Improving Design of SCR Systems with CFD Modeling

B. Adams, C. Senior

Reaction Engineering International

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Project Objective

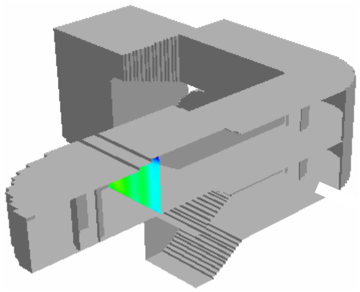
- **Demonstrate value of CFD in SCR design and tuning**
  - **Improved insight of flue gas properties through AIG, SCR catalyst, and ductwork**
  - **Impact of flue gas profiles and flow rates on SCR performance**
  - **Guidance for matching AIG flows with flue gas profiles and resulting impact of AIG tuning**

Project Approach

- Use CFD and 1-D reactor modeling to predict flow properties and NO reduction in 550 MW coal-fired boiler SCR system
  - Flow patterns and velocity profiles
  - Overall pressure drop through duct work
  - Temperature distribution
  - NH_3 distribution from ammonia injection grid (AIG)
  - NO reduction through SCR catalyst
  - Ammonia slip after catalyst
  - NO reduction sensitivities

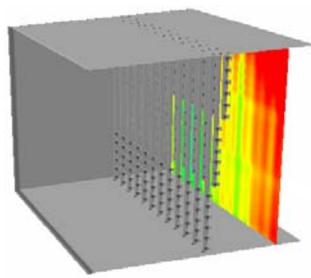
Modeling Approach

Duct Flow Model



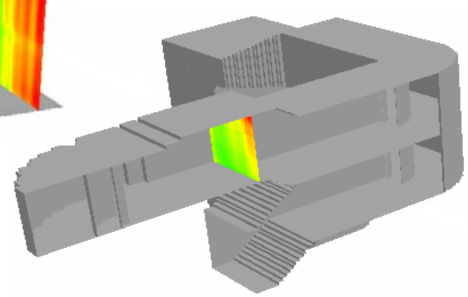
- ΔP
- *Flow distribution*

Detailed AIG Model



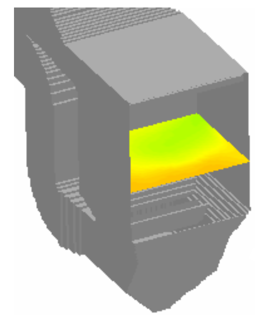
- *NH_3 distribution*

Duct Flow Model



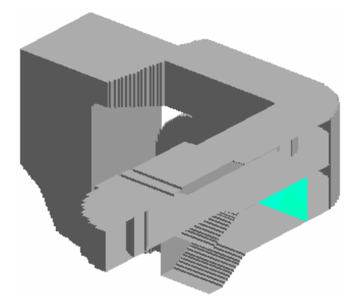
- *SCR model inlet properties*
  - *NH_3 distribution*
  - *NO distribution*
  - *Flow distribution*

SCR Reactor



- *NO reduction*
- *NH_3 slip*

Duct Flow Model

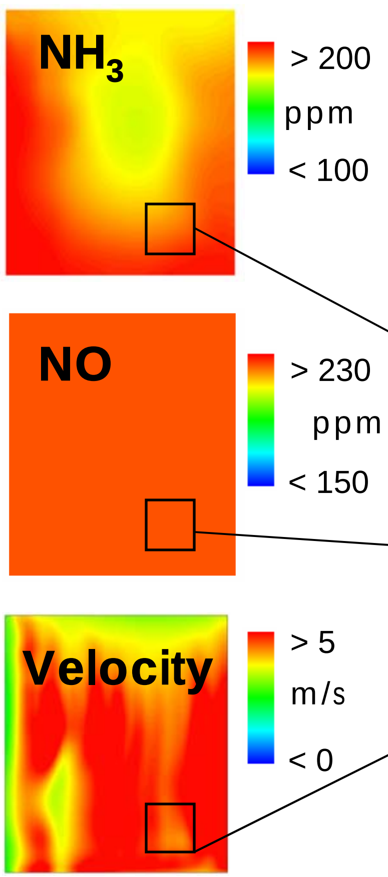


- ΔP
- *Flow field*
- *NH_3 slip distribution*
- *NO distribution*

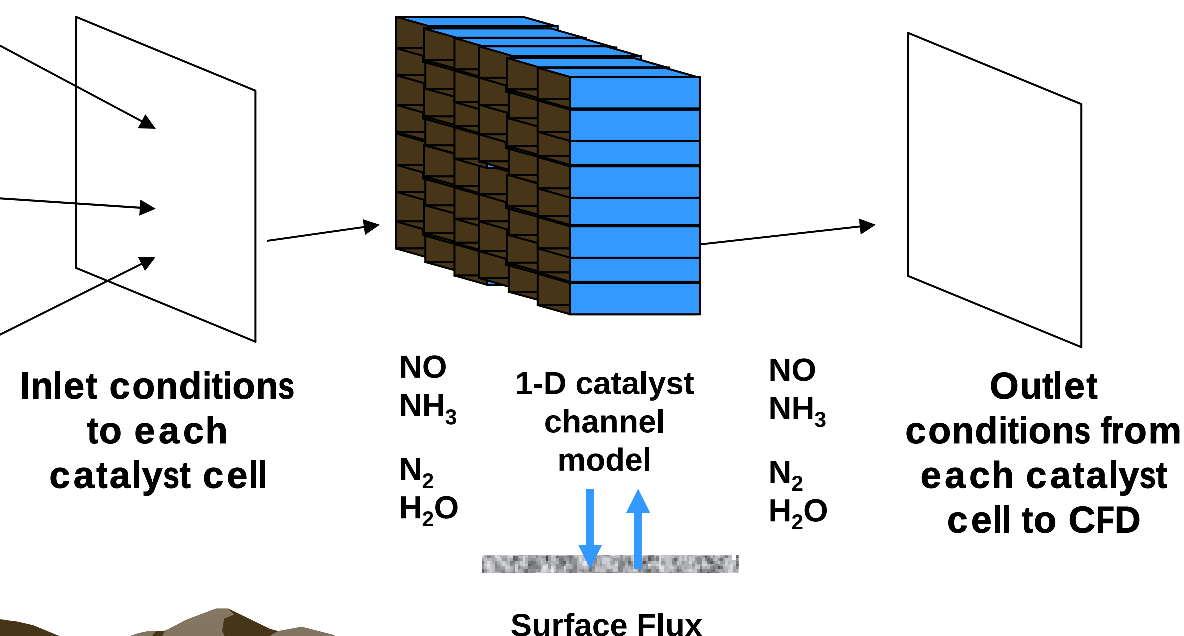
- **Three model components:**
  - Duct flow model
  - Ammonia Injection Grid (AIG) submodel
  - SCR catalyst submodel

SCR Model – Implementation

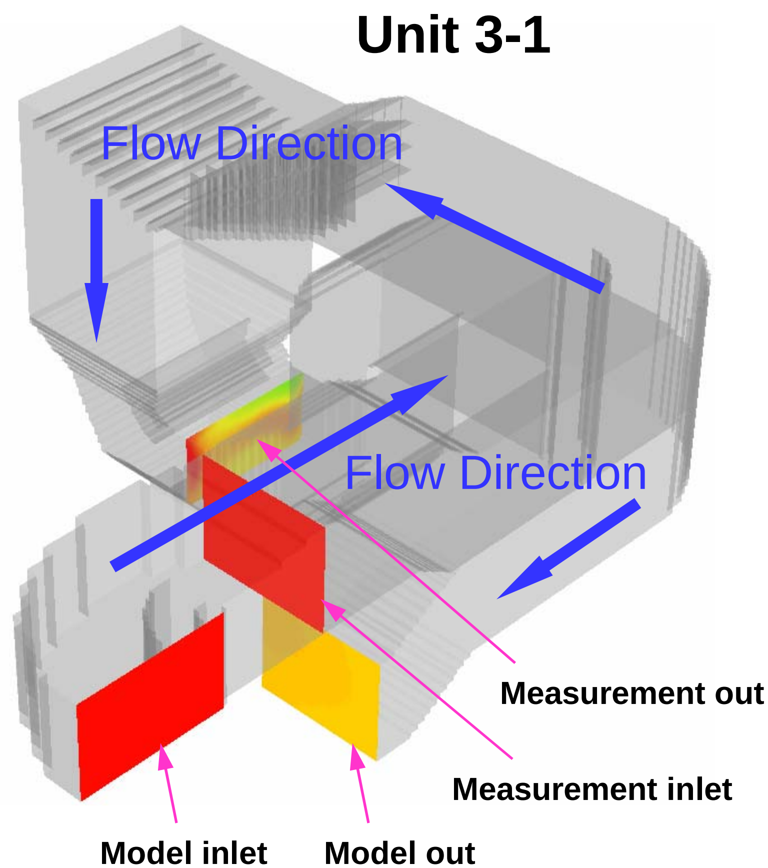
Results at SCR Inlet

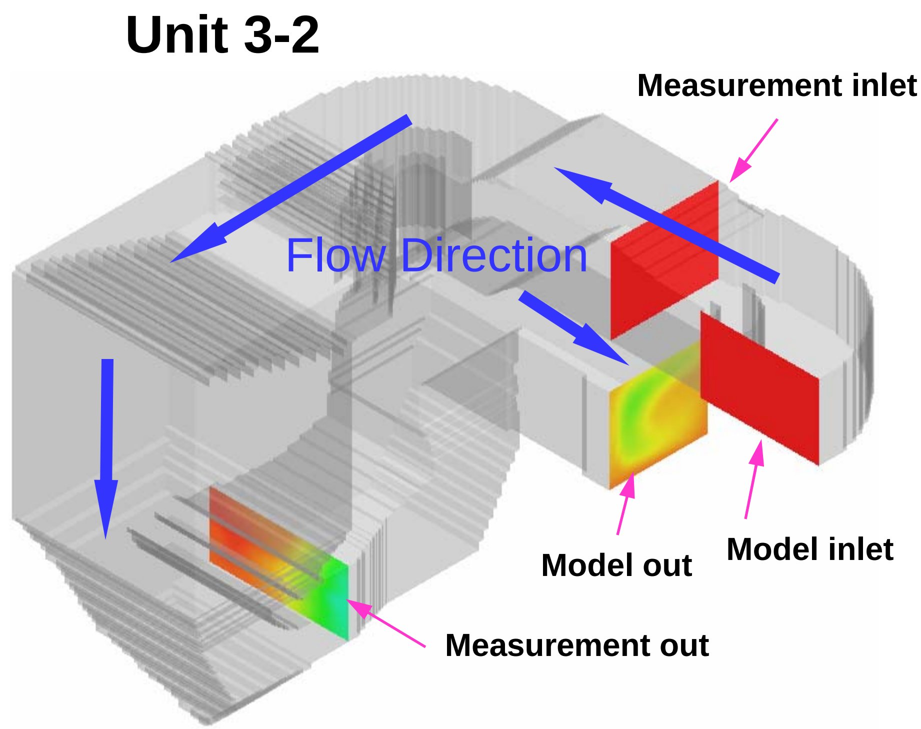


- **1-D plug flow model with heterogeneous kinetics for NO reduction by NH_3 over vanadia/titania catalysts**
- **Solves gas transport and surface reactions along catalyst**
- **Number of "active sites" for reaction calibrated with design data**
- **Predicts dependencies of NH_3/NO ratio, temperature, residence time and flue gas composition**



SCR Geometries

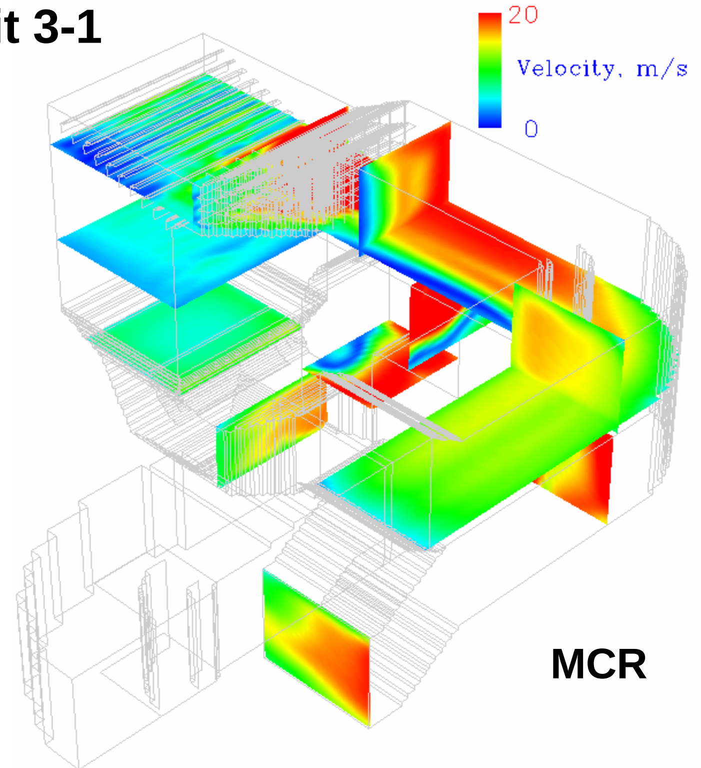


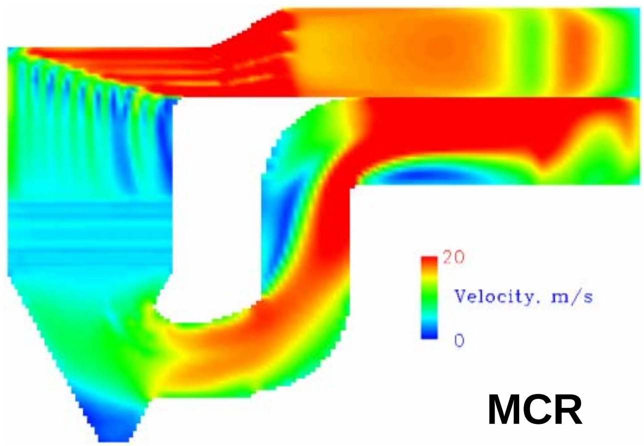


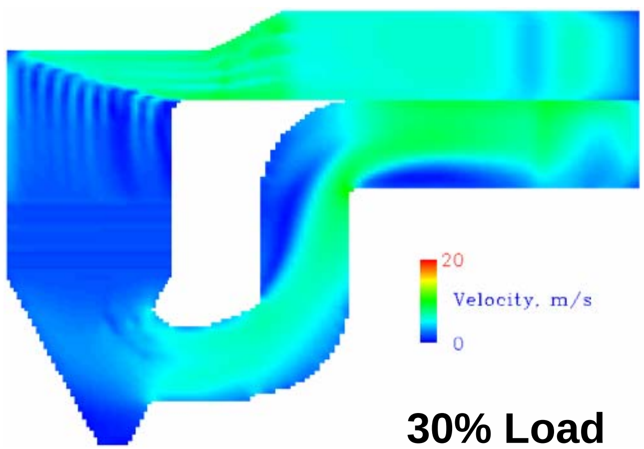
Unit 3-2 has shorter run length between turn and AIG and shorter run length between AIG, turn, and guide vanes

Gas Velocity Profile

Unit 3-1



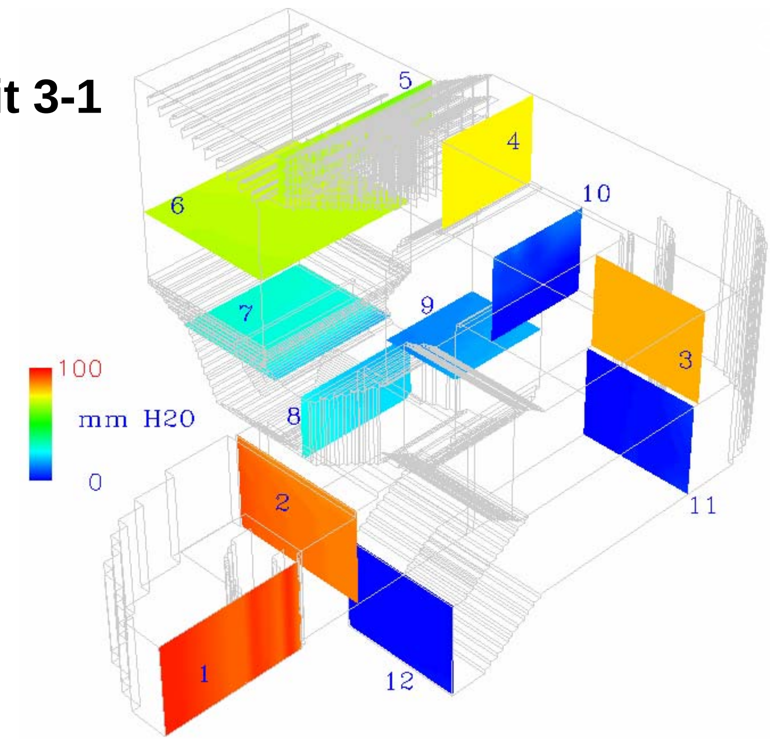


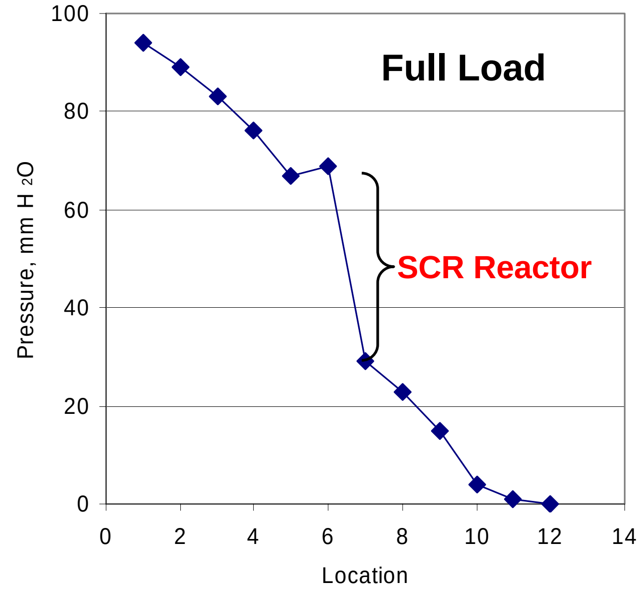


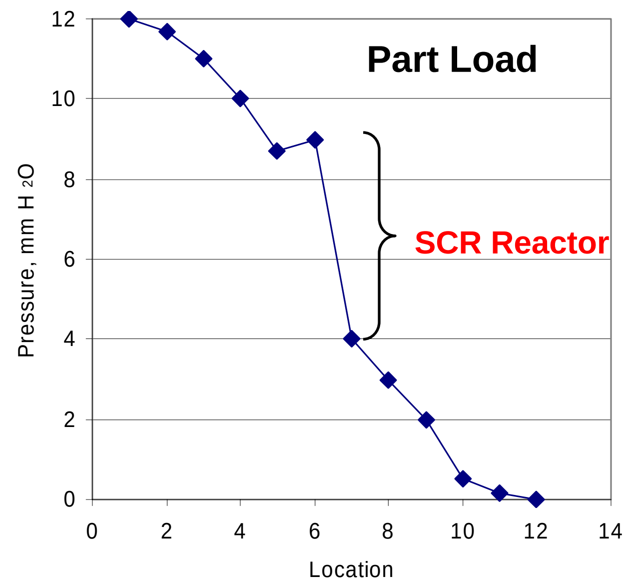
Velocity profiles can suggest improvements to guide vane design

Pressure Drop

Unit 3-1







Profiles identify specific contributors as well as total system pressure drop

Flow Comparisons

			Unit 3-1	Unit 3-2	Total
		Flow, 10^3 kg/hr	1128.5	1128.5	2257.0
	MCR	ΔP (mm H_2O, SCR)	40.0	37.5	-
		ΔP (mm H_2O, N1 to N3 or N4 to N6)	89.1	79.2	-
		Total ΔP (mm H_2O)	94.0	84.0	-
		Flow, 10^3 kg/hr	-	694.2	-
Model	30% Load	ΔP (mm H_2O, SCR)	-	13.1	-
	(July 17, 2004)	ΔP (mm H_2O, N1 to N3 or N4 to N6)	-	27.7	-
		Total ΔP (mm H_2O)	-	29.0	-
		Flow, 10^3 kg/hr	431.5	431.5	863.0
	30% Load	ΔP (mm H_2O, SCR)	5.0	4.9	-
	(design)	ΔP (mm H_2O, N1 to N3 or N4 to N6)	11.7	10.4	-
		Total ΔP (mm H_2O)	12.0	10.8	-
		Flow, 10^3 Nm^3/hr	948.3	871.0	1819.2
	MCR	Flow, 10^3 kg/hr	1260.8	1158.0	2418.9
	(July 16, 2004)	Design SCR ΔP (mm H_2O)	39.8	37.3	-
Measured		ΔP (mm H_2O, N1 to N3 or N4 to N6)	98.4	73.7	-
		Flow, 10^3 Nm^3/hr	576.2	522.1	1098.3
	30% Load	Flow, 10^3 kg/hr	766.1	694.2	1460.3
	(July 17, 2004)	ΔP (mm H_2O, N1 to N3 or N4 to N6)	44.1	34.1	-

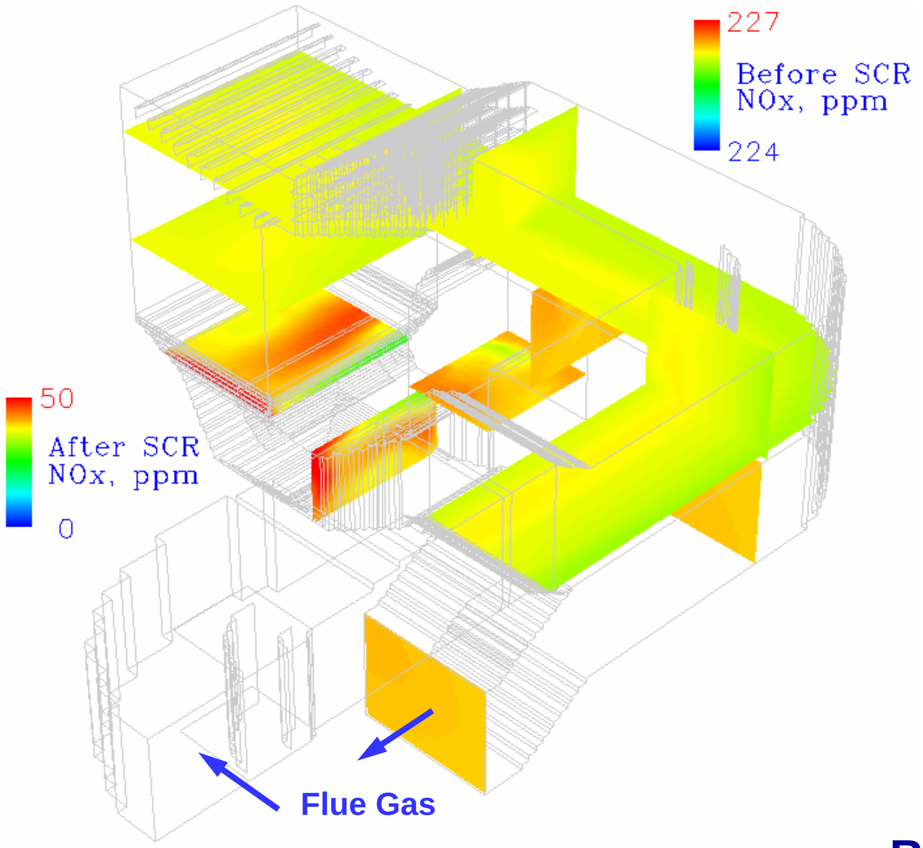
- **Predictions consistent with the measured data**
- **Differences likely due to:**
  - **Inlet flow profile**
  - **Different flow rates**
  - **Measurement locations/grid**
  - **Model accuracy**

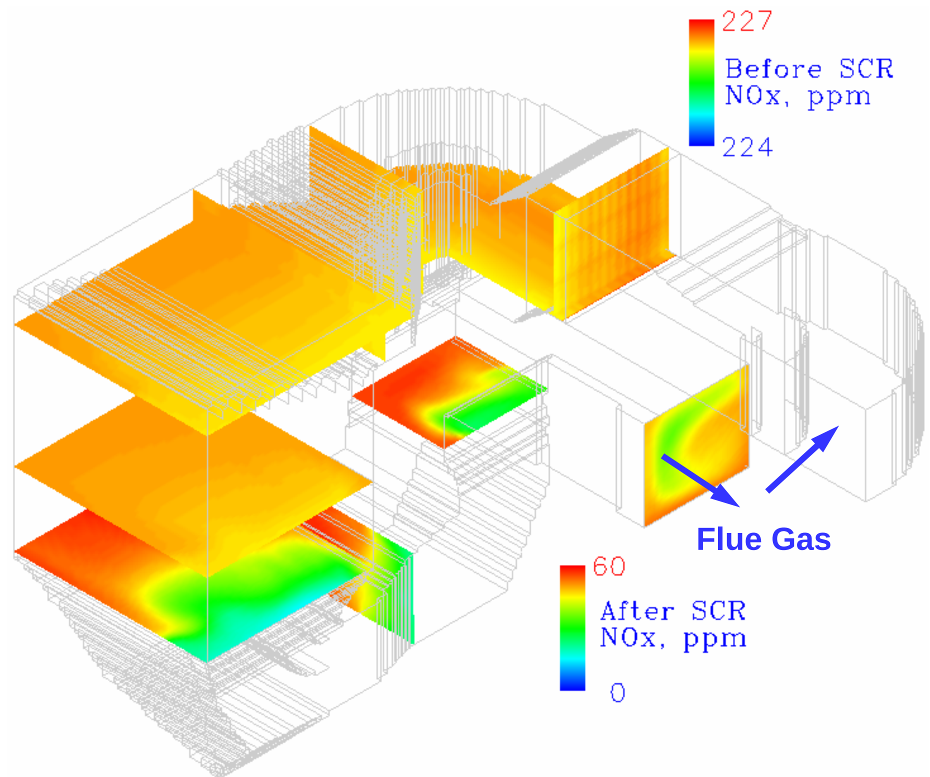
NO Reduction Dependencies

- **NO reduction depends on:**
  - **NH_3/NO ratio – insufficient ammonia (ratio<1.0) will not reduce all available NO (NO remaining)**
  - **Residence time – insufficient residence time will not allow NH_3 enough time to react with NO (NO and NH_3 remaining)**
- **NH_3 slip depends on:**
  - **NH_3/NO ratio – too much ammonia (ratio>1.0) will reduce all NO (NH_3 remaining)**
  - **Residence time – insufficient residence time will not allow NH_3 enough time to react with NO (NO and NH_3 remaining)**

NO Concentration Profile

Unit 3-1 vs 3-2 at MCR

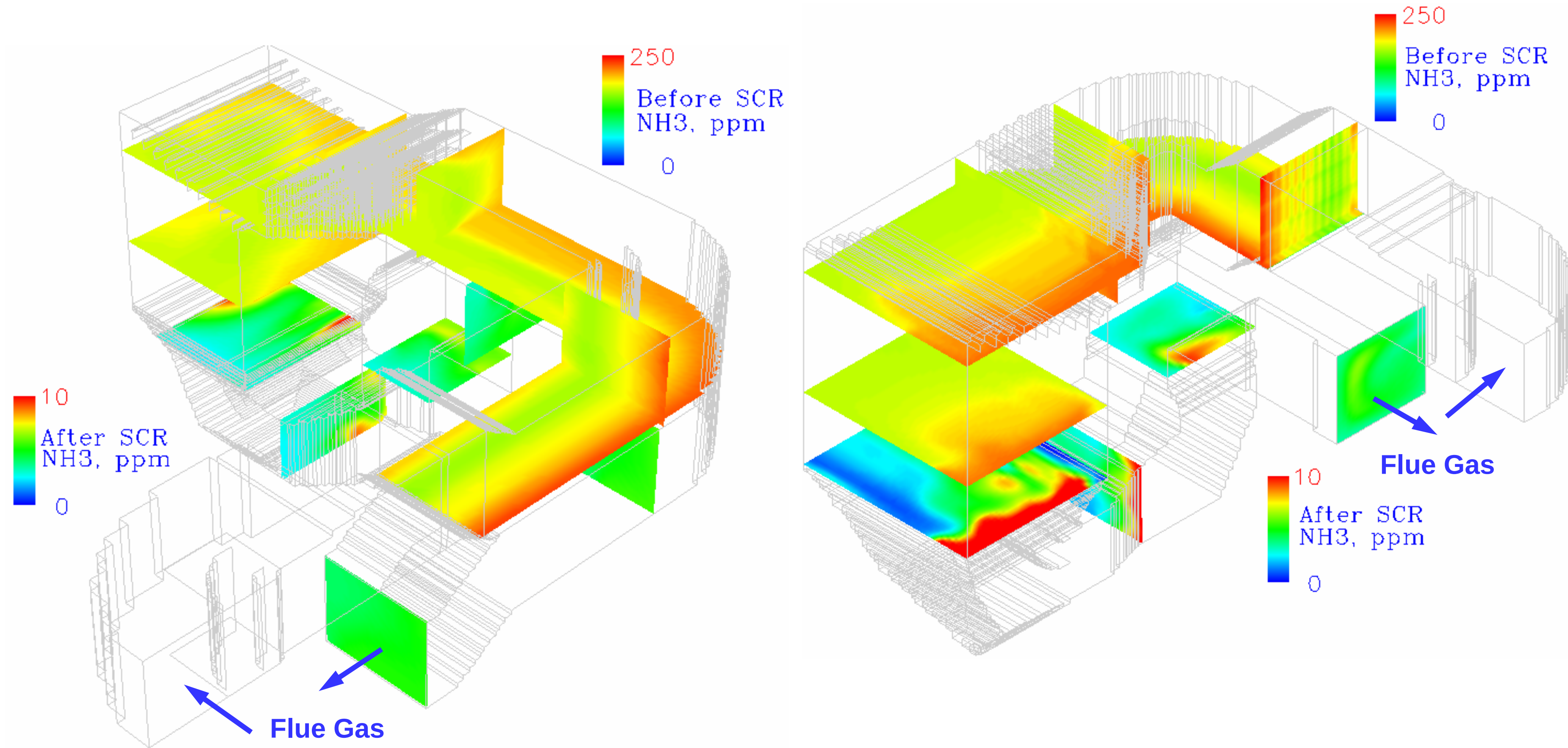




Both cases show biased NOx profiles

NH_3 Concentration Profile

Unit 3-1 vs 3-2 at MCR



Both cases show biased NH_3 profiles

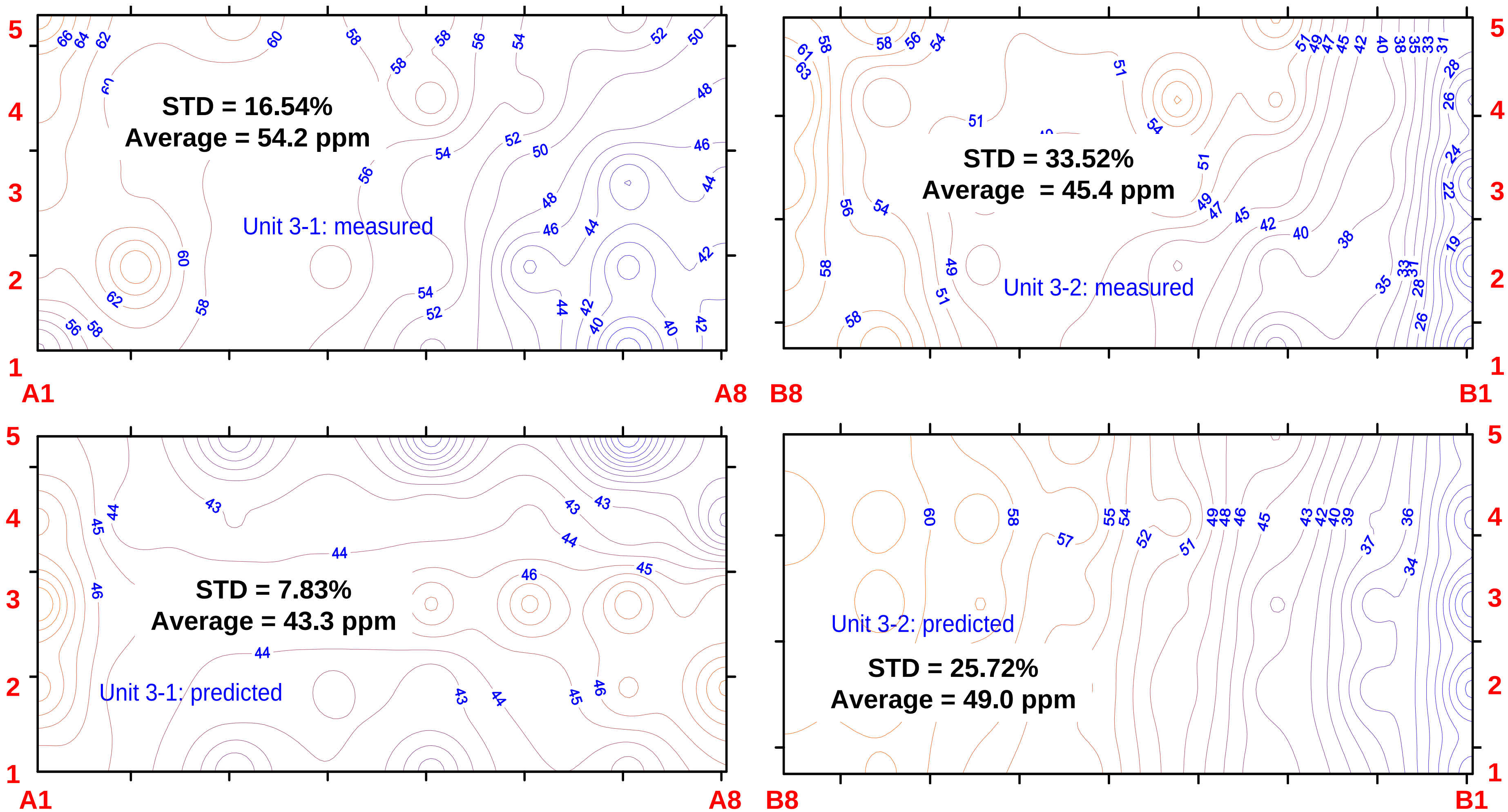
SCR Model Predictions

		Unit 3-1		Unit 3-2	
		INLET	OUTLET	INLET	OUTLET
MCR, Fully Open AIG	NH_3, ppm @ 6%O_2 Dry	171	4.0	171	4.2
	NO, ppm @ 6%O_2 Dry	210	42.7	210	43.0
	NO Reduction, %	-	79.6	-	79.5
30% load, Fully Open AIG	NH_3, ppm @ 6%O_2 Dry	171	0.0	171	0.2
	NO, ppm @ 6%O_2 Dry	210	38.8	210	38.9
	NO Reduction, %	-	81.4	-	81.4
30% load with higher O_2 Fully Open AIG	NH_3, ppm @ 6%O_2 Dry	-	-	171	1.5
	NO, ppm @ 6%O_2 Dry	-	-	210	40.2
	NO Reduction, %	-	-	-	80.8

- **Ammonia slip likely due to higher than design velocities in catalyst (lack of residence time)**
- **Limited residence time also reduces NO reduction**
- **Will more uniform NH_3/NO profiles improve performance?**

Outlet NO Profile at MCR

Measurement taken with fully open AIG nozzles (NO ppm, dry)



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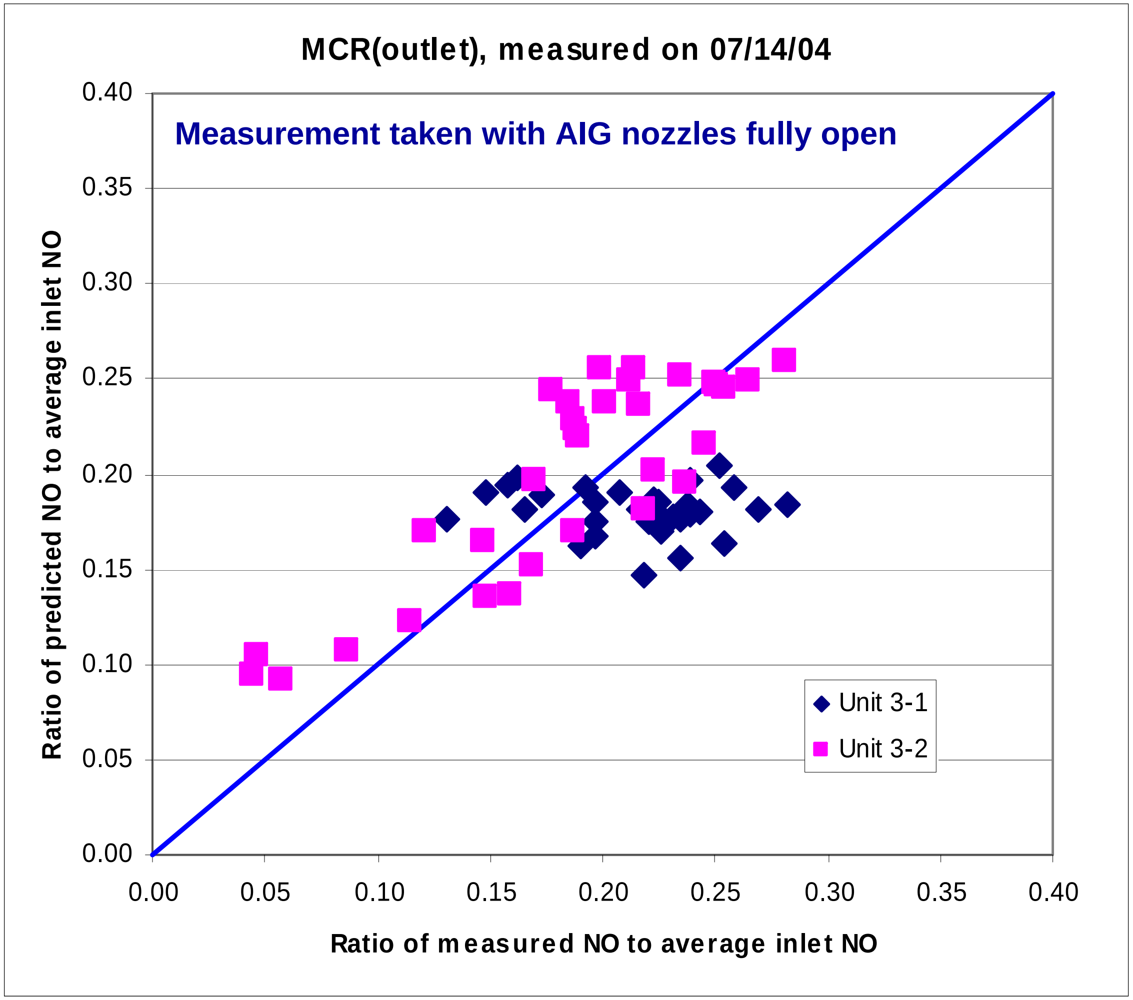
NO Exit Profile Results



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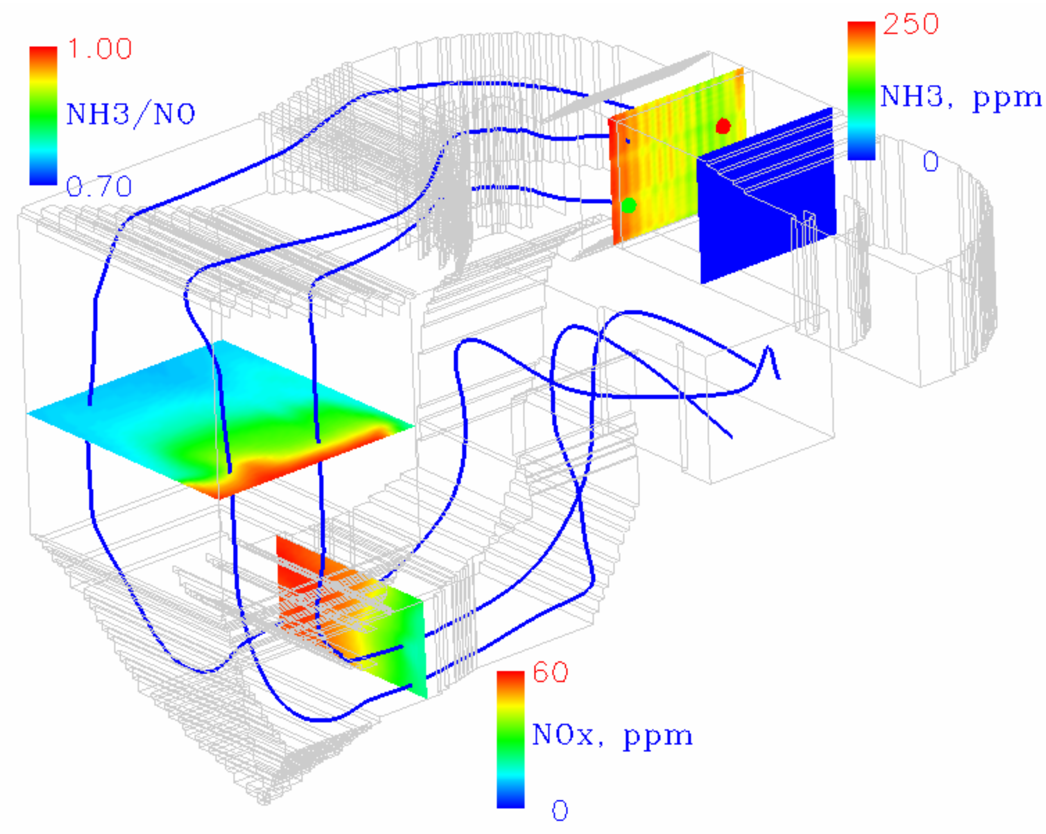
AIG Tuning

- ***Background:*** **Modeling results with fully open AIG nozzles indicate a bias in the flue gas flow in the AIG region, leading to NH_3 biasing at the catalyst inlet**
- ***Objective:*** **Use CFD modeling to simulate AIG tuning and show how CFD can be used to guide AIG in the SCR duct (Unit 3-2)**
- ***Approach:*** **Use zonal AIG biasing to achieve more uniform NH_3/NO ratio (0.814)**

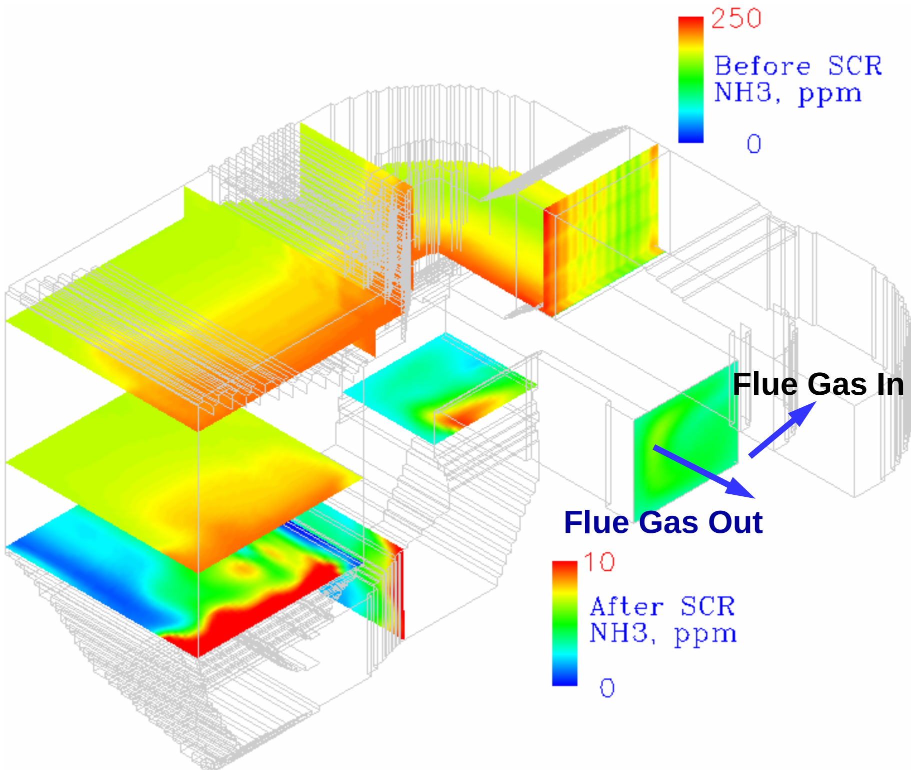
Using CFD For Tuning



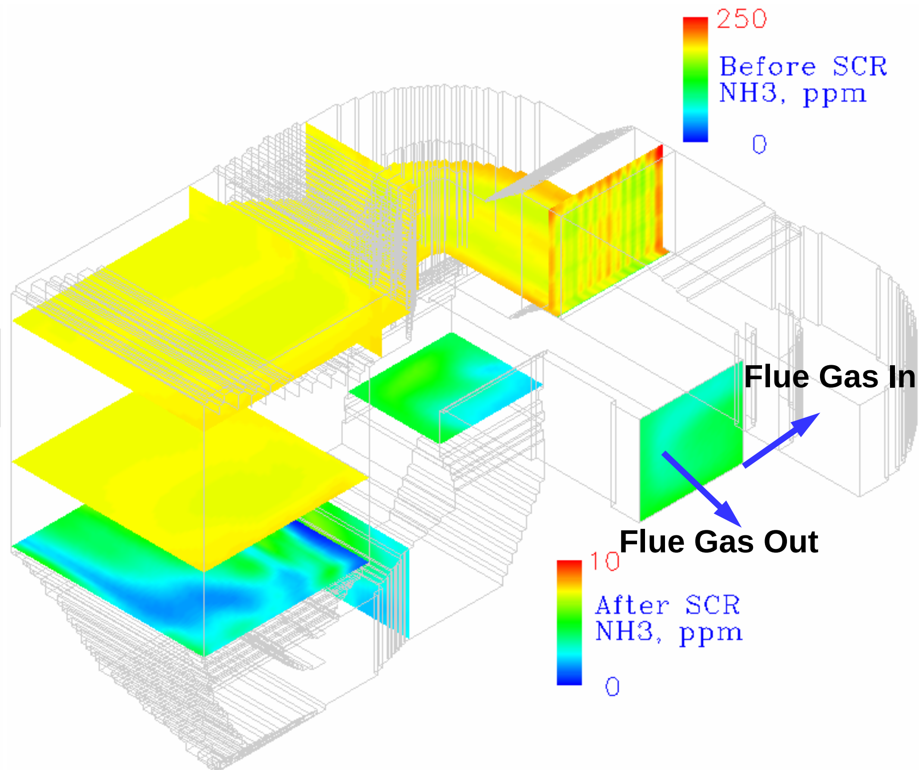
- **CFD can show profiles through system**
- **CFD can be used to trace source of profile**
- **Streamlines correlate local NO at outlet with corresponding NH_3/NO entering the catalyst, and ultimately with the corresponding AIG nozzles**

NH_3 Concentration Profile

Unit 3-2 at MCR

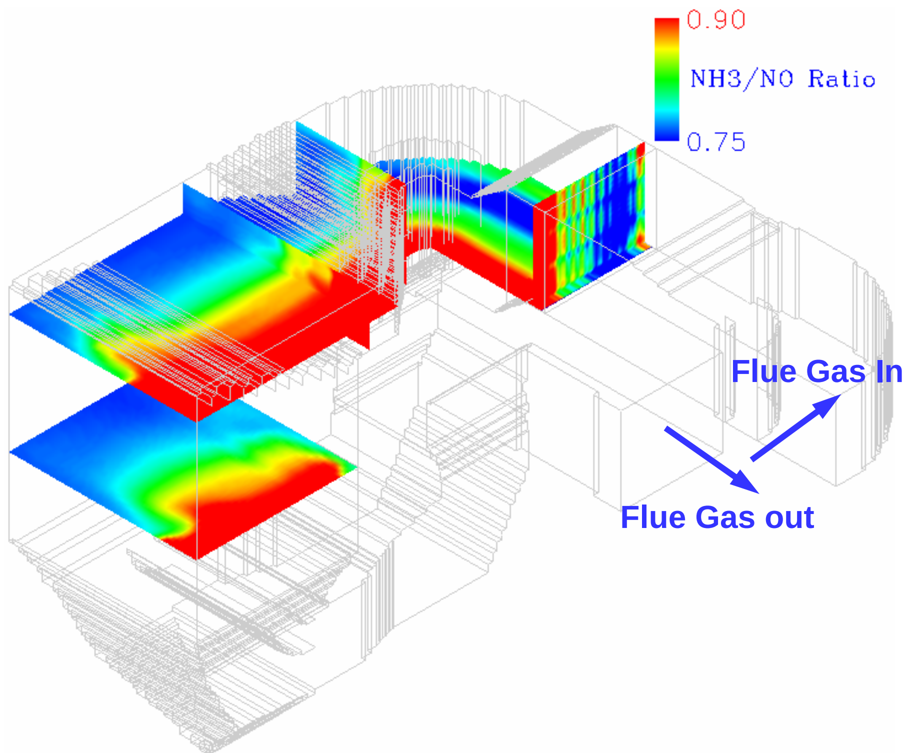


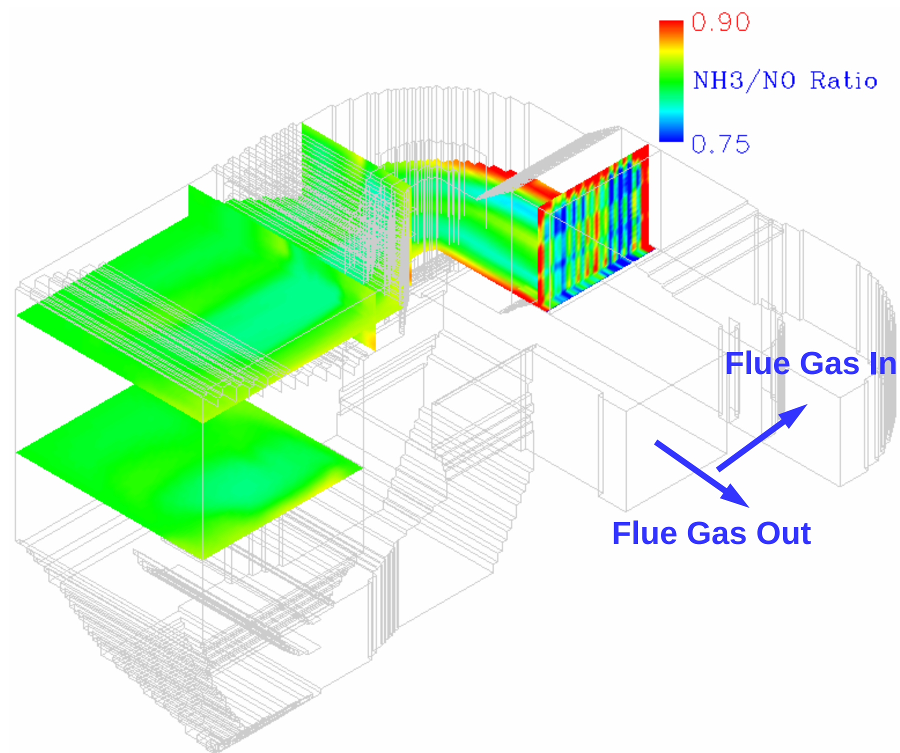
Fully Open AIG Nozzles
(Uniform NH_3 injection)



AIG Tuning
(Biased NH_3 injection)

NH_3/NO Ratio Profile
Unit 3-2 at MCR



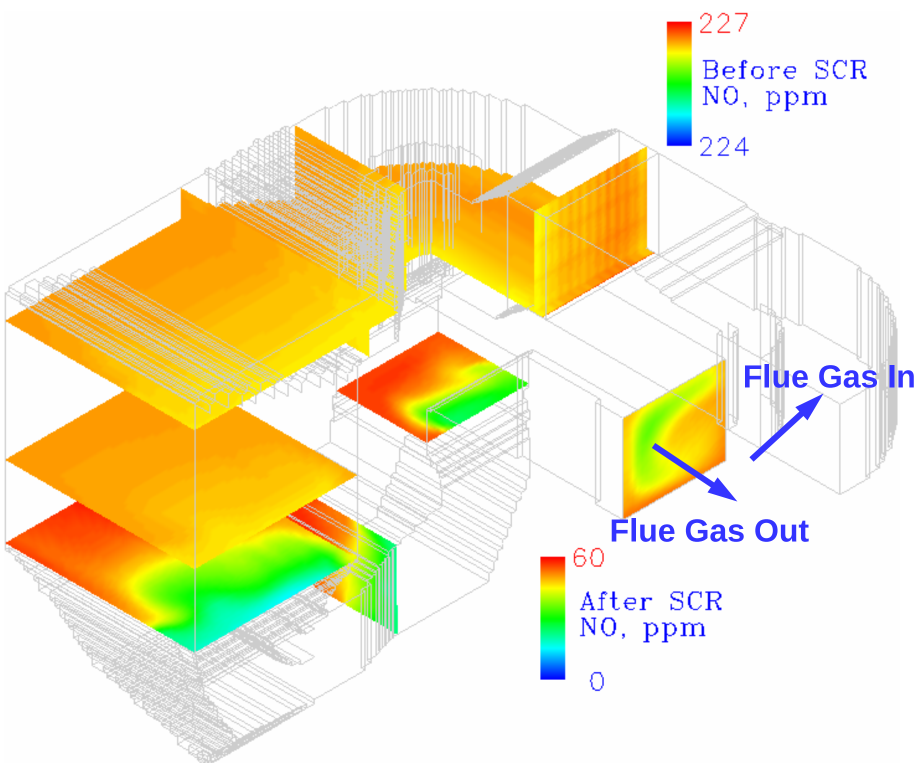


Fully Open AIG Nozzles
(Uniform NH_3 injection)

AIG Tuning
(Biased NH_3 injection)

NO Concentration Profile

Unit 3-2 at MCR



Fully Open AIG Nozzles
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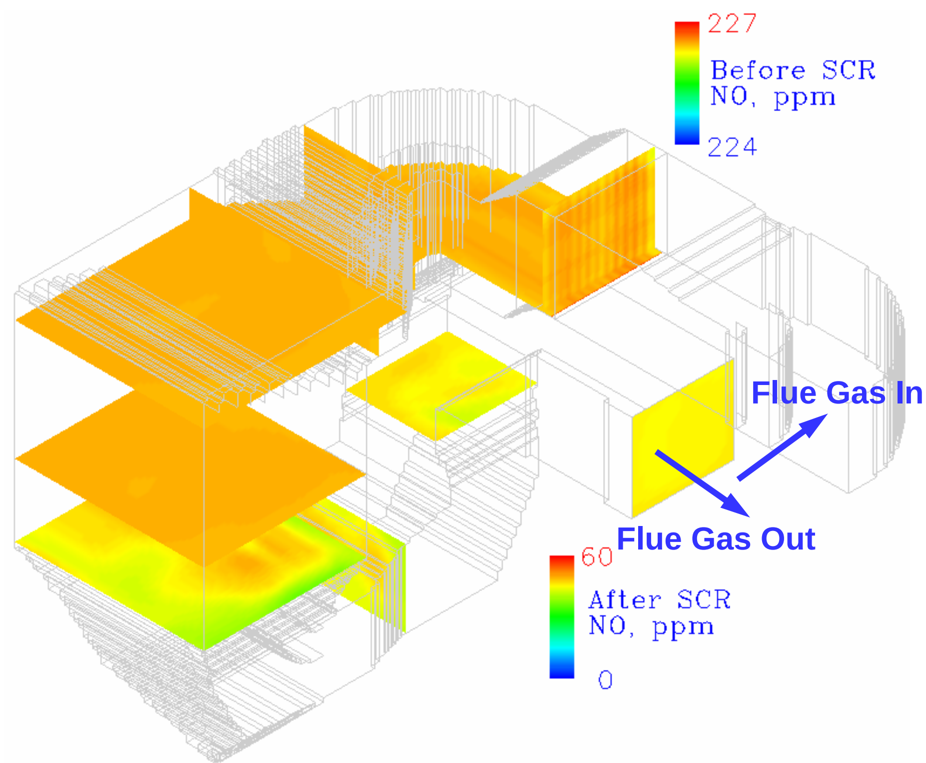
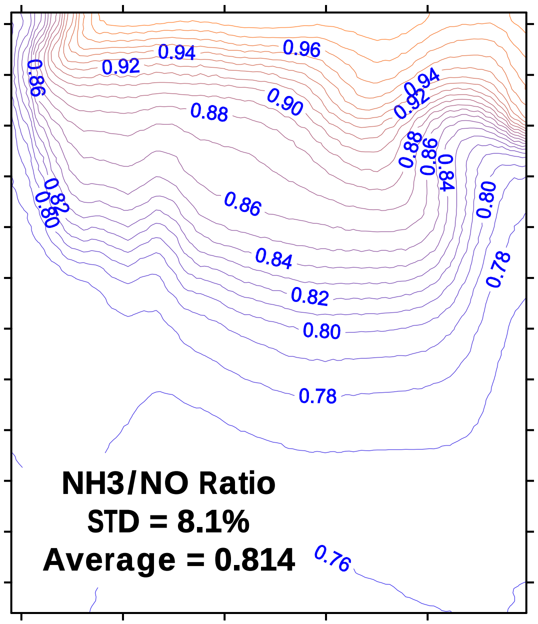
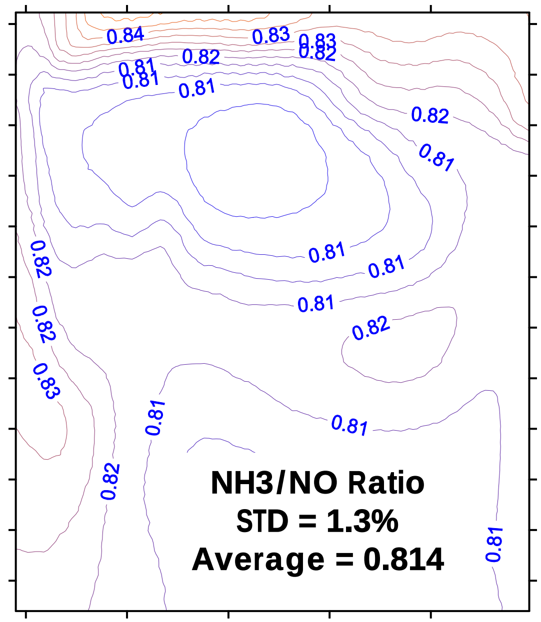


AIG Tuning
(Biased NH_3 injection)

Predicted Effects of AIG Tuning





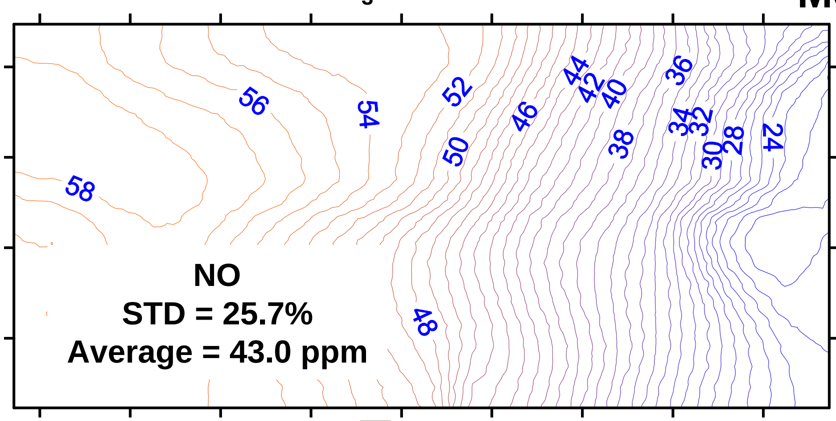
Catalyst Inlet

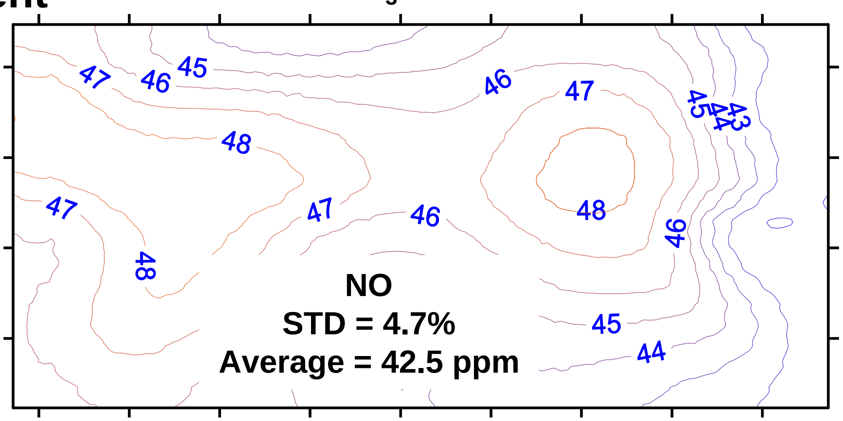
Uniform NH_3+Air Flow

Biased NH_3+Air Flow

Measurement Outlet

Dry, 6% O_2





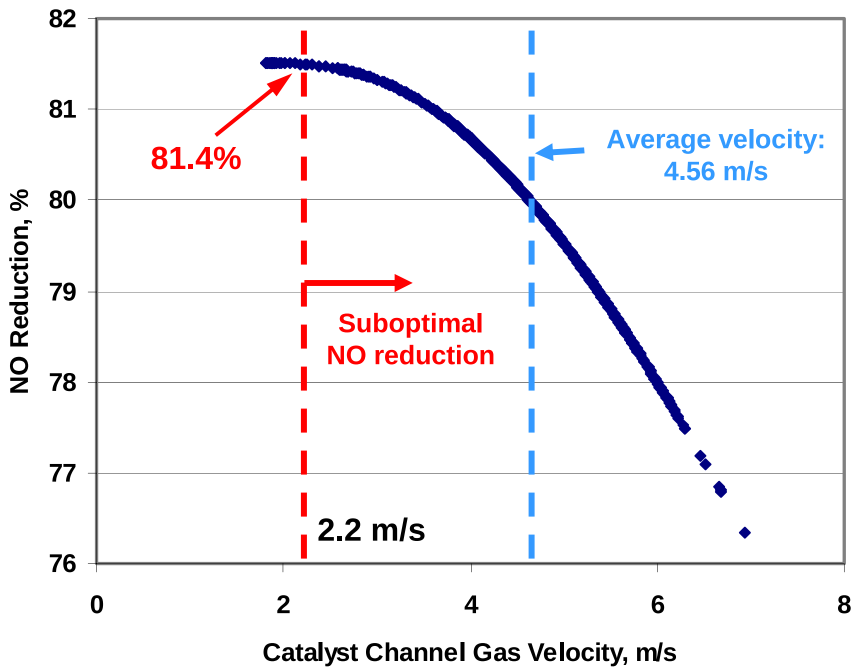
SCR Model Predictions

AIG Conditions	Unit 3-2: MCR			
	Uniform		Tuning	
	INLET	OUTLET	INLET	OUTLET
NH_3, ppm @ 6%O_2 Dry	171	**4.2**	171	**3.8**
NO, ppm @ 6%O_2 Dry	210	**43.0**	210	**42.5**
SCR Inlet NH_3/NO Mole Ratio	0.814		0.814	
NO Red, %		**79.50**		**79.71**
NH_3 Slip, ppm @ 6%O_2 Dry		**4.2**		**3.8**

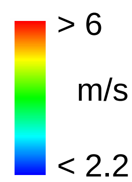
- **Why didn't the NO reduction improve with a more uniform NH_3/NO ratio at the SCR reactor inlet?**
  - **More uniform NH_3/NO ratio improved reduction in low ratio regions, but decreased reduction in high ratio regions**
  - **Average residence time unchanged, still too short to allow full conversion to 81.4%**
  - **Both results were close to the optimal reduction specified in the catalyst design for this load, NH_3/NO ratio, and catalyst size (80%)**

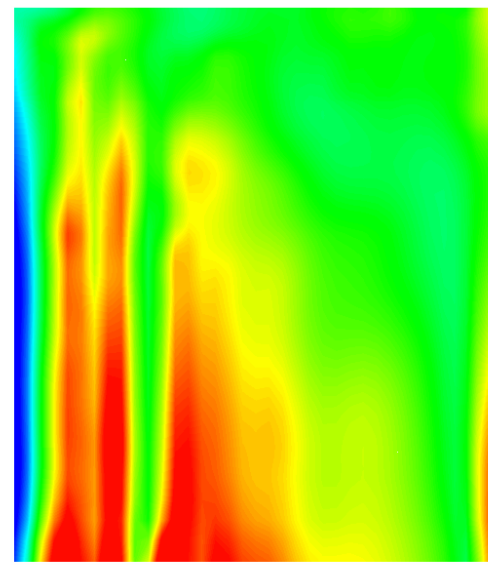
SCR Model: Effect of Gas Velocity on NO Reduction

Velocities plotted are from actual duct velocities



Velocity profile at SCR catalyst inlet



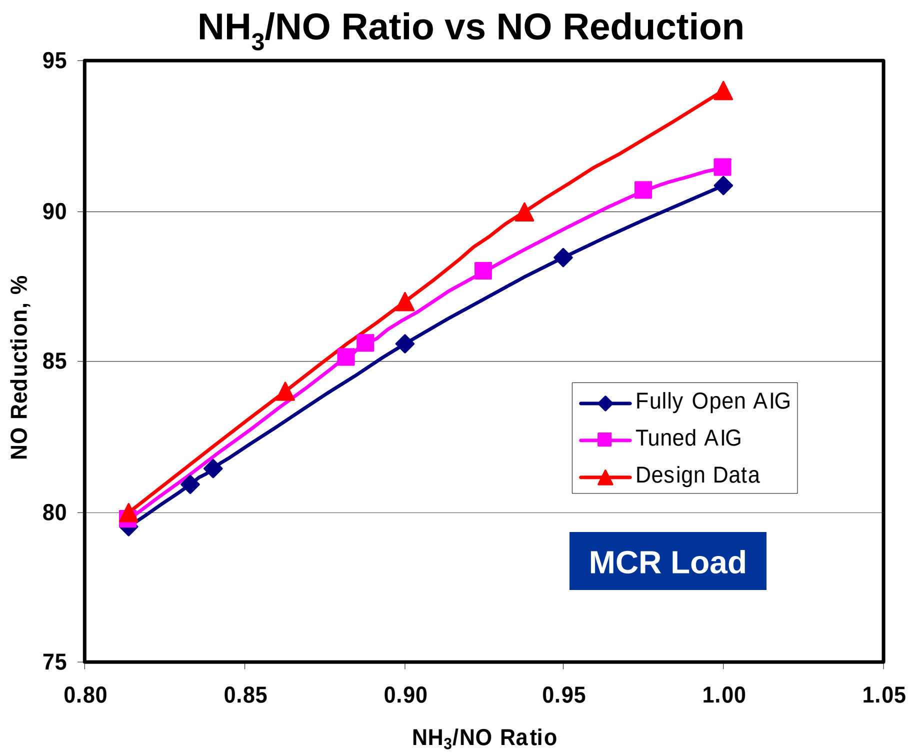


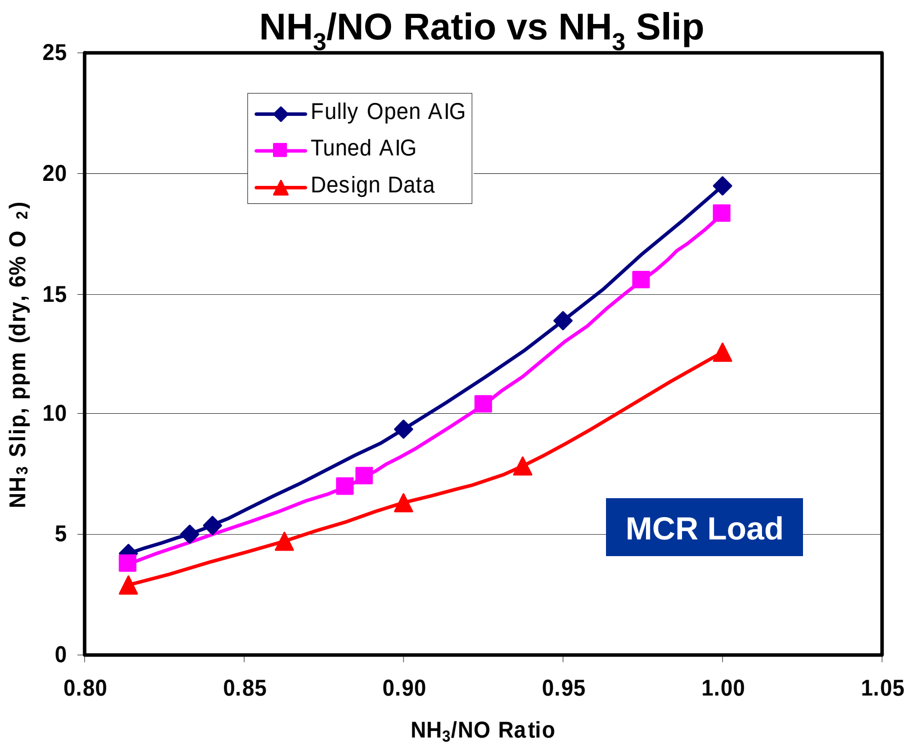
Average vel: 4.56 m/s

All non-blue colors represent velocities that could lead to suboptimal NO reduction

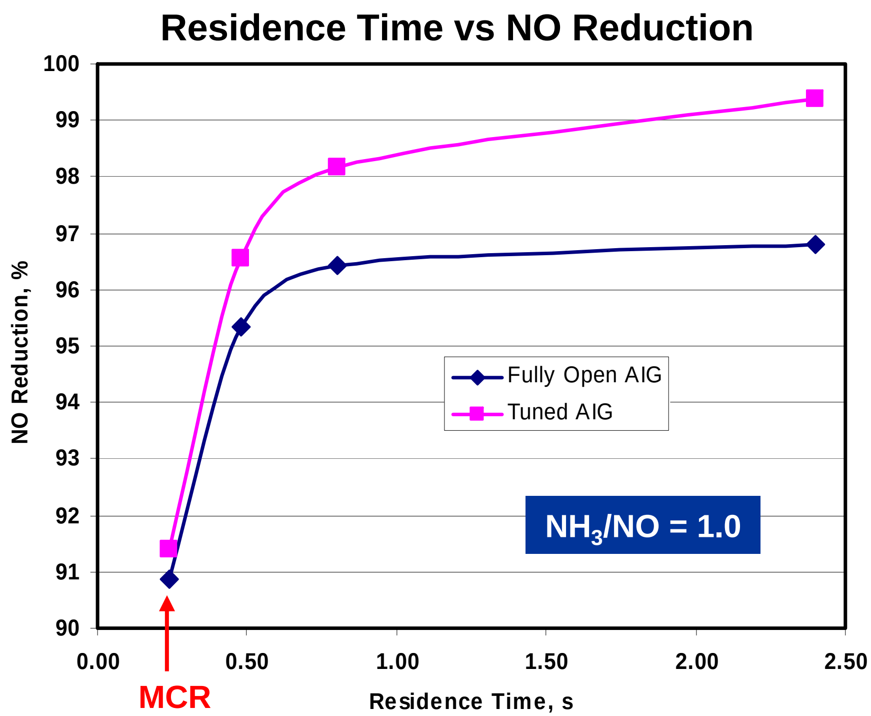
At MCR, catalyst design does not allow sufficient residence time to react all NH_3 with NO, even with optimal NH_3/NO ratio

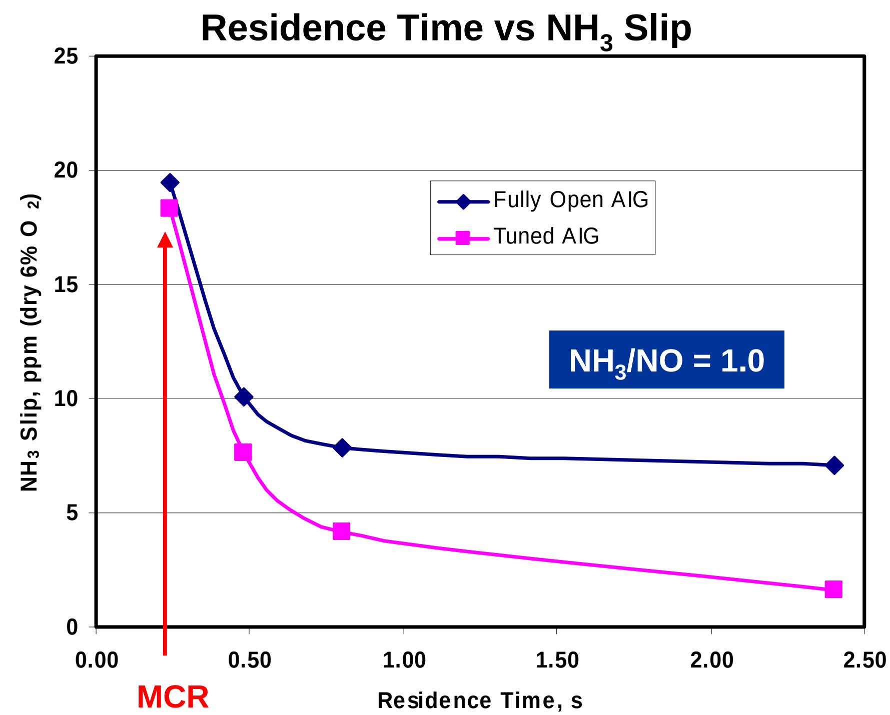
Predictions at Higher NH_3/NO Ratios





Predictions at Higher Residence Times





What Can Model Do

- **Predict performance and identify potential design problems before design/installation**
  - **Predict NO reduction and ammonia slip (measurements verify accuracy for the same NH_3/NO ratio, load, catalyst design)**
  - **Guide how much NH_3 needed to reach NO reduction goal**
  - **Guide amount of catalyst needed for NO reduction goal**
  - **Suggest duct designs to provide more uniform flow**
- **Aid tuning and troubleshooting**
  - **Illustrate tuning impacts**
    - **Guidance on how to tune AIG injection**
    - **Determine if tuning worthwhile for a particular design**
  - **Identify measurement locations for testing and/or analyzer**

Thank You

adams@reaction-eng.com