Urea Mixing Design

-- Simulation and Test Investigation

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Integrations and Emissions

General Motors Company

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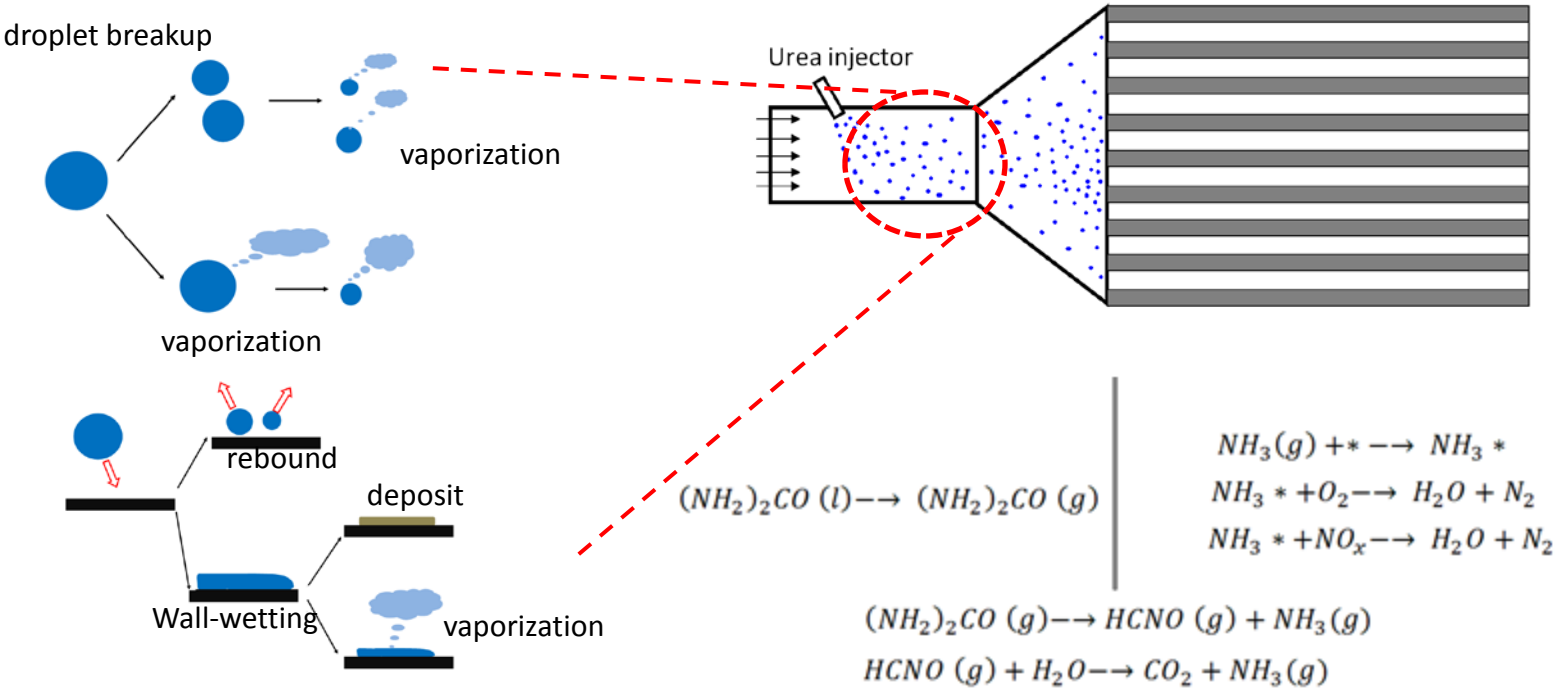
- Summary

- Urea SCR System
  - Liquid urea is introduced into exhaust flow
  - Urea droplet goes through vaporization, hydrolysis reactions to form ammonia gas
  - Ammonia adsorbs on catalyst first then reacts with NOx

(it is pre-stored ammonia to have SCR reaction, but not instant injected urea)



- Urea Mixing Design

  It is a whole system design targeting high SCR efficiency, including spray(injector), exhaust pipe/cone and mixer, but not just mixer itself.

  - Impact factors for SCR efficiency
    - SCR catalyst (formulation, deactivation …)
    - Temperature (exhaust temperature, heat loss)
    - Space velocity
    - NH3 storage level (urea dosing control algorithm)
    - Local NH3/NOx ratio (urea mixing)
  - Impact factors for urea mixing
    - Temperature
    - Flow uniformity
    - Injector type (spray angle, droplet size and momentum)
    - Injection location
    - Mixing length(time)
    - Mixing structure (flow turbulence)

- Mixer Design

Mixer is widely used to enhance urea vaporization, mixing and avoid deposit. The functions of mixer are summarized in the following:

– Droplet breakup

– Liquid vaporization

– Mixing enhancement

– Mixing Length/Time increase

Larger surface area,
small flow channel

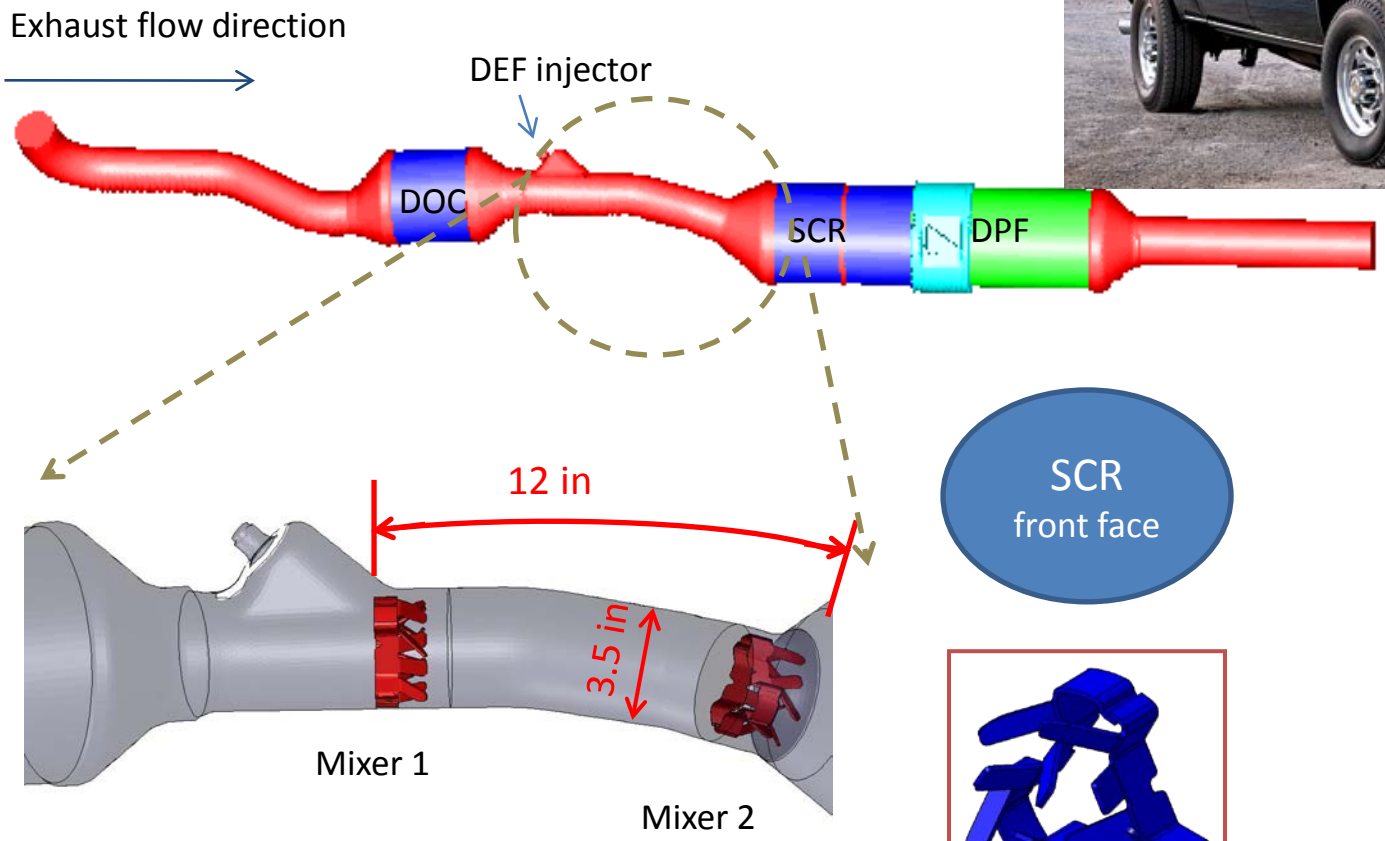
Larger surface area,
small flow channel
Blade to generate turbulence

Larger surface area,
Blade to generate turbulence
Increased actual flow path

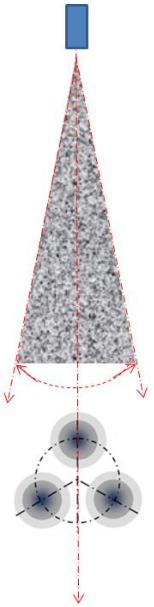
Comparison of Different Urea Mixing Systems

- Test Baseline

  2011 Chevrolet Silverado 2500HD



SCR
front face



SMD: 130µm
Angle: 16°
3-hole injector

Comparison of Different Urea Mixing Systems

- Investigated Impact Factors
  - ~~Temperature~~
  - ~~Flow uniformity~~
  - Injector type (spray angle, droplet size and momentum)
  - Injection location
  - ~~Mixing length(time)~~
  - Mixing structure (flow turbulence)
- Test Used for Investigation
  - Transient vehicle emission cycle test (overall SCR efficiency)
    - FTP75 (bag 1&2), US06
  - Steady-state bench test (NH3/NOx distribution measurement*)
    - 160kg/hr, 220°C, 650kg/hr, 320°C

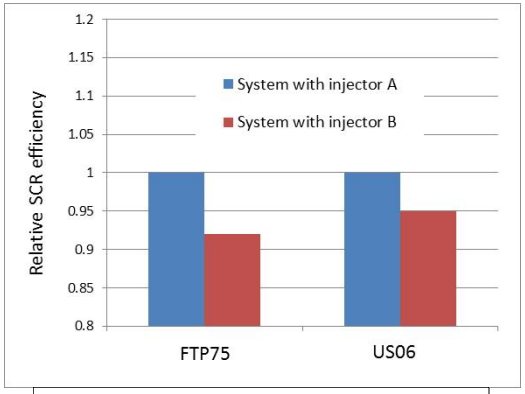
* NH3 and NOx concentration at SCR outlet are measured by FTIR, and SCR inlet NH3-to-NOx-Ratio is calculated by mass balance:

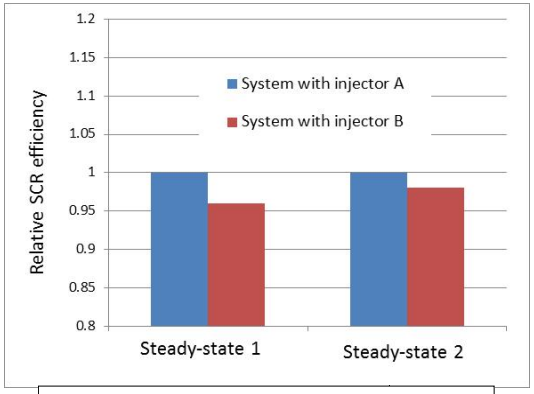
NH3_inlet = NH3_outlet + (NOx_inlet – NOx_outelt)

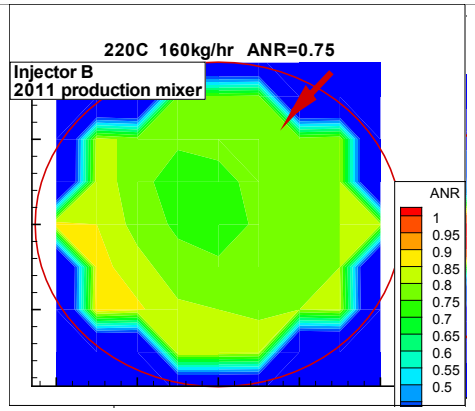
Comparison of Different Urea Mixing Systems

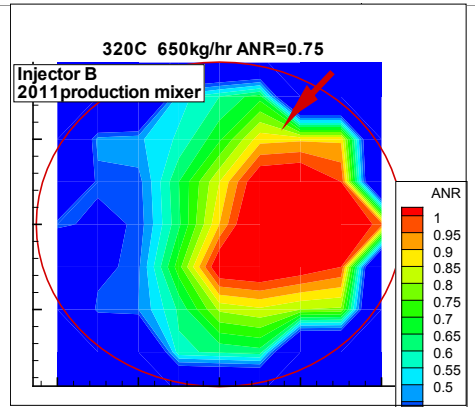
- Spray(injector) Impact

  Keep the same architecture and just switch injector

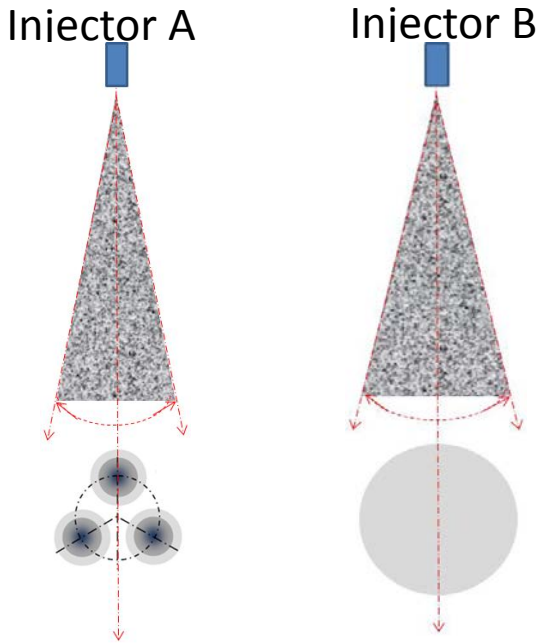








SCR inlet ANR (NH3-to-Nox-Ratio) distribution



- Finer spray does not give better urea/NH3 distribution for a fixed exhaust system.
- The exhaust flow has greater impact on finer droplet

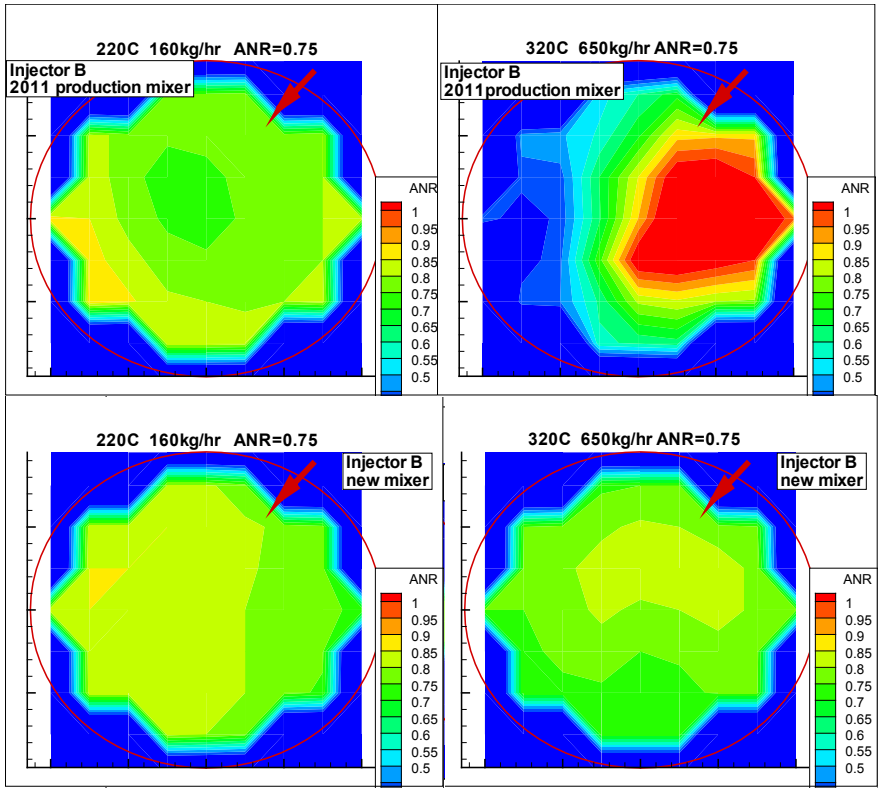
SMD: 130µm
Angle: 16°
3-holes injector

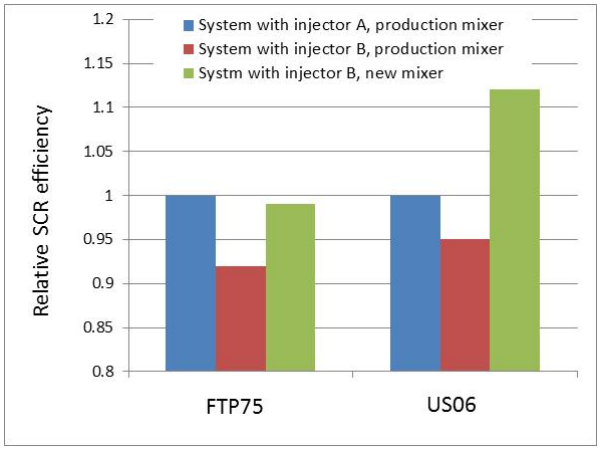
SMD: 20µm
Angle: 20°
Single-hole injector

Comparison of Different Urea Mixing Systems

- Mixer Impact

  Using the same injector and exhaust pipe, switch mixer

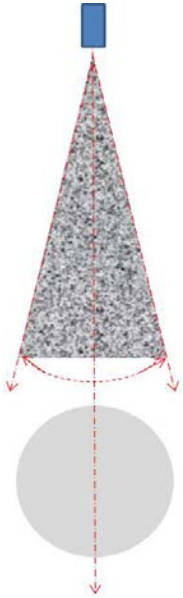




2011 production mixer

New mixer with enhanced mixing (picture not available)

Injector B

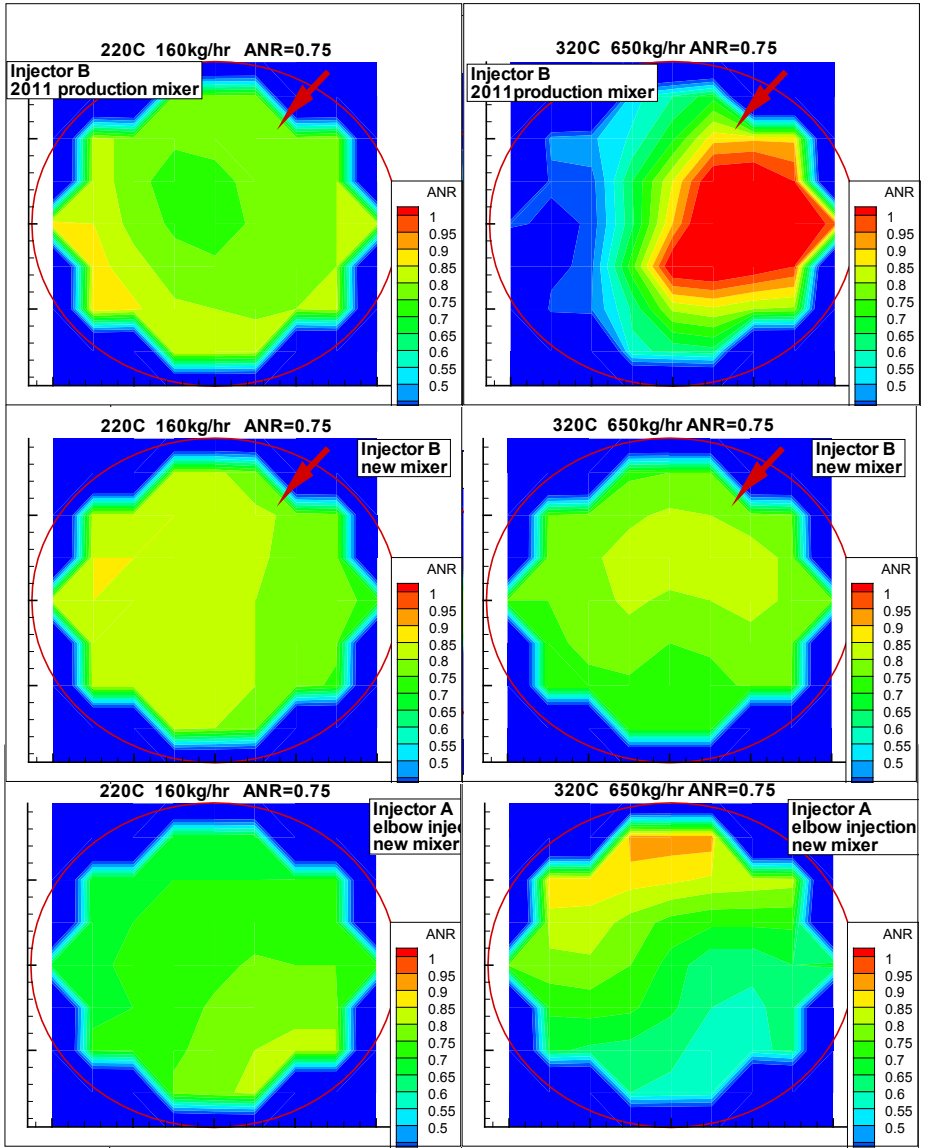


SMD: 20µm
Angle: 20°
Single-hole injector

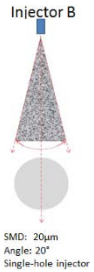
- New mixer helps to:
  - ✓ Generate stronger turbulence
  - ✓ Prevent urea droplet slip through without contact with mixer
- This is just preliminary result, further system optimization should lead to greater improvement for mixing

Comparison of Different Urea Mixing Systems

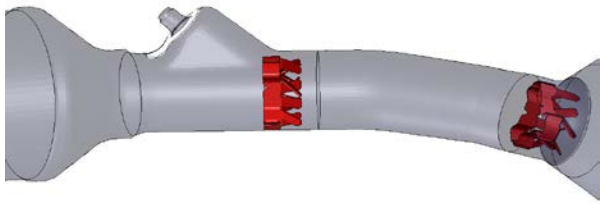
- Combined Impact of Injection and Mixer

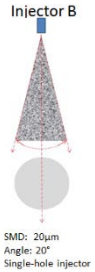


Injection Location	Diagram	Pros	Cons
Side		1. Easy for packaging	1. Poor mixing 2. Wall wetting (deposit)
Center		1. Good mixing	1 difficult for injector packaging
Elbow		1 relative good mixing and packaging	1.Back pressure 2. Flow impact

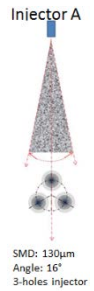


Injector B, side injection, 2011 production mixer

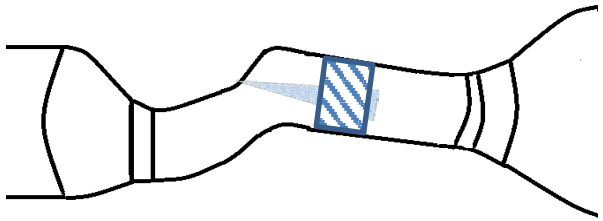




Injector B, side injection, new mixer

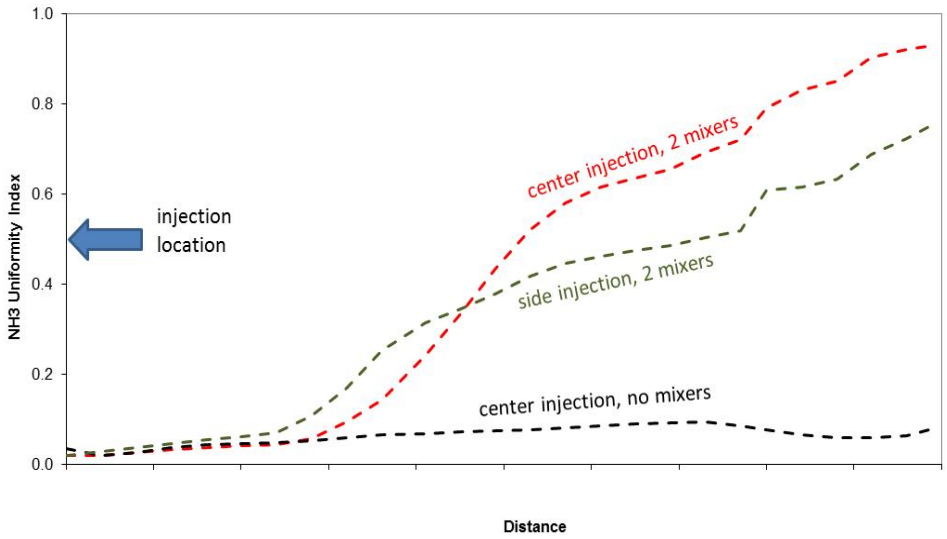


Injector A, elbow injection, new mixer



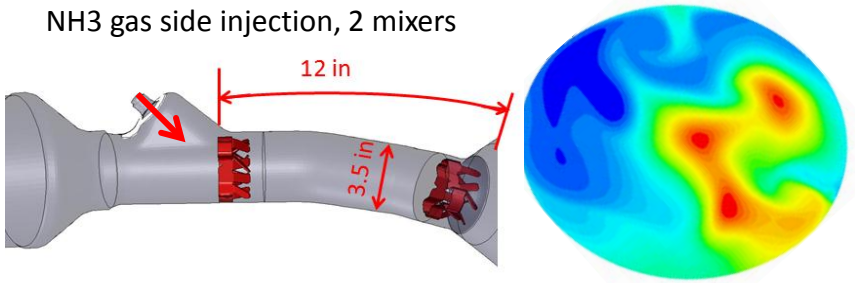
NH3 Gas Dosing Simulation

- CFD Results for NH3 gas dosing

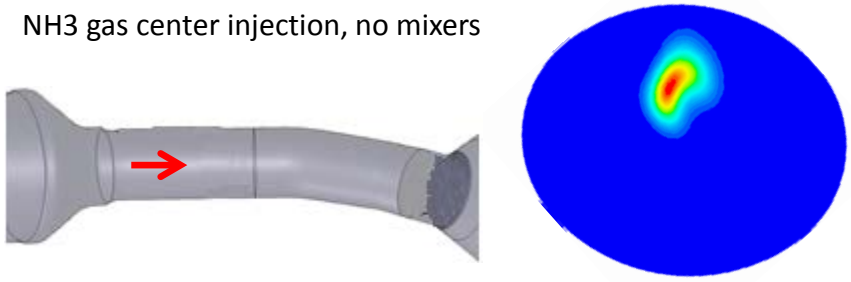


NH3 distribution at SCR inlet

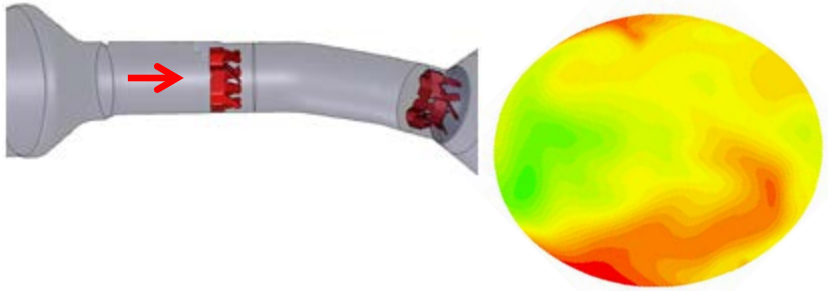
NH3 gas side injection, 2 mixers



NH3 gas center injection, no mixers



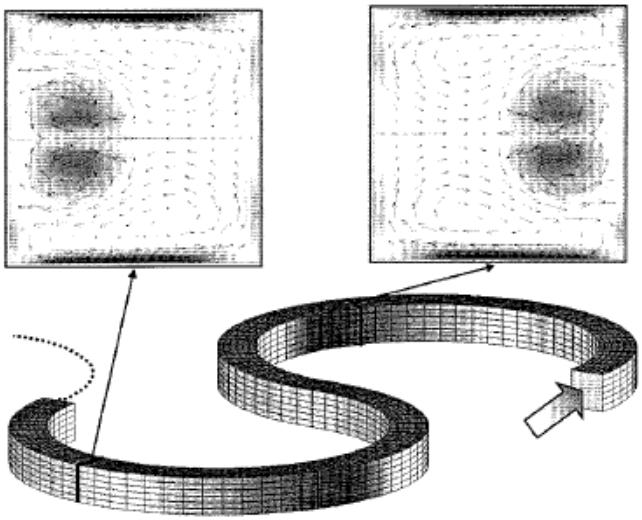
NH3 gas center injection, 2 mixers



- Center injection shows higher uniformity than side injection
- It is also challenging to achieve good mixing within short distance.

Future Mixing Design

- Spray-Mixer Coupled System Design
  - Big droplet: droplet break and vaporization
  - Small droplet/NH3 gas: flow impact
- Center Injection with Round Catalyst/Pipes
  - Center injection helps for spray distribution
  - Round exhaust pipe/can makes flow distribution more uniform
- New Mixing Idea
  - Recirculation flow
    - High Re flow in curved channel
  - Active mixing
    - Extra energy input can help



Jiang F., et.al. AIChE J Vol 50, No 9, 2297-2305

Summary

- Effective urea mixing design should be based on the nature of the selected injector (spray)
- In general, center injection is better than side injection for urea distribution, and the smaller the droplet, the greater the difference is
- NH3 gas dosing still needs proper mixing design
- We may get new idea for mixing from biotech and chemical engineering, where mixing is a widely used in unit operation.