MDEC 2022

Optimization of SCR Emissions Control with Electrically Heated Catalyst System

ADVANCED TECHNOLOGY EMISSION SOLUTIONS

Meeting Tomorrow's Emissions Standards...Today

Rob Crawford, CTO - rob.crawford@atesinc.ca

1

Induction Heated Catalyst (IHC) Benefits

Advanced Technology Emission Solutions

- Lower emissions under engine start and low-load conditions
- Faster light-off during cold start phases
- Keeps catalyst from cooling off during deceleration/coasting/idling/stop light shutdown
- Active emissions treatment system (thermal management)
- Independent of exhaust flow (preheating or post-ignition)
- Potential reduction of precious metal content
- No electrical connectors to substrate
  - High reliability
- Additional benefits for diesel applications
  - Diesel exhaust fluid can be added sooner
  - Conversion temperature reached more quickly
  - Assisted particulate filter regeneration

2

ATES Smart Induction Catalyst (SI-Cat)

Advanced Technology Emission Solutions

- ***SI-CAT*** (***S***mart ***I***nduction ***CAT***alyst) system is comprised of:
  - Aftertreatment emission system component (TWC, GPF, DOC, DPF, or SCR, among others)
  - Induction power supply compatible with 12V up to 400V+ vehicle electrical system and 1kW to 20kW heating output (integratable into vehicle ECU or standalone operation)
  - Smart control for maximum operating efficiency and minimum energy wastage over various heating strategies (preheat, post-ignition, or hybrid of the two, real-world driving, maintain catalyst temperature)
  - Features: onboard diagnostics, CAN bus communication, data acquisition, feedback, safety limits

Aftertreatment Emissions System ⟷ SI-CAT ⟷ **Induction Power Supply**

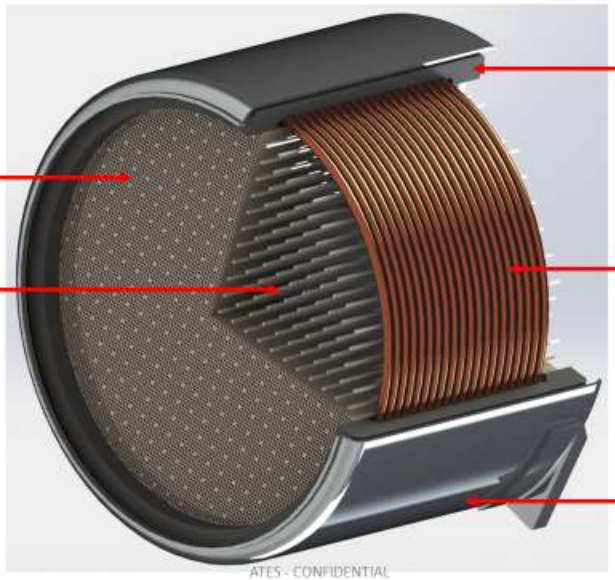
Smart Control

ATES - CONFIDENTIAL 3

3

Aftertreatment System - Cutaway

Advanced Technology Emission Solutions



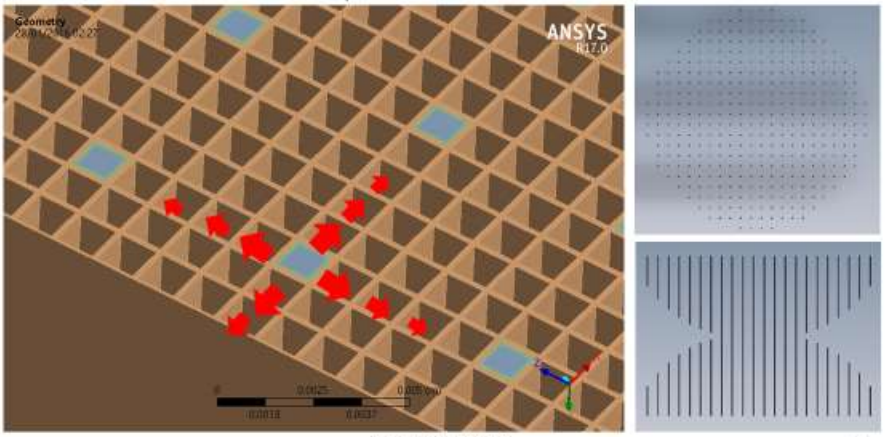
ATES - CONFIDENTIAL 4

4

Wire Inserts – Precision Heating

Advanced Technology Emission Solutions

- Wire geometry quantitatively directs heat to where it is needed
- Tunable heating profile with focus on frontal heating
- Uniform cross-sectional temperature
- Washcoat locks wires in place

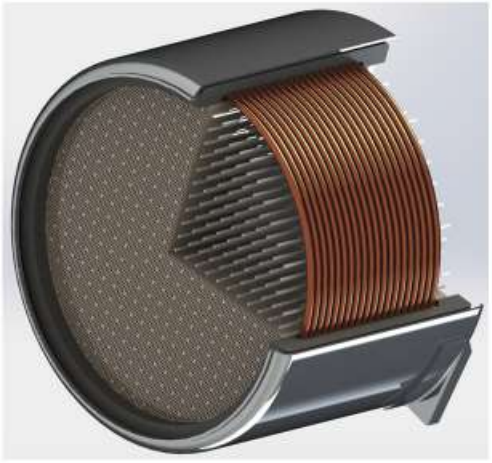


5

Design Flexibility

Advanced Technology Emission Solutions

- Substrate
  - Industry standard honeycomb or particulate filter
- Material
  - Cordierite, SiC, Extruded SCR
- Size
  - 3" up to 13" diam
  - 3"up to 24"length
- Cell density
  - 100 up to 900cpsi
- Input Voltage
  - 12V up to 800V+
- Power Output
  - 1kW up to 20kW+
- Heating Strategy
  - Preheat, post-ignition or hybrid of the two
- Heating Location
  - Front face, middle, rear or other



6

IHC SCR Development for NOx

Advanced Technology Emission Solutions

- WLTC light-duty used to evaluate IHC for heavy-duty (first 600s)
  - More challenging cold start phase
  - 5.66" SCR catalyst substrate ~2l volume
- Test configuration
  - Conditioning SS275°C – NH_3 prefill (consistency between runs)
  - 160°C minimum face temperature for urea dosing
  - ANR1.5 @ TC front-face-centre > 160°C
- Focus on shifting IHC heating towards front
  - Balance of exhaust and substrate heating
  - IHC shifted heating provides sufficient SCR face temperatures for dosing and sufficient catalyst heat for NOx conversion
- IHC improved NOx conversion over various heating strategies
  - Flexibility allows for further IHC optimization and NOx reduction
  - Preheating minimizes time to dosing and improves NOx conversion
  - NH_3 storage capability to further reduce NOx
  - IHC controlled burn-off of accumulated HC from long idle periods to avoid exothermic reaction

ATES - CONFIDENTIAL 7

7

Thermocouple Plan for IHC SCR

Advanced Technology Emission Solutions

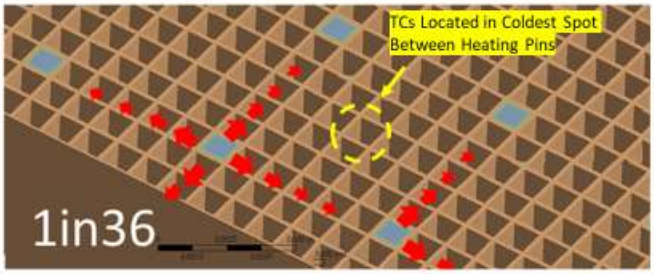
ATES – CONFIDENTIAL 8

8

Thermocouple Location Between Pins

Advanced Technology Emission Solutions

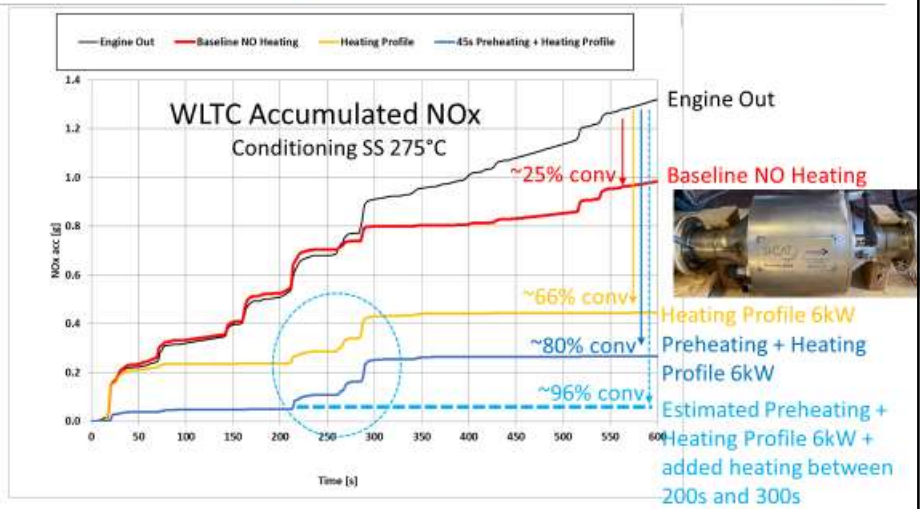
- Typically place thermocouple in coldest spot between heating pins
  - Shows worst case temperature
  - Temperatures are hotter moving towards any heating pin
- Option to move thermocouples away from coldest spot if desired



9

IHC SCR Development for NOx

Advanced Technology Emission Solutions

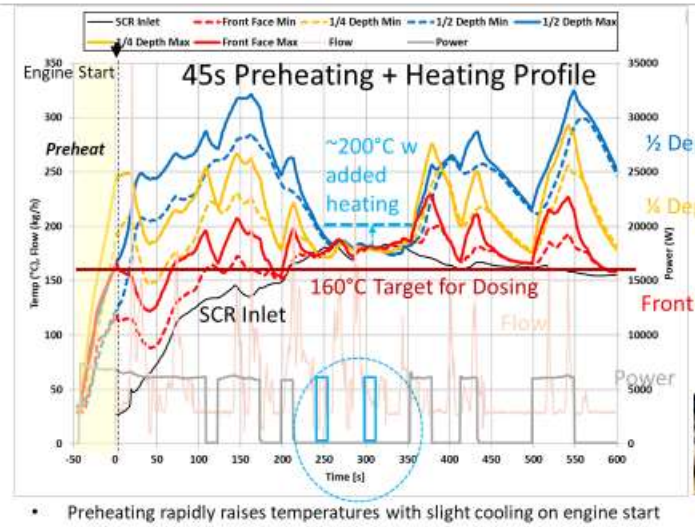


- IHC Heating Profile reduces NOx after 30s and Preheating reduces NOx immediately at 0s
- Non-optimized IHC design and heating strategy provide opportunity for further NOx reduction

10

IHC SCR Development for NOx

Advanced Technology Emission Solutions



- Preheating rapidly raises temperatures with slight cooling on engine start
- Not just front face needs to be hot but also front ¼+ of ceramic for NOx conversion
- Need to move heat forward and add heating between 200 and 300s where whole substrate cools

11

IHC SCR Development for NOx

Advanced Technology Emission Solutions

- IHC SCR comparison ongoing
  - Urea dosing start time reduced by >100s (110s down from 225s)
  - IHC heat translates to lower NOx throughout the cycle
  - Preheating takes advantage of stored NH_3 for even lower NOx
  - Double-cone design concentrating flow through centre (more uniform distribution would further improve NOx)
- HC controlled burn ongoing
  - HC loading successful
  - Controlled exothermic reaction observed using IHC
    - Longer IHC run time for complete burn – residual HC
- Further improvement
  - Shifting IHC heat profile forward would reduce NOx and energy consumption
  - Mixer and/or straight section between DOC and IHC SCR for better uniformity
- Scaling to heavy-duty vehicles
  - 10.5" to 13" substrate and up to 20kW of power
  - 10.5" 15kW prototype for testing

12

IHC DOC Development for NOx

Advanced Technology Emission Solutions

- WLTC light-duty used to evaluate IHC for heavy-duty (first 600s)
  - More challenging cold start phase
  - 5.66" SCR catalyst substrate ~2l volume
- Test configuration
  - No Conditioning
  - 160°C minimum SCR Inlet temperature for urea dosing
  - ANR1.5 @ SCR Inlet > 160°C
- Focus on shifting IHC heating upstream of SCR
  - Balance of exhaust and substrate heating
  - DPF added between IHC DOC and SCR (conventional configuration)
- IHC improved NOx conversion over various heating strategies
  - Flexibility allows for further IHC optimization and NOx reduction
  - Preheating minimizes time to dosing and improves NOx conversion

ATES - CONFIDENTIAL 13

13

Thermocouple Plan for IHC DOC w Post-Injection

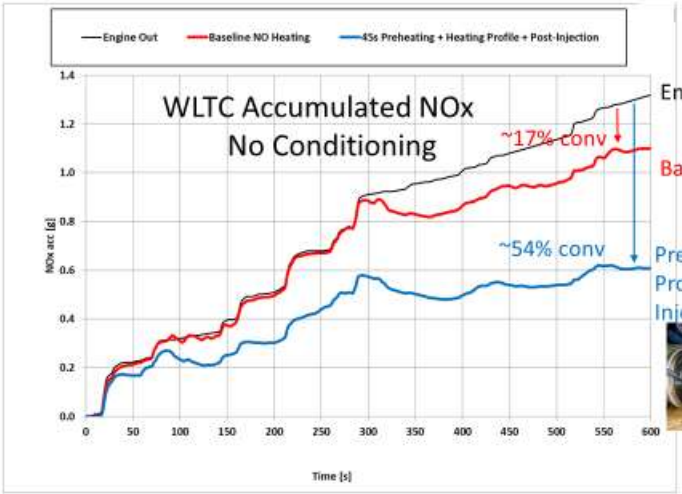
Advanced Technology Emission Solutions

ATES – CONFIDENTIAL 14

14

IHC DOC w Post Injection for NOx

Advanced Technology Emission Solutions

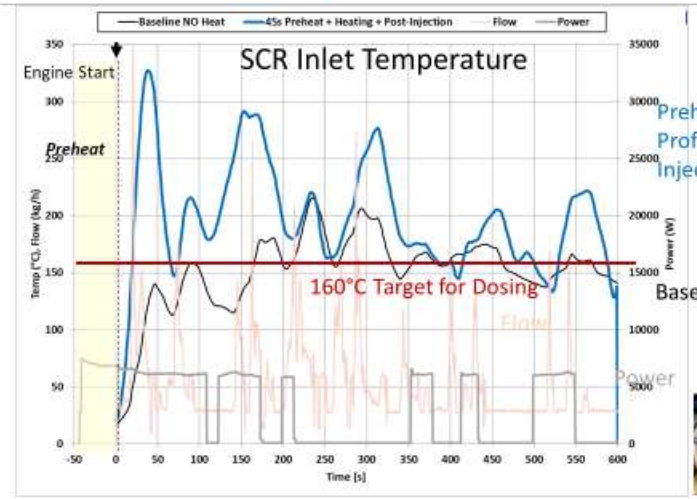


- IHC Preheating + Heating + Post Injection profile reduces NOx after 30s
- Non-optimized IHC design and heating strategy provide opportunity for further NOx reduction

15

IHC DOC Development for NOx

Advanced Technology Emission Solutions



- Preheating + heating + post-injection are above the dosing target in less than 20s
- Time delay between target temperature and NOx sensor heat-up before dosing
- DOC temperature is very high to pass heat through DPF for SCR (IHC + post-injection)

16

IHC DOC Development for NOx

Advanced Technology Emission Solutions

- IHC DOC comparison ongoing
  - Urea dosing start time reduced by 250s (30s down from 280s)
  - IHC heat initiates and maintains heat from post-injection oxidation to lower NOx throughout the cycle
  - DPF is a large heat sink but also smooths out temperature spikes through DOC (cool zone – 250s to 350s from IHC SCR)
  - Lower potential NOx reduction than IHC SCR which is direct heating of SCR
  - No NH_3 prefill of SCR but likely not useful as dosing starts early enough
- Further improvement
  - Tuning SCR dosing system for better response and lower target concentrations
  - Optimize IHC heating strategy for less power consumption
  - NOx reduction limit unknown
- Scaling to heavy-duty vehicles
  - 10.5" to 13" substrate and up to 20kW of power
  - 10.5" 15kW prototype for testing

17

Thank You!

Optimization of SCR Emissions Control with Electrically Heated Catalyst System

ADVANCED TECHNOLOGY EMISSION SOLUTIONS

Meeting Tomorrow's Emissions Standards…Today

Rob Crawford, CTO - rob.crawford@atesinc.ca
Cell - 1-(289)-237-3535

18