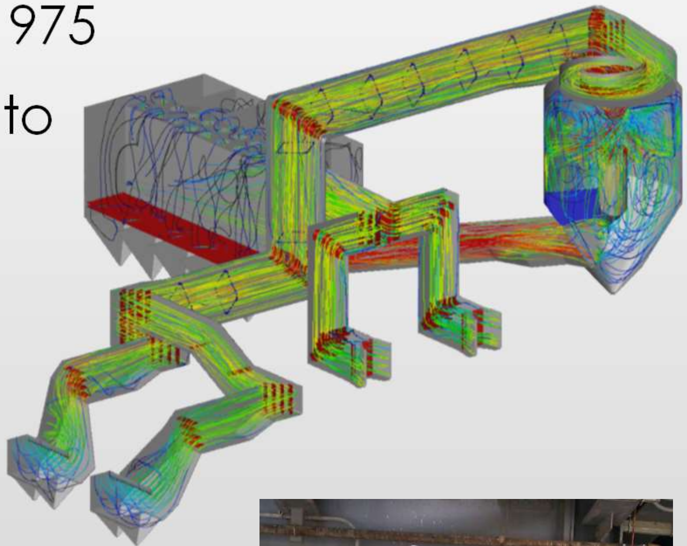
AGENDA

- Introduction
- Analysis Methodology
  - CFD Modeling
  - Physical Flow Modeling
  - Field Testing
- HRSG (and Simple Cycle) Plant Design Objectives
  - Flow
  - Temperature
  - Ammonia/NOx
  - Pressure Drop
  - External Flow Considerations
- Case Study – HRSG Modeling
- Summary



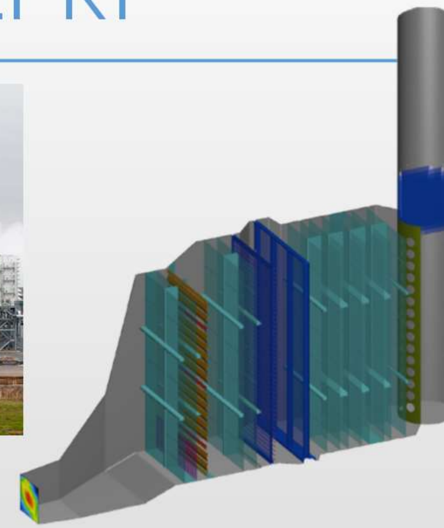
AIRFLOW SCIENCES CORPORATION

- Providing engineering services to industry since 1975
- Specialize in developing cost-effective solutions to problems in many industries involving
  - Fluid flow
  - Heat transfer
  - Particulate transport
  - Chemical reaction
  - Aerodynamics
- Flow Modeling Services – CFD, physical
- Field Testing – SCR tuning, boiler/duct/stack testing
- CFD Software - Azore®
- Portable and Online Test Equipment

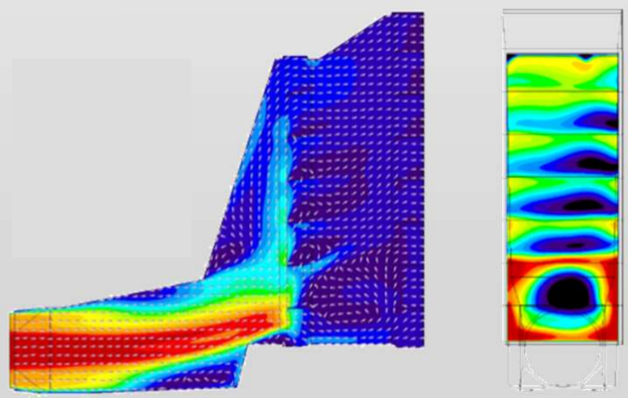


PAST GAS TURBINE PROJECTS FOR EPRI

- HRSG Inlet Flow Optimization
- HRSG Steam Header Erosion
- HRSG Start-Up / Purge Research



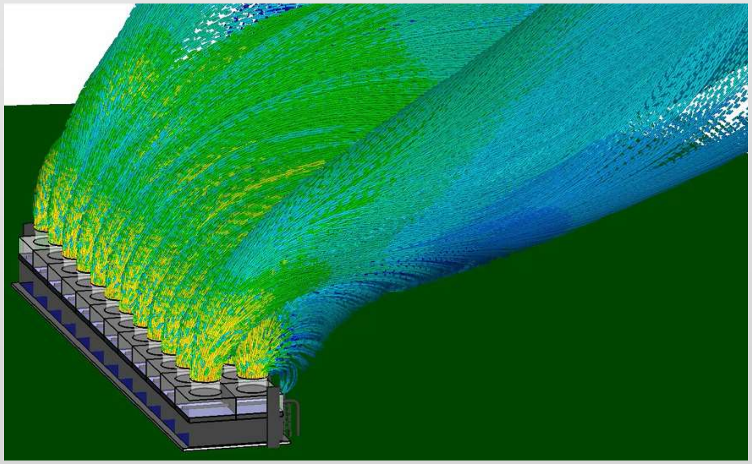
- Related Projects
  - Air Cooled Condenser Research
  - Cooling Tower Research
  - Condenser Research / WRCC
    - Fossil & Nuclear
  - Stack / PM / CEMs
  - Air Inleakage Testing / Reduction



- Flow deviation of +/- 45% top to bottom

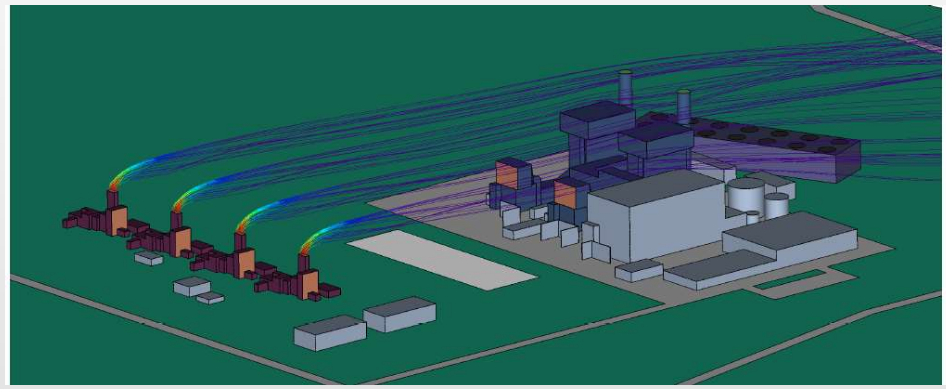
WHY PERFORM FLOW MODELING

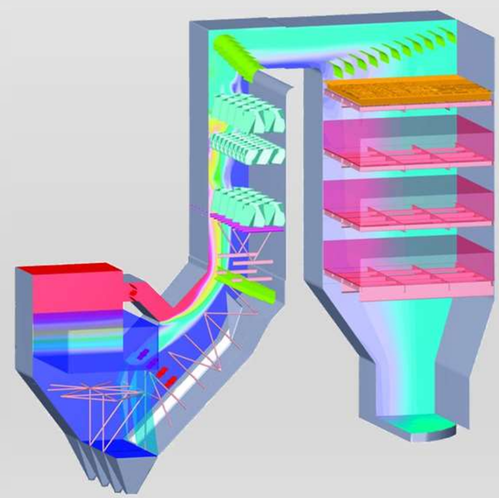
- Verify initial design of new equipment (required for most large capital projects)
- Conduct troubleshooting/optimization of existing equipment
  - Velocity
  - Heat transfer
  - Emissions
  - Flow-induced vibration
- Trial and error design optimization without modeling can work, but…
  - Fixes can be costly
  - Results may not be as expected
  - New problems could develop
- Modeling can save time and $ in the long run



COMPUTATIONAL FLUID DYNAMICS (CFD)

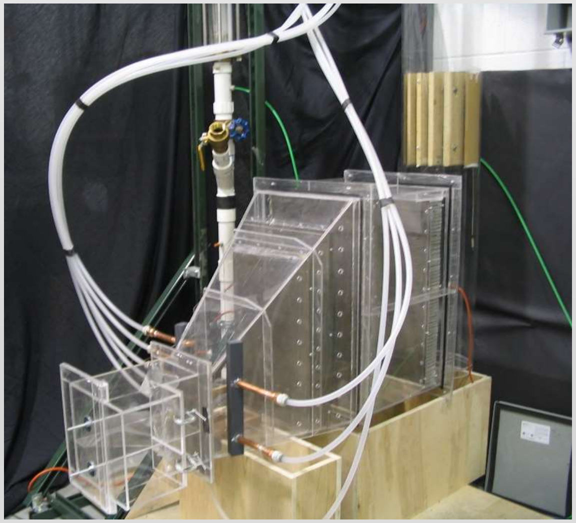
- Numerical simulation of flow
- Utilize high speed computers and sophisticated software
- Calculate flow properties
  - Velocity, temperature, pressure
  - Chemical species, combustion
  - Particle behavior
  - Steady state or transient flows
- Azore and Fluent software accuracy has been proven for a wide range of industrial applications

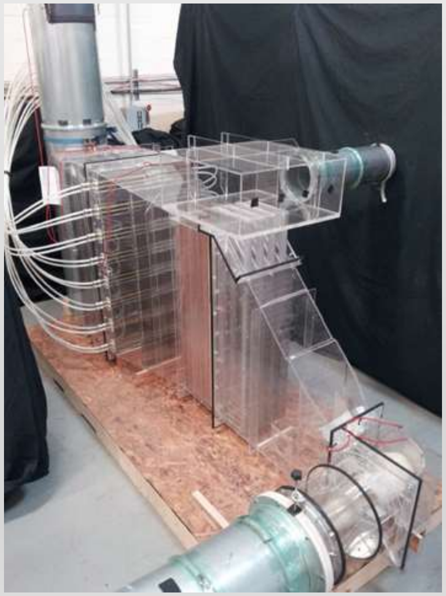




PHYSICAL FLOW MODELING

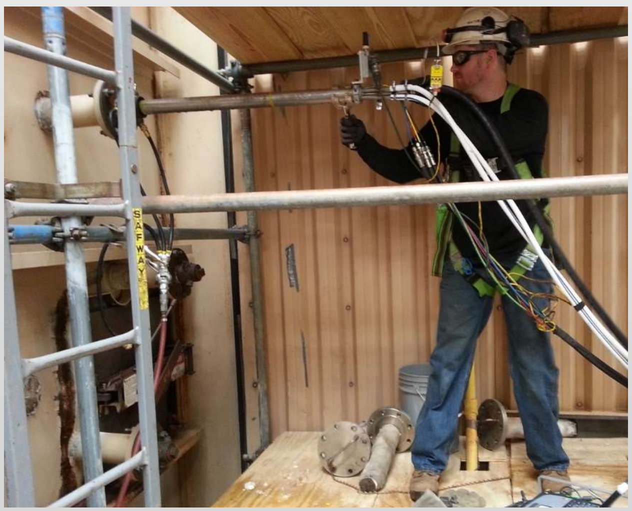
- Laboratory representation of geometry
  - Typical scale between 1:8 and 1:16
  - "Cold flow" modeling
- Velocity, pressure, and/or species concentration data collected





FIELD TESTING

- Troubleshoot flow/thermal/emissions issues
- Obtain data for flow model correlation or input
- Tune / optimize performance



Turbine outlet flow profiling
(water cooled 3D probe)

AIG inlet flow measurement

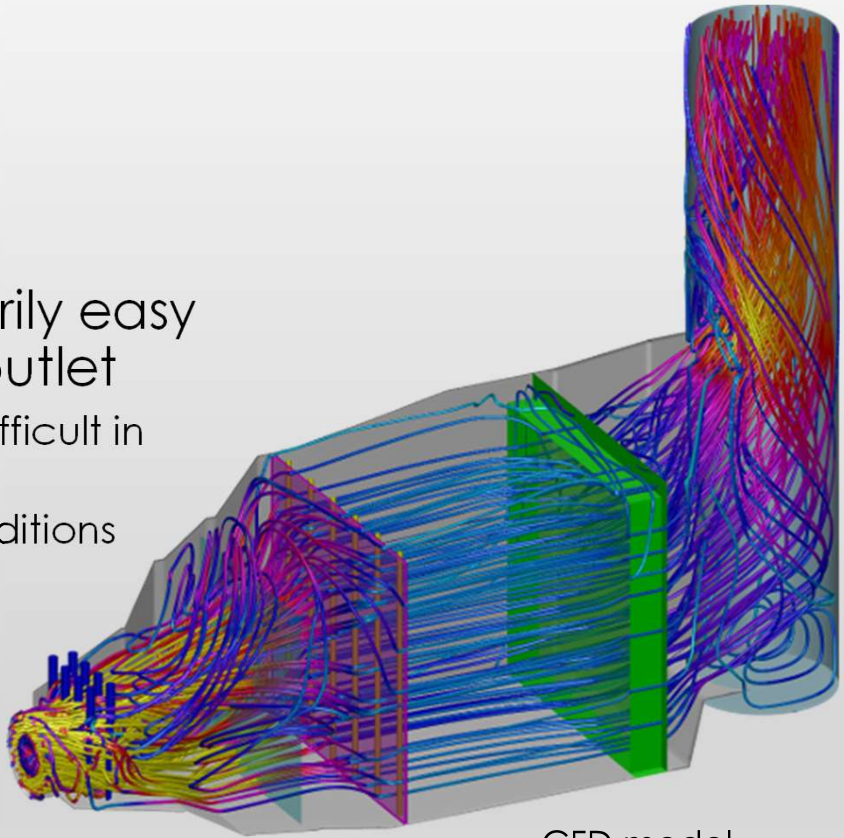
3DDAS test system

HRSG AND SIMPLE CYCLE DESIGN OBJECTIVES

- Velocity Profile
- Temperature
- Ammonia/NOx Ratio
- Pressure Drop
- External Flow Considerations
- Performance optimization involves a balance of competing goals
- Larger engines are making flow control more challenging
  - Turbine outlet flow patterns vary with load
  - Simple cycles require large mass flow of tempering air

DESIGN OBJECTIVES

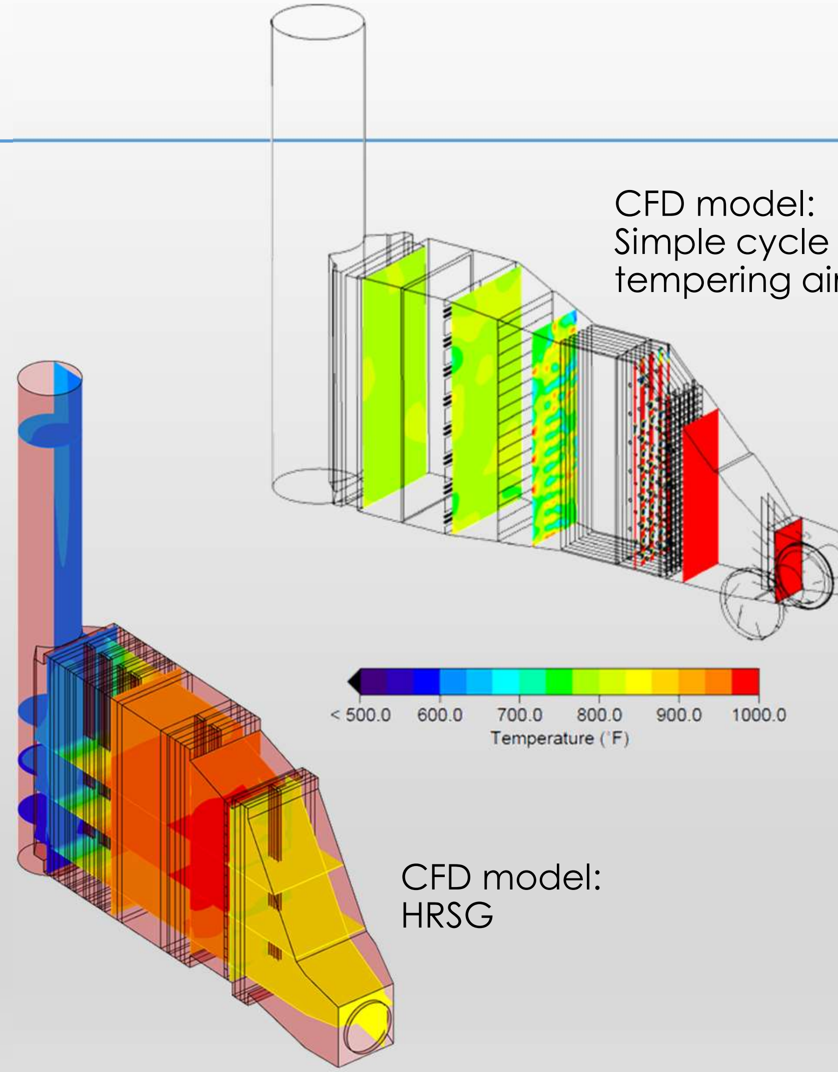
- Gas Velocity Profile Uniformity
  - Tube banks
  - Catalyst inlet (CO/NOx/Dual Action)
  - Ammonia Injection Grid (AIG)
- Obtaining uniform velocity is not necessarily easy due to swirling, turbulent flow at turbine outlet
  - Representing the turbine discharge velocity is very difficult in physical models
  - CFD modeling more advantageous to replicate conditions
- Requires intricate design of flow devices
  - Baffles
  - Straighteners
  - Perforated plates



CFD model
Flow streamlines

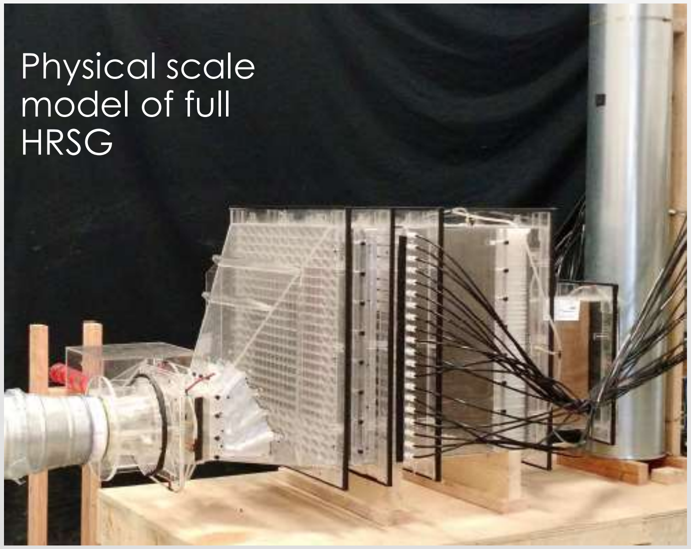
DESIGN OBJECTIVES

- Temperature uniformity at catalyst (CO, NOx) affects performance
  - Typical goal +/-50°F
  - Can be challenging to achieve this on simple cycles with high tempering air injection
  - Duct burners can influence temperatures on HRSGs
  - Temperature is not necessarily uniform exiting the turbine
- Heat transfer to tube banks is very important
  - Performance
  - Tube life, fouling
- CFD often the better tool for heat transfer vs. physical model



DESIGN OBJECTIVES

- Ammonia Distribution at SCR Inlet
  - Old goal <10% RMS
  - Modern goal <5% RMS (or better)
  - Tighter uniformity goals related to more stringent NOx regulations plus potential for Hydrogen firing
- AIG Design
  - Need to ensure sufficient number of lances/nozzles to cover the cross section
  - Depends on residence time to catalyst <u>and</u> turbulence
  - Additional mixing may be required
    - Static mixer after AIG
    - Turbulence generators integrated with AIG
- CFD and physical modeling complement each other to develop optimal design

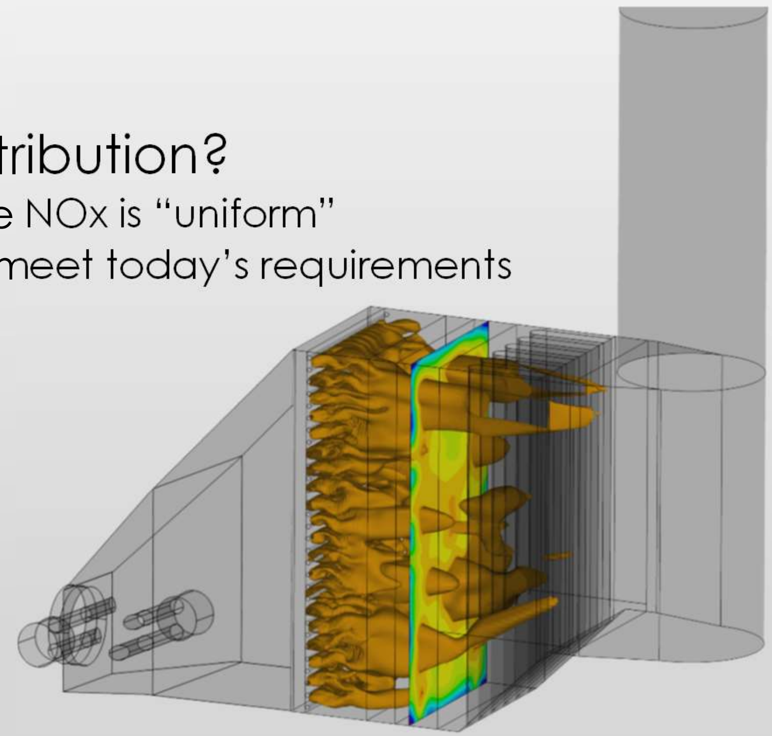


Physical scale model of full HRSG

AIG lance and mixer detail

DESIGN OBJECTIVES

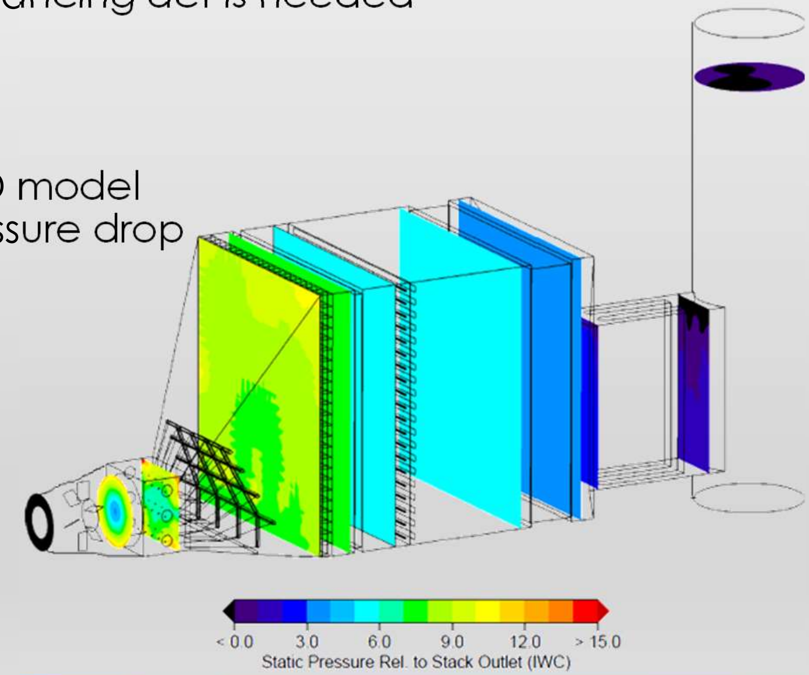
- Ammonia to NOx Ratio
  - Old goal <10% RMS
  - Modern goal <5% RMS (or better)
- How is this different from ammonia-only distribution?
  - Old days: get uniform ammonia and all is well because NOx is "uniform"
  - Modern days: NOx is not as uniform as you thought to meet today's requirements
- Why?
  - NOx is not necessarily uniform exiting the latest turbines
  - Large amounts of tempering air dilute the NOx
  - Duct burners create subtle NOx "stripes" at catalyst
- Flow model needs to consider NOx too
  - Best applied to CFD modeling
  - Harder to implement in physical model
- Makes it more important to have margin on the AIG design!!!



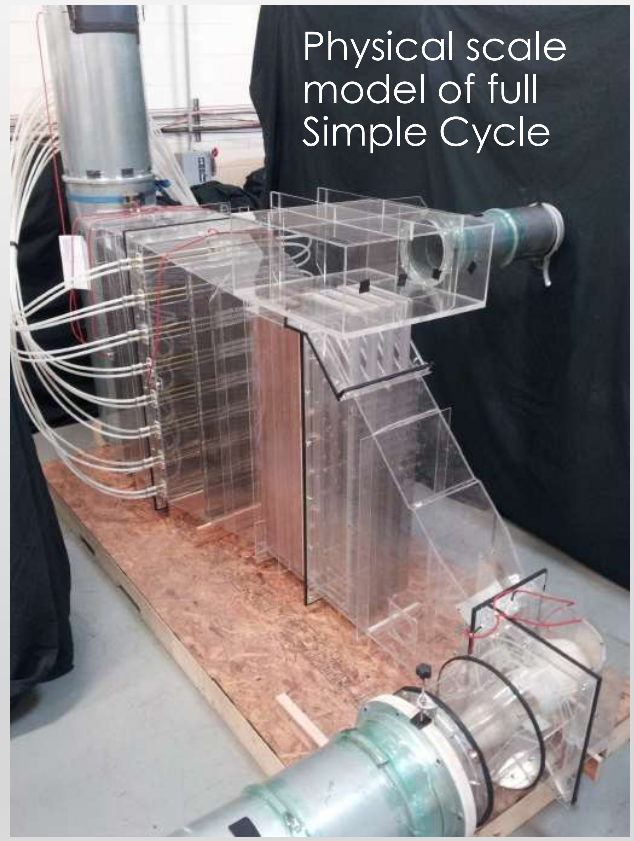
DESIGN OBJECTIVES

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

CFD model
pressure drop



Physical scale
model of full
Simple Cycle



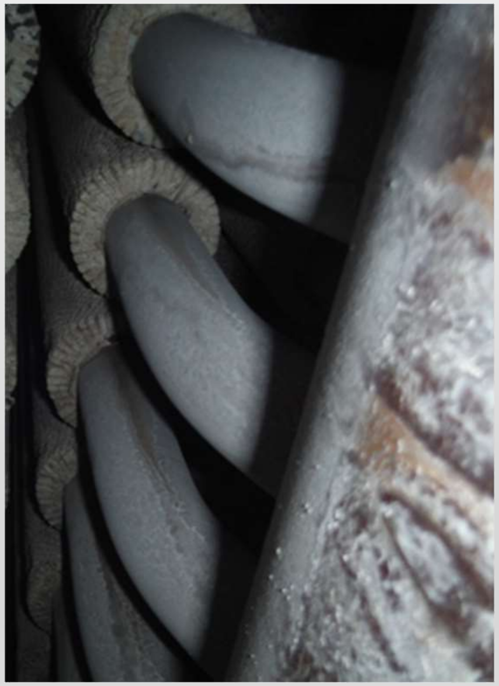
CASE STUDY – HRSG CFD MODELING

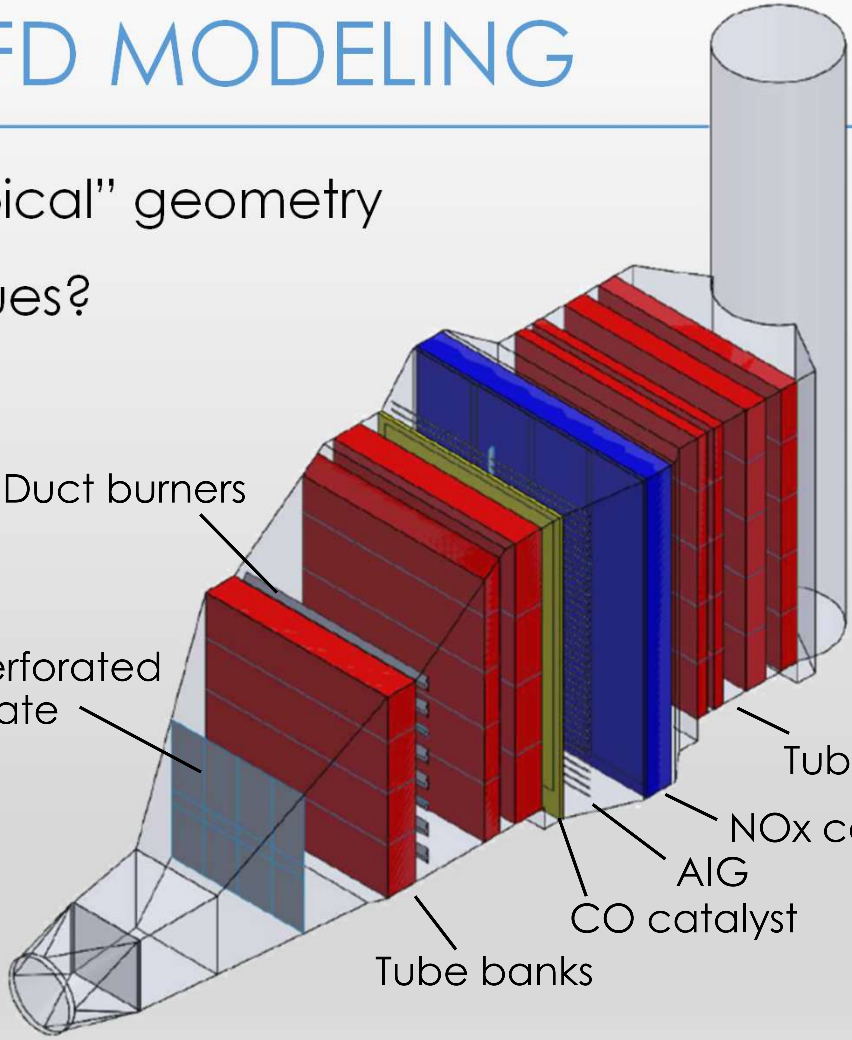
- HRSG unit – Siemens 501FC Turbines, 2x240MW
- Since plant startup in 2000, the HRSGs have experienced high gas pressure drop in the next to last tube bundle before the exhaust gas leaves the HRSG through the stack. The cause of the high pressure drop was due to ammonium salts building up within the tube bundle caused by high local ammonia slip.
- The HRSGs were cleaned annually utilizing costly ice blasting, but the pressure drop quickly increased after cleaning, from 2.1 IWC pressure drop in clean condition to often greater than 6.8 IWC.

CASE STUDY – HRSG CFD MODELING

- The HRSG was thought to have "typical" geometry
- So why did it have performance issues?

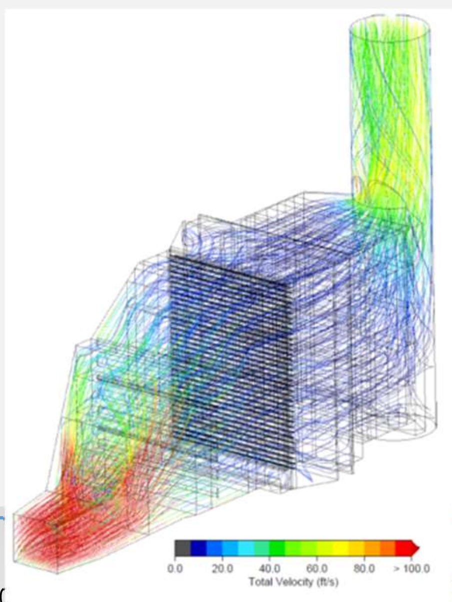
Fouled tubes

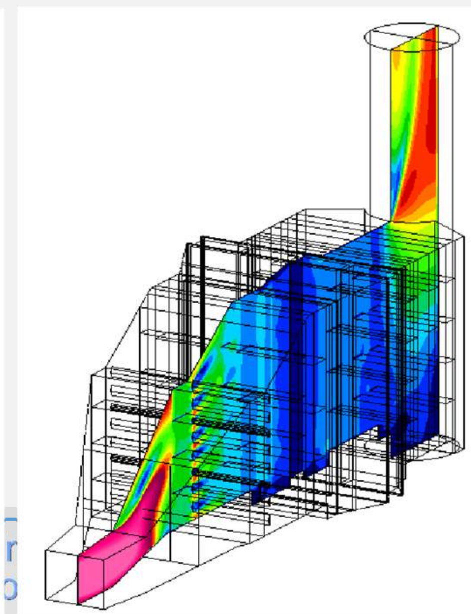


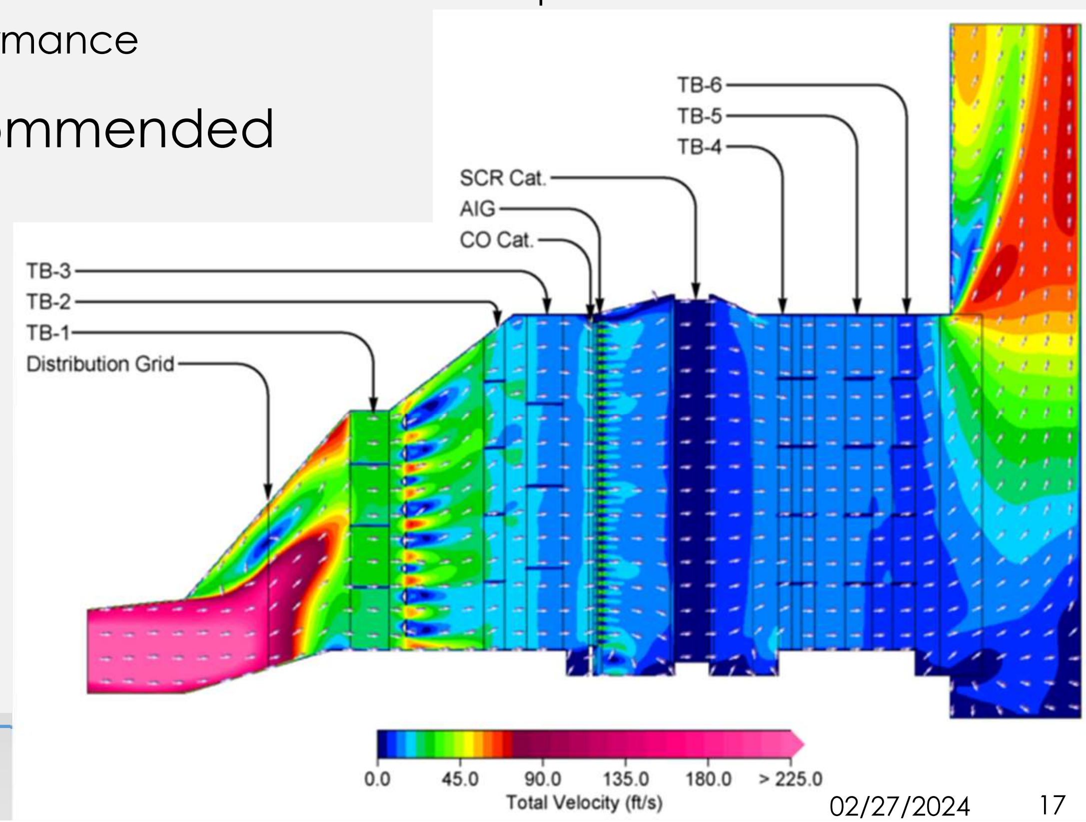


CASE STUDY – HRSG CFD MODELING

- Initial field testing showed poor ammonia distribution at the SCR inlet
  - Goal was <10% RMS; data indicated >20% RMS
  - The plant struggled balancing de-NOx performance and ammonia slip
  - Could not tune the AIG to improve performance
- Baseline CFD modeling was recommended

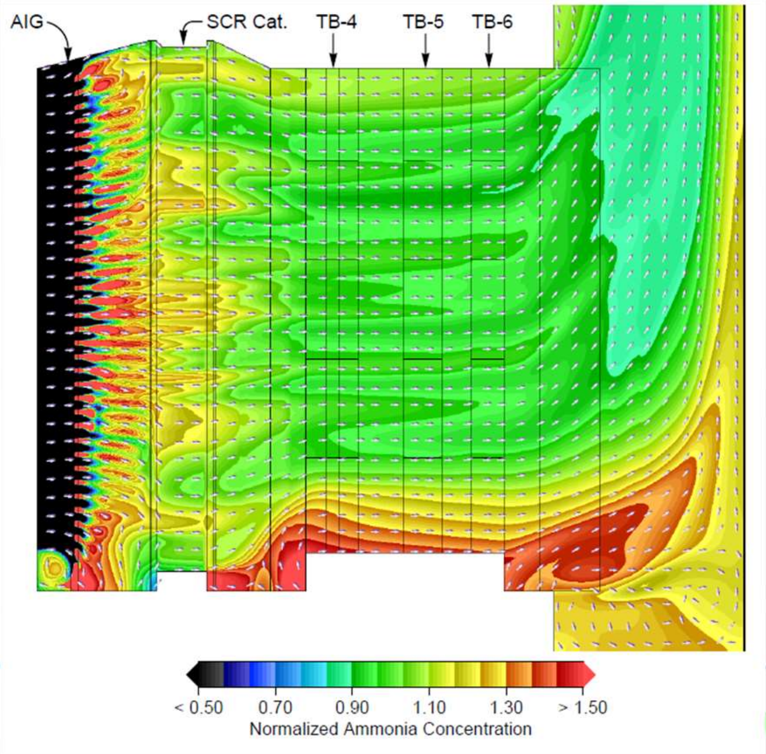


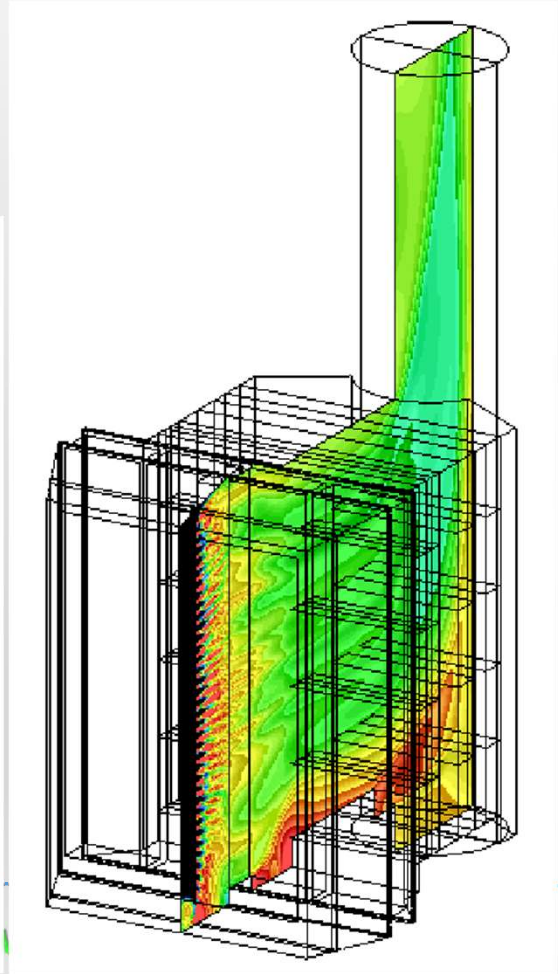




CASE STUDY – HRSG CFD MODELING

- Baseline CFD modeling showed two problems with the ammonia injection grid
  - Localized mixing from each lance / nozzle was insufficient due to low turbulence level exiting CO catalyst

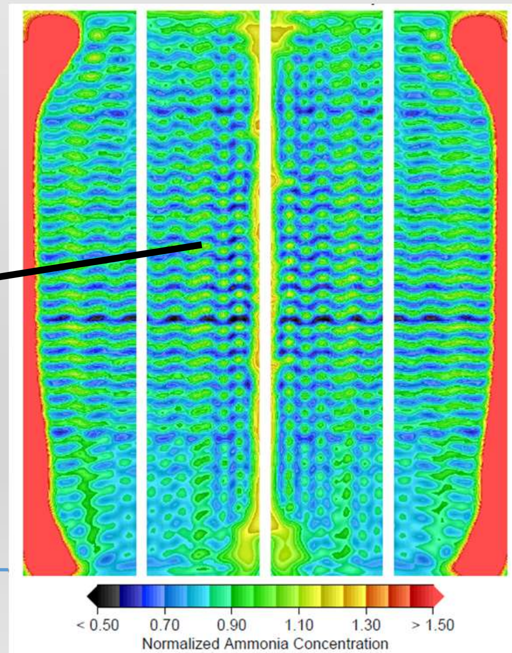


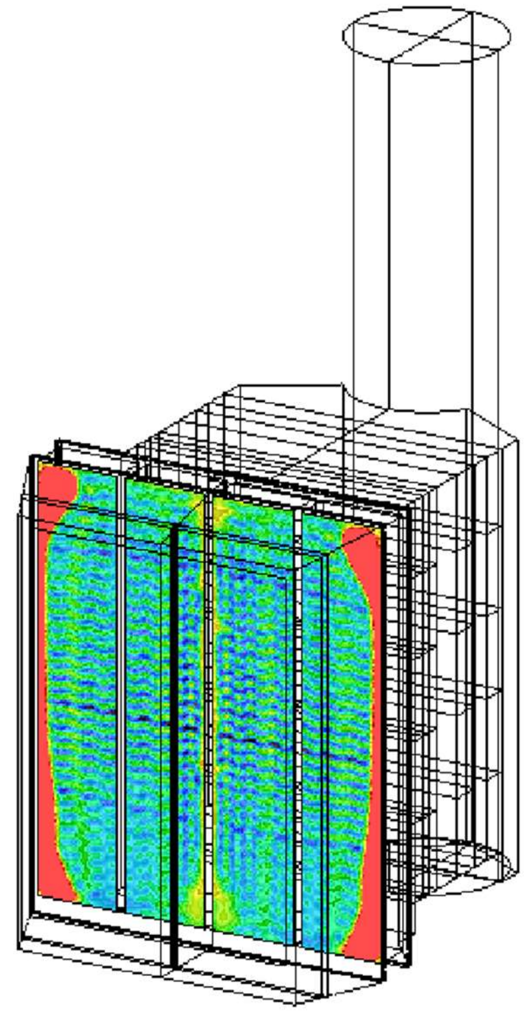


CASE STUDY – HRSG CFD MODELING

- Baseline CFD modeling showed two problems with the ammonia injection grid
  - Localized mixing from each lance / nozzle was insufficient due to low turbulence level exiting CO catalyst
  - Perimeter flow control was poor, resulting in very high ammonia along walls and through the SCR

Bulk of SCR Inlet Area 25% RMS





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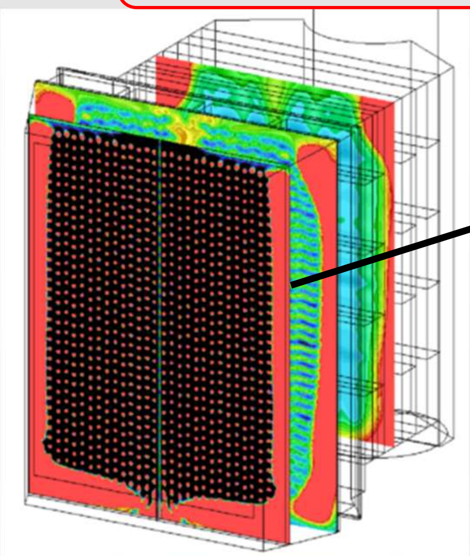
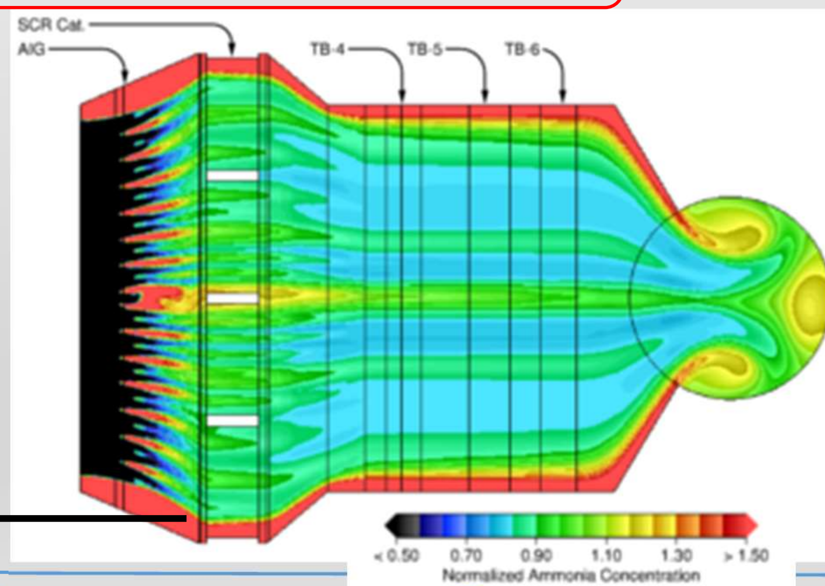
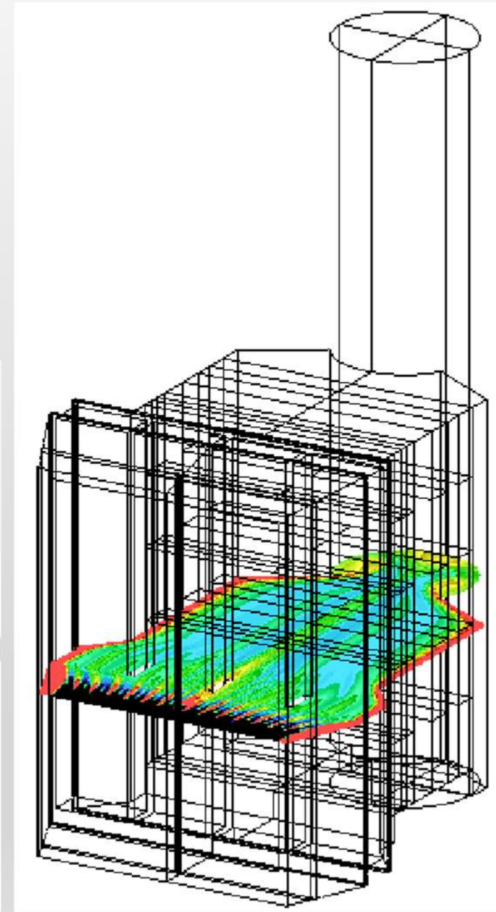


Full SCR Inlet Area 58% RMS

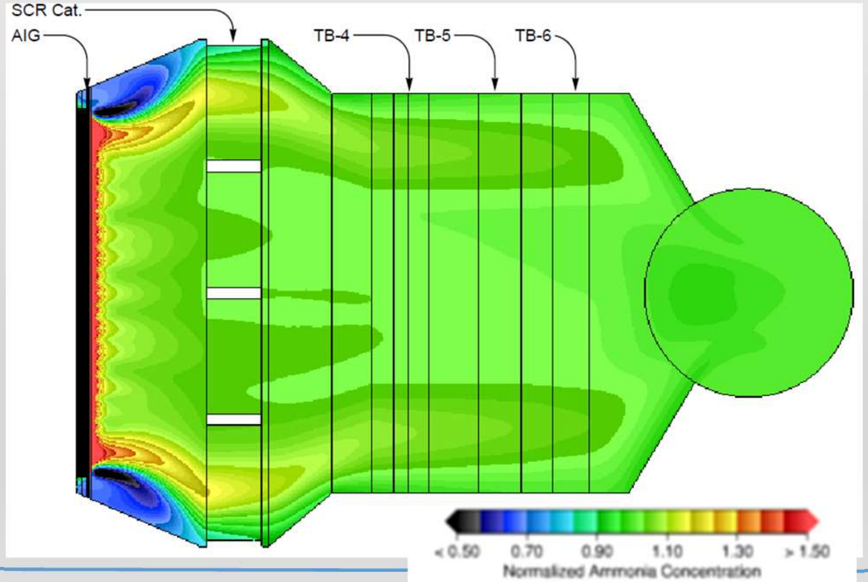
Ammonia along side walls 6X target

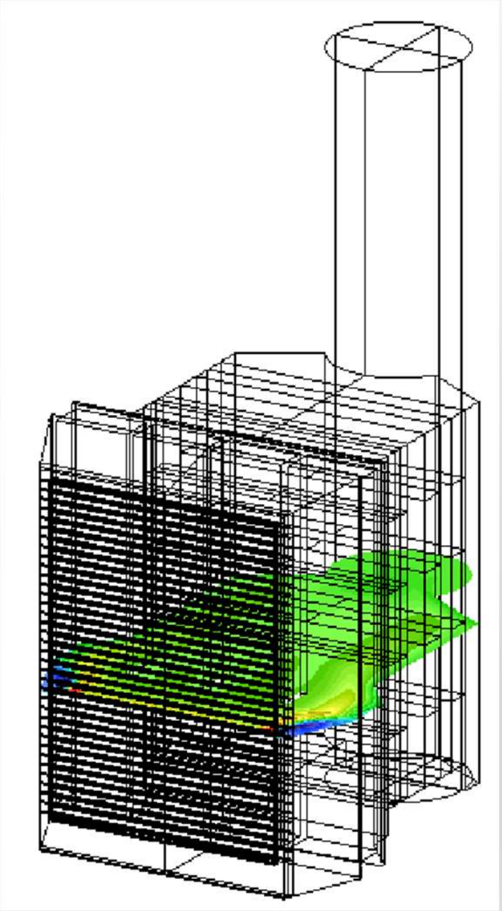




CASE STUDY – HRSG CFD MODELING

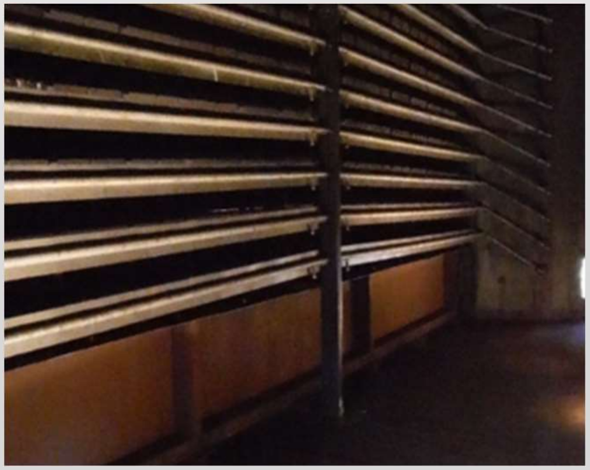
- Solution: Redesign the AIG
  - Improve local mixing in the center
  - New AIG lances with integrated mixing baffle
  - Control the flow at the perimeter
  - Proper design of flow baffling at CO catalyst and AIG

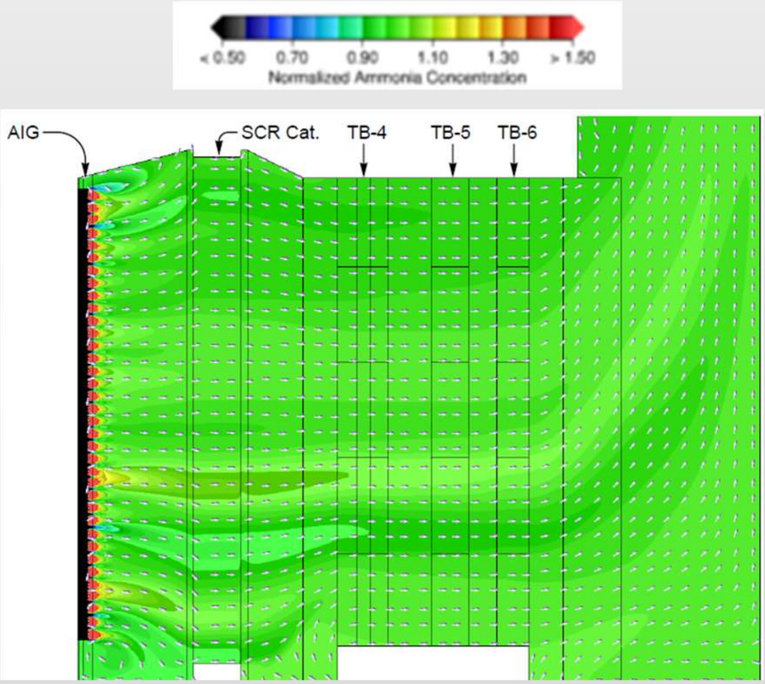


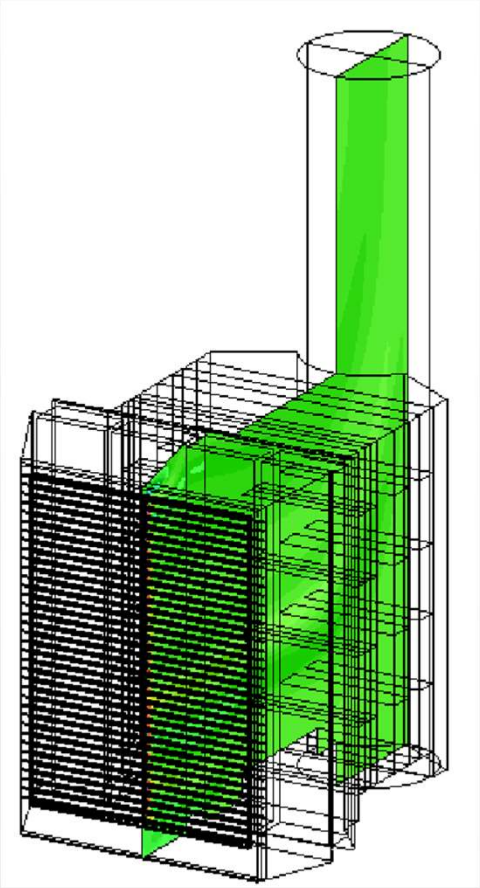


CASE STUDY – HRSG CFD MODELING

- Final Design: Ammonia RMS improved to 5.8% at the catalyst face







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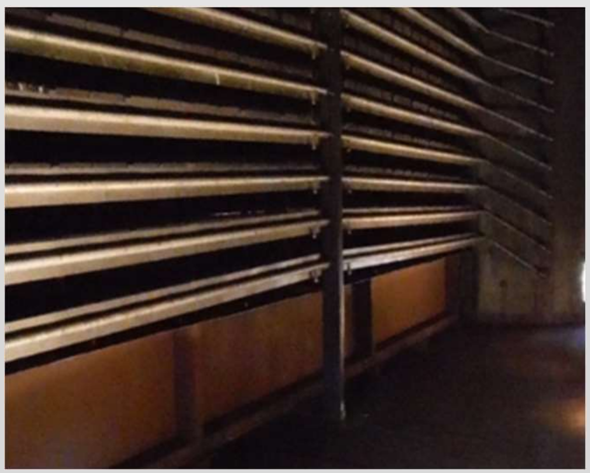

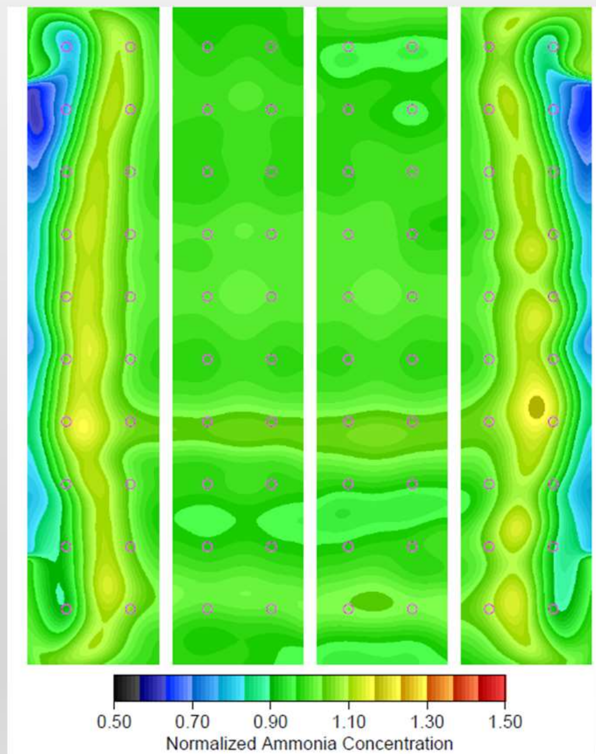

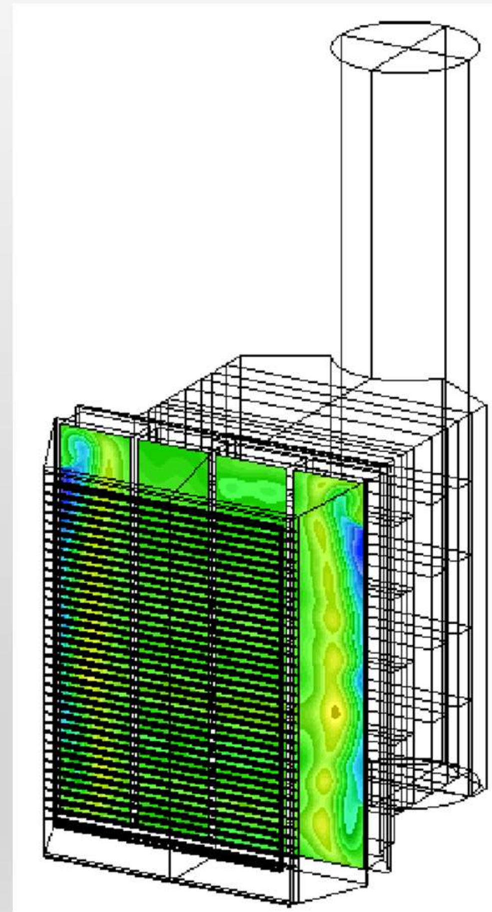

CASE STUDY – HRSG CFD MODELING

- After modifications:
- Plant performance improved significantly on both units
- Small increase in pressure drop due to the new baffles (0.25 IWC), but pressure drop held steady over the next 6 months, indicating that the ammonia salt buildup on the tubes was not occurring
- Ammonia consumption was reduced by 15-25% depending on load

CASE STUDY – HRSG CFD MODELING

- Installation of the new AIG, fall 2017
- Plant feedback, April 2018 (6 months of operation)

We had our first outage/inspection since the installation, and the AIG looks great. No issues to note. Our NOx control has improved, and ammonia usage has decreased 15-25%, depending on load and other conditions. Ammonia salt formation appears to have dropped off significantly. We cleaned the tubes this outage and removed less than half of the debris we typically encounter. We ran half of the last year without the new AIG, so this makes perfect sense. The cleaning crew recommended we either skip the next cleaning or reduce the scope next year. We'll continue to monitor differential pressures and fouling buildup to make that determination.
I again want to thank you for all of the work you put into our project and let you know that it appears to be a great success.
Take care,
XXX (plant engineer name withheld upon request)

CASE STUDY – HRSG CFD MODELING

- Installation of the new AIG, fall 2017
- Plant feedback, January 2024 (6.5 years of operation)

Heat rate improvement wasn't something we looked for to judge the success of the project. We did see an immediate decrease in aqueous ammonia usage (~20%), improved NOx control, and a reduced rate of ammonia salt deposition on the HRSG tube surfaces over time. The bulk of salt deposition also appears to have shifted further back in the HRSG from Module 5 to Module 6. As you know, the reduced salt deposition directly affects heat rate, but there hasn't been any reason for us to quantify the correlation. Since the project was completed, we have only cleaned the HRSGs once, and there was minimal debris recovered. In our opinion, the project was a huge success.

Take care,

XXX (plant engineer name withheld upon request)

CASE STUDY – HRSG CFD MODELING

- Heat rate impact
- Data from a gas turbine manufacturer on latest (2024) large engines
  - Turbine backpressure reduces engine power output and degrades heat rate
  - Every 2 IWC of additional backpressure accounts for ~0.1% on power output and ~0.1% on heat rate
- Data from NAES 2018 article "Cleaning Your HRSG Tubes Improves Performance"
  - Every 4 IWC reduces GT output by 0.42% and increases heat rate by 0.45%

SUMMARY

- There are many parameters that affect HRSG and simple cycle plant performance
- Need an optimized design for flow, temperature, ammonia, NOx, and pressure drop
  - CFD modeling
  - Scale physical modeling
  - Field testing
- Many flow-related parameters are inter-related
  - Ammonia non-uniformity can cause DP and heat rate issues
  - Poor velocity distribution can result in skewed heat transfer at tube banks
  - Tube bank, catalyst and AIG seals/baffles seem "simple" but if not designed/maintained can have significant negative impact
  - Bigger engines require a new look at goals, margin vs. goals, and goals over the load range

CONTACT INFORMATION

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