
***Thermal Enhancer – Airless Exhaust
Thermal Management Device***

***DEER Conference
Technical Session 5: Emission Control
Technologies, Part 2***

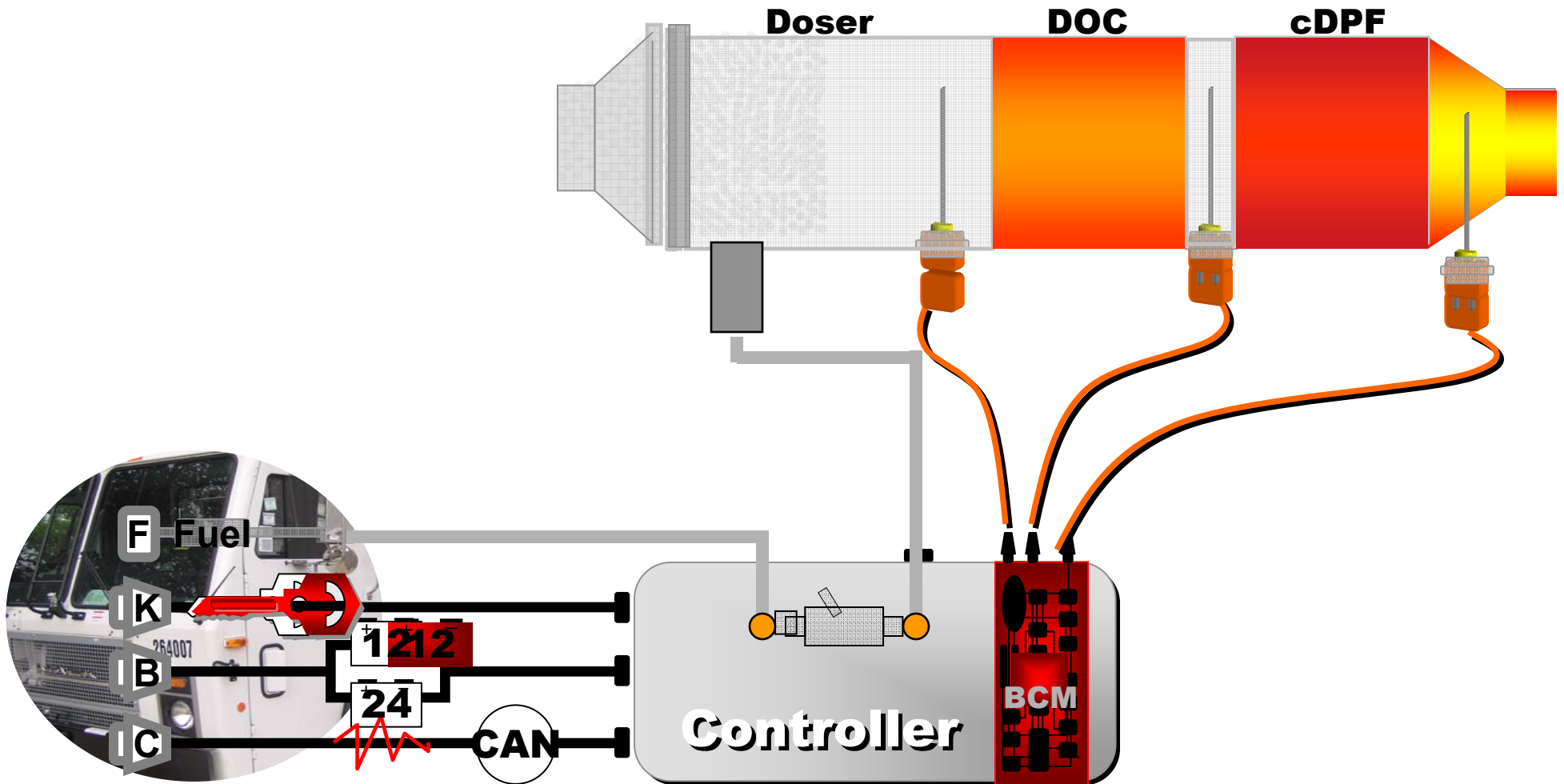
August 24, 2006



Introduction

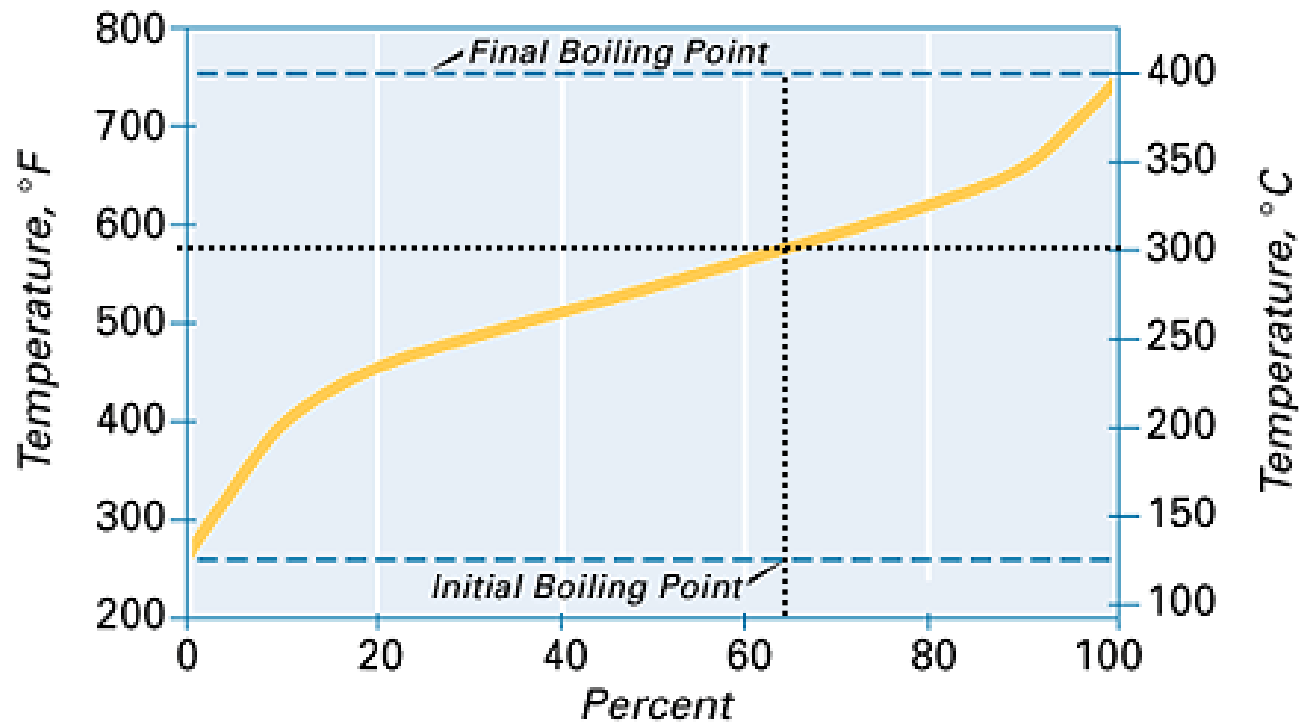
- 2007 & Beyond Requirements
 - Vaporizing Liquids
 - Temperature, Time/Velocity, Pressure
 - Controlling Chemical Reaction Rates
 - Temperature, Time/Velocity, Pressure, O₂ Concentration
- Thermal Management?
 - Diesel Duty Cycle
 - A/F Ratio
 - Throttling
 - Post Injection
 - EGR
 - Electric Heating
 - Exhaust Burners

Typical US07 System Overview



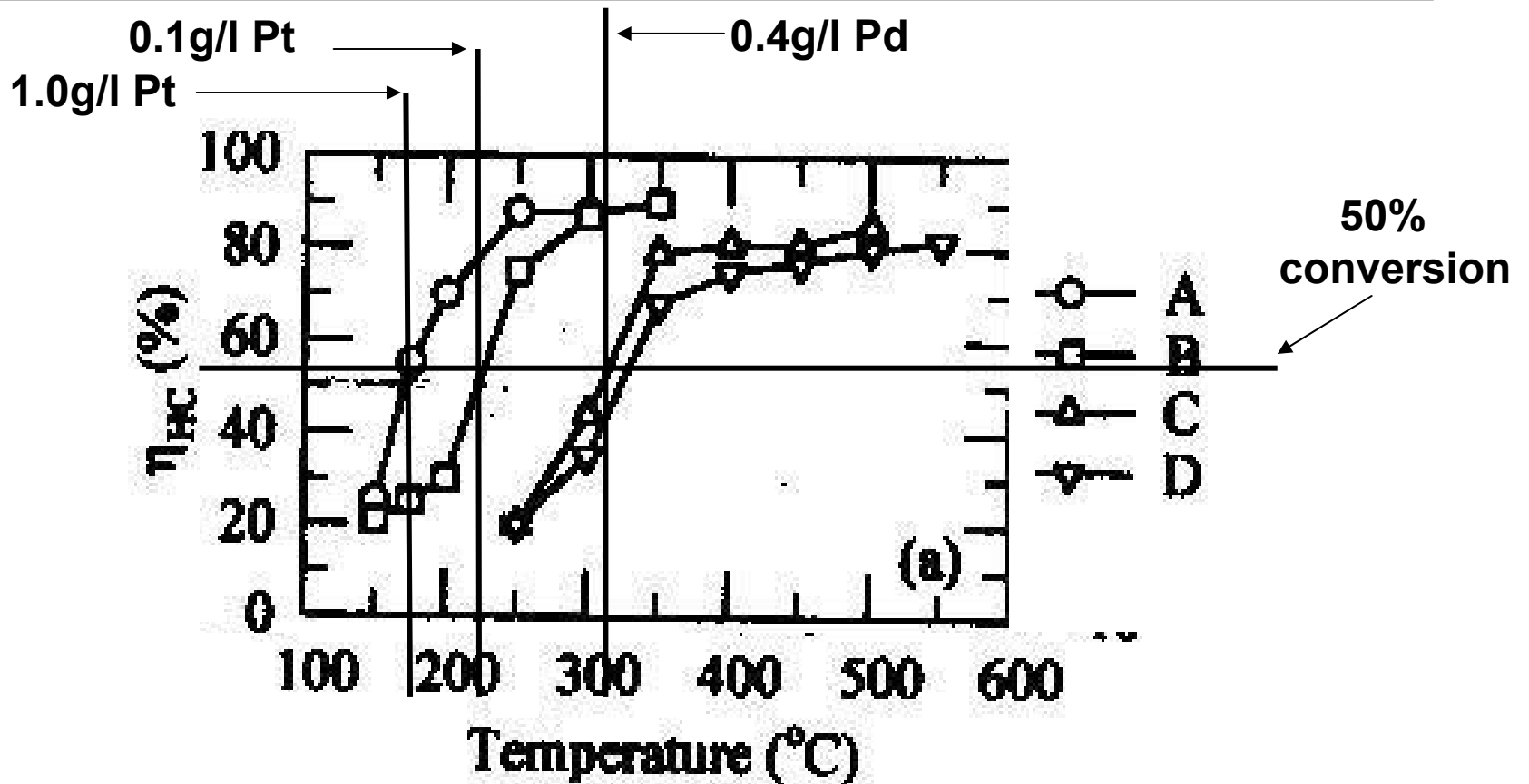
Diesel Vaporization Characteristics

Figure 4-3
Typical Distillation Profile – No. 2 Diesel Fuel



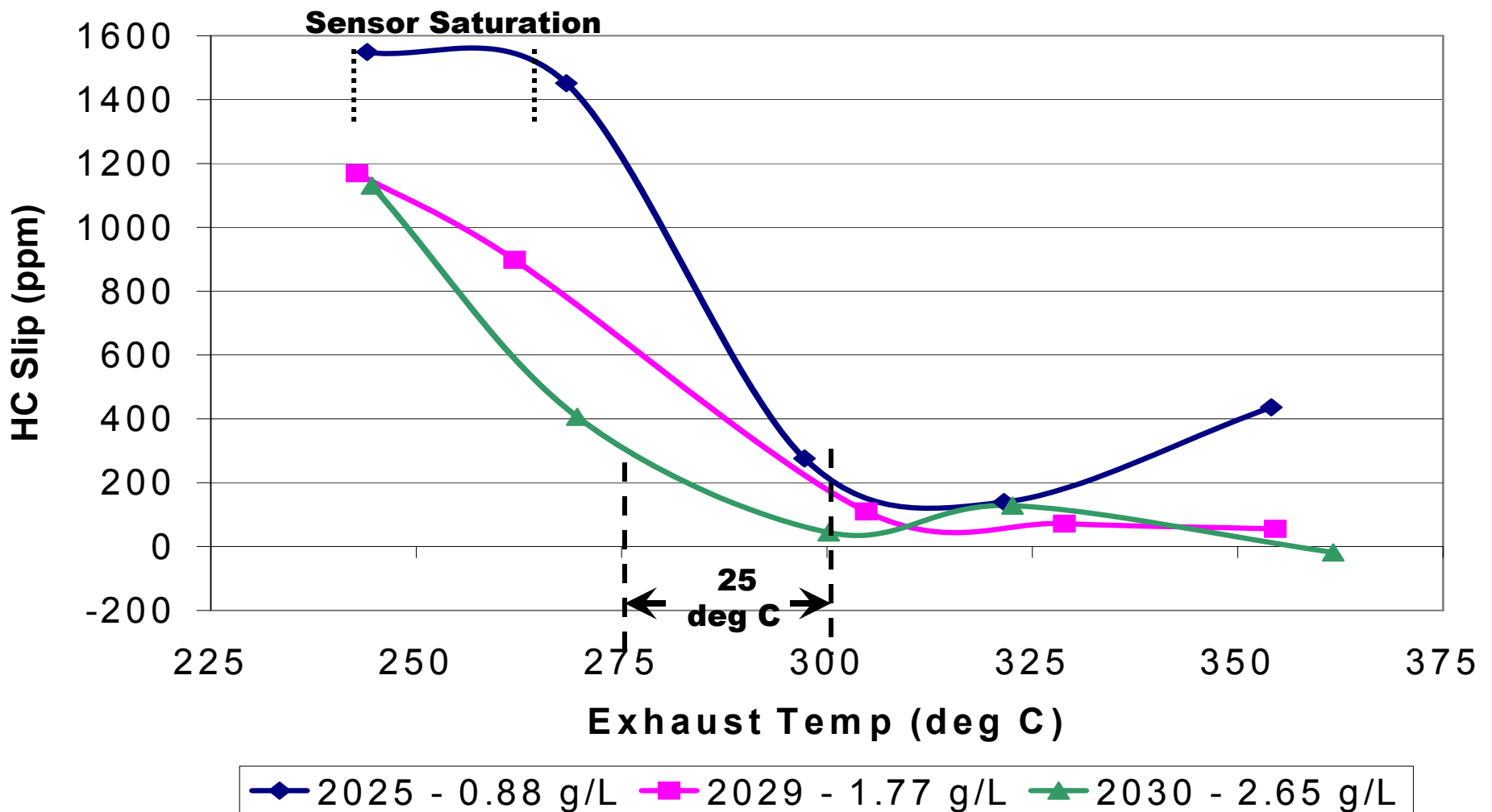
Source: Chevron.com

HC Slip vs. Precious Metal Loading

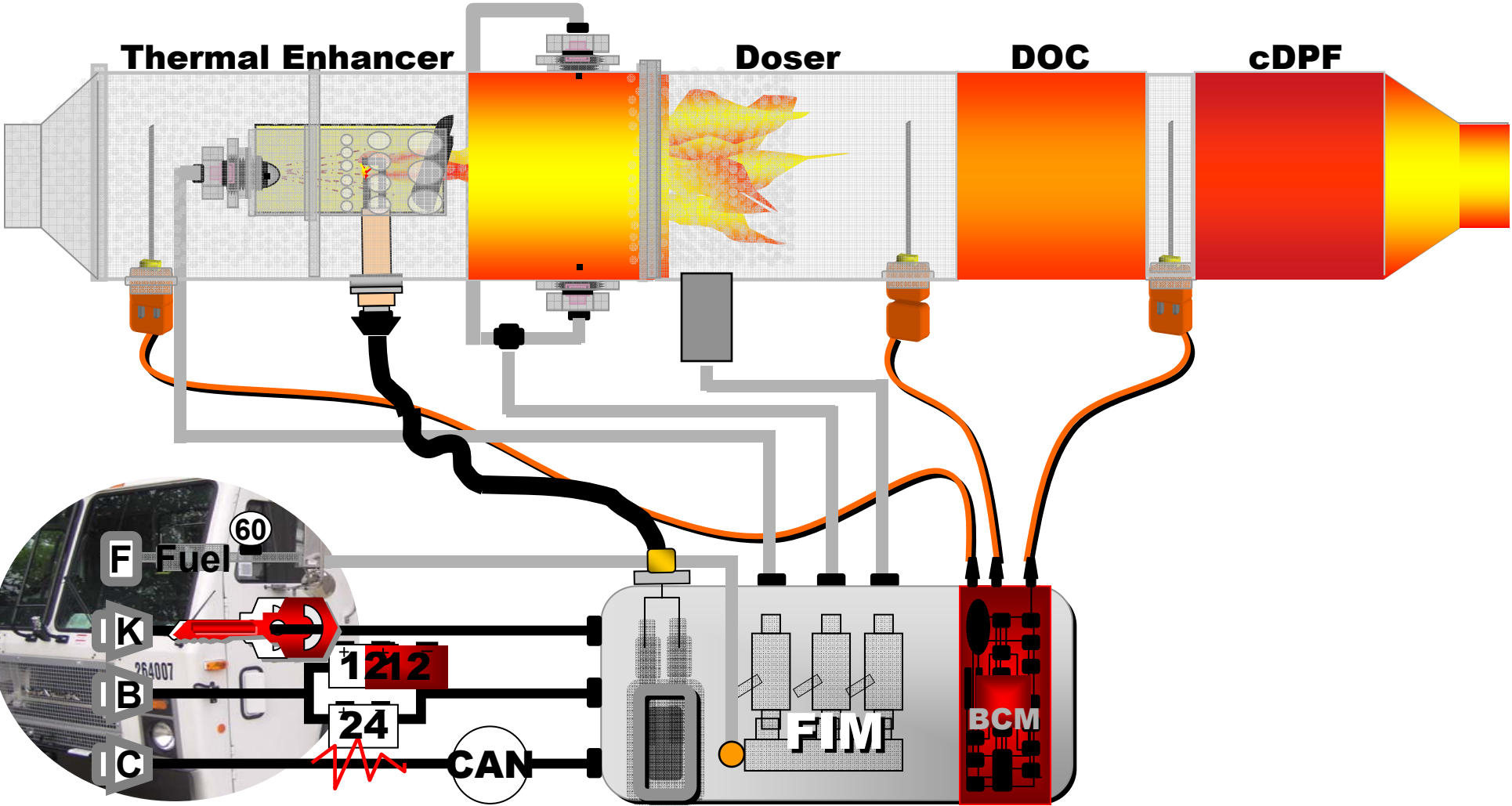


Source: Kawanami *et al*, 1998

Catalyst Behavior- 20Hr Degreen



Thermal Enhancer Integration Overview



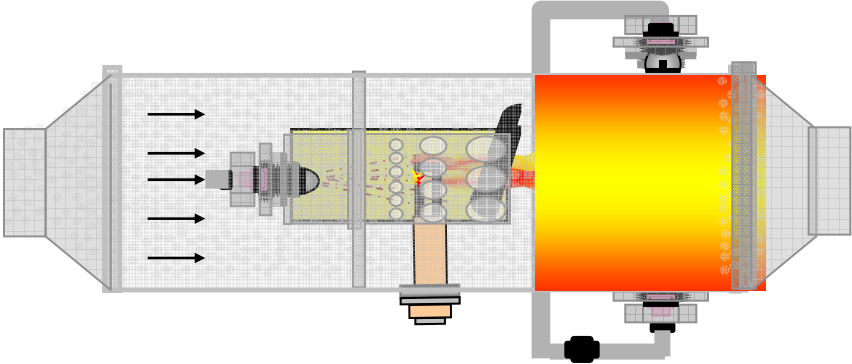
Thermal Enhancer Benefits

- Raising Exhaust Temperature with Thermal Enhancer Lowers Required Precious Metal Loading
 - Mini Burner Pays for Itself in Precious Metal Reduction
 - Less Dependence on Market Volatility
- Small Package
- Close-coupled Technology
- Airless System
- Tune Engine for Emissions & Economy

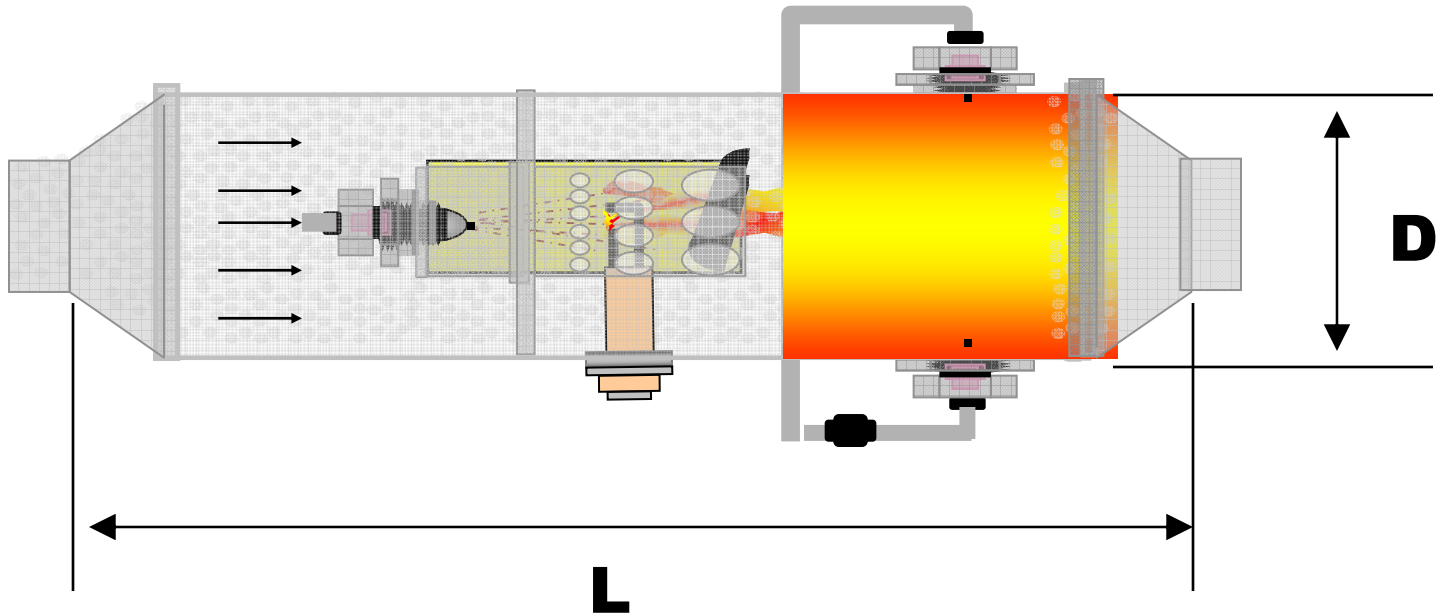
Thermal Enhancer Profile

- Tenfold Velocity, Threefold Temperature, and Twofold Oxygen Concentration Changes
- Temperature Target Control
 - 250-350 deg C
- No External Air Supply Required
- Controlled Hydrocarbon Slip
- 4 Bar Fuel Up to 100 deg C
- Fuel Cooling Required in Some Applications

Thermal Enhancer



Thermal Enhancer Dimensions



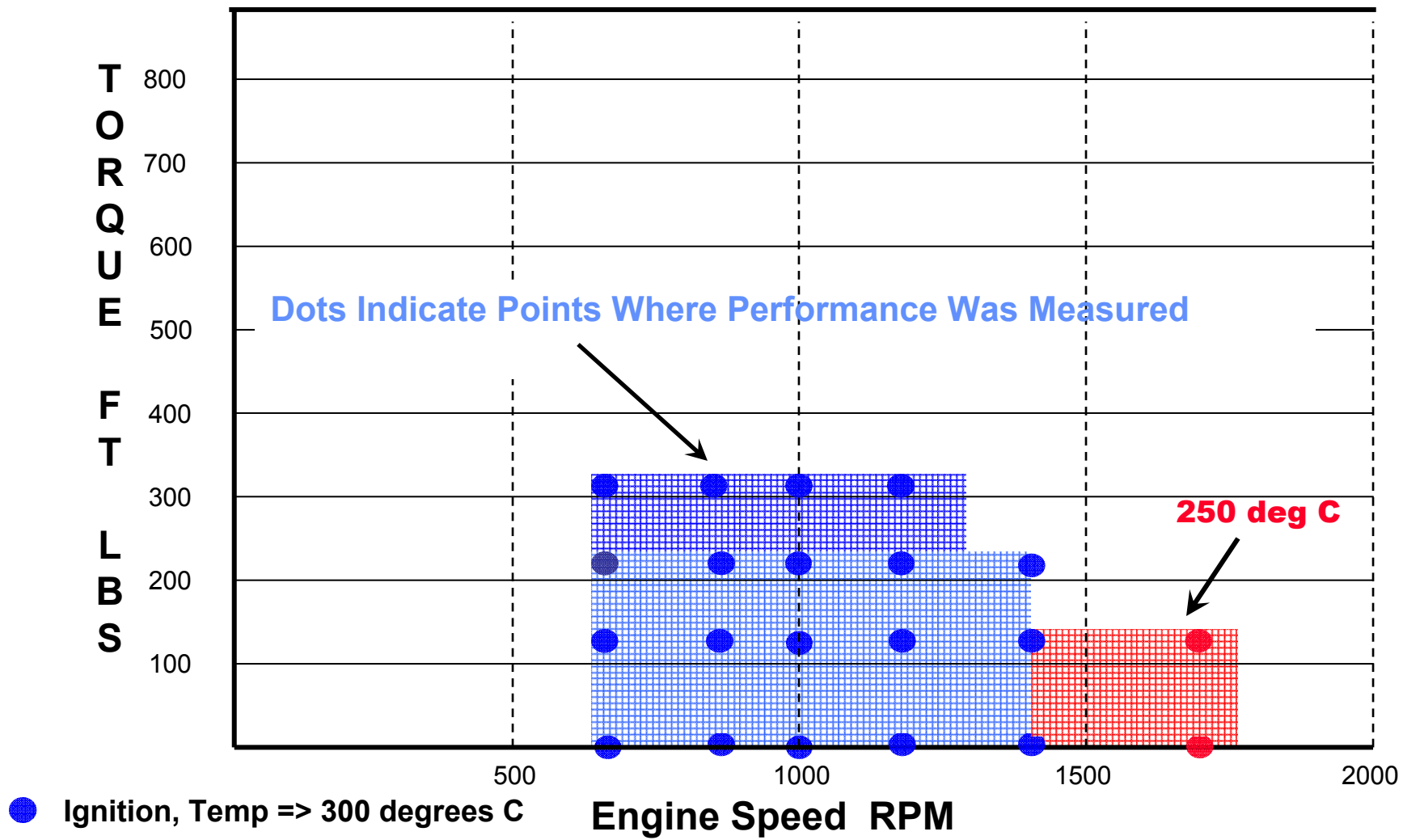
| Length (L) | Diameter (D) |
|------------|--------------|
| 315 mm | 150 mm |

Thermal Enhancer Performance Data

Test Setup

- ISX 14.9L Engine
 - Prototype Thermal Enhancer
- Fuel Temperature 70 deg C
- Fueling Fixed 0.77 g/sec
- Test Points
 - 3 Transient Points
 - 2 Torque Load-up Modes
 - 1 Free Acceleration Mode
 - 21 Steady State Points
 - AC Modes, EURO Modes, and Lower Loads
 - Ignition Up to 1250 kg/hr

Thermal Enhancer Characterization Engine (14.9 – 354 kW) Measured Data



Testing Modes

| Mode | Speed % | Torque % |
|------|---------|----------|
| AC 1 | idle | 0 |
| AC 2 | idle | 25 |
| AC 3 | 60 | 5 |
| AC 4 | 40 | 0 |
| AC 5 | 40 | 25 |
| AC 6 | 40 | 50 |
| AC 7 | 50 | 0 |
| AC 8 | 50 | 25 |
| AC 9 | 50 | 50 |

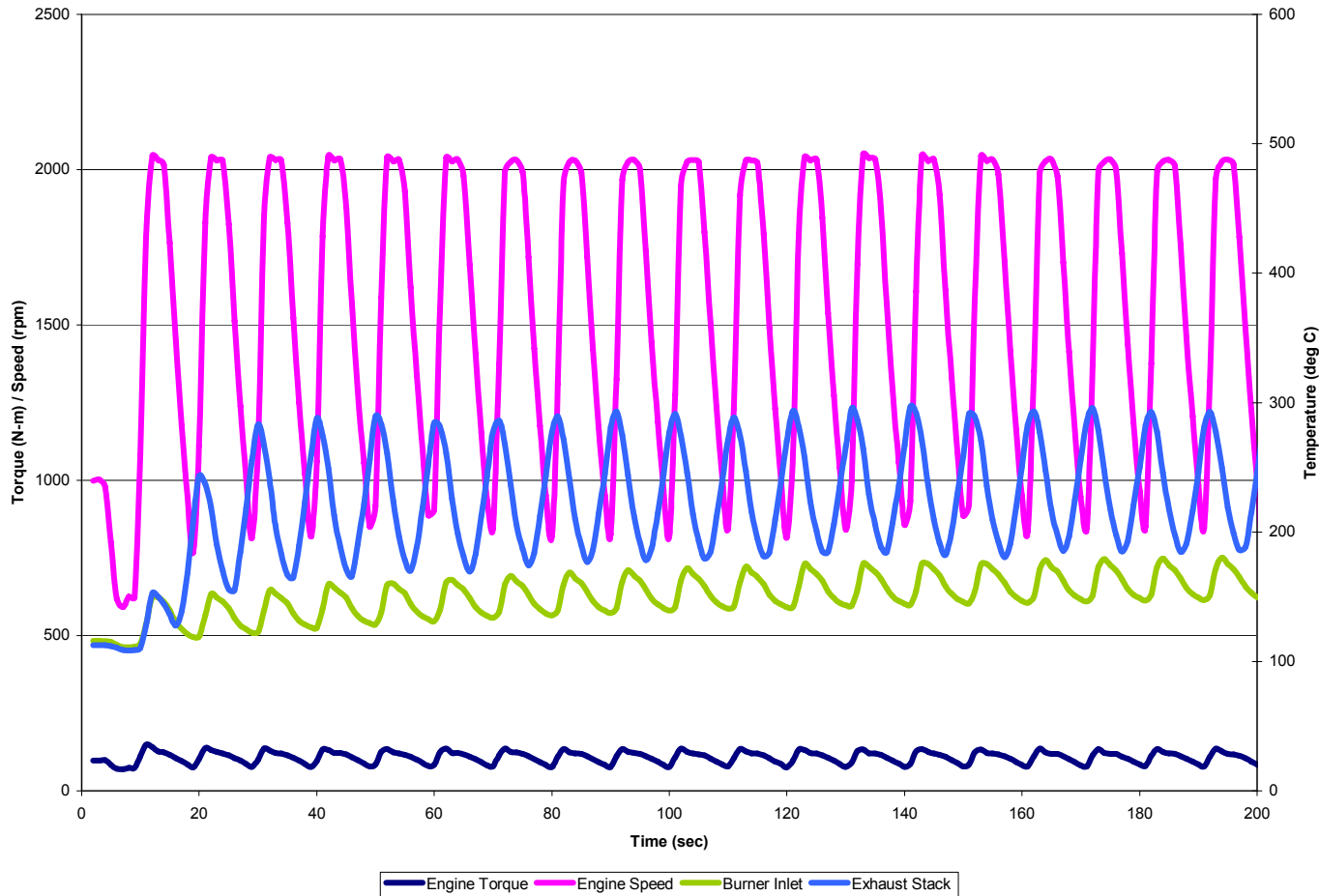
| Mode | Speed (rpm) | Torque (N-m) |
|-----------|-------------|--------------|
| torque2 | trans | trans |
| freeaccel | trans | trans |
| torque1 | trans | trans |
| EURO 7 | 1040 | 339 |
| AC 1 | 600 | 0 |
| AC 2 | 600 | 339 |
| AC 3 | 1200 | 84 |
| AC 4 | 800 | 0 |
| AC 5 | 800 | 339 |
| AC 7 | 1000 | 0 |
| AC 8 | 1000 | 339 |
| | 600 | 152 |
| | 600 | 287 |
| | 800 | 152 |
| | 800 | 287 |
| | 1000 | 152 |
| | 1000 | 287 |
| | 1200 | 152 |
| | 1200 | 287 |
| | 1420 | 152 |
| | 1420 | 287 |
| | 1420 | 373 |
| | 1700 | 152 |
| | 1700 | 287 |

Quasi-Ramp
No Load
Quasi-Step

Other Points Investigated

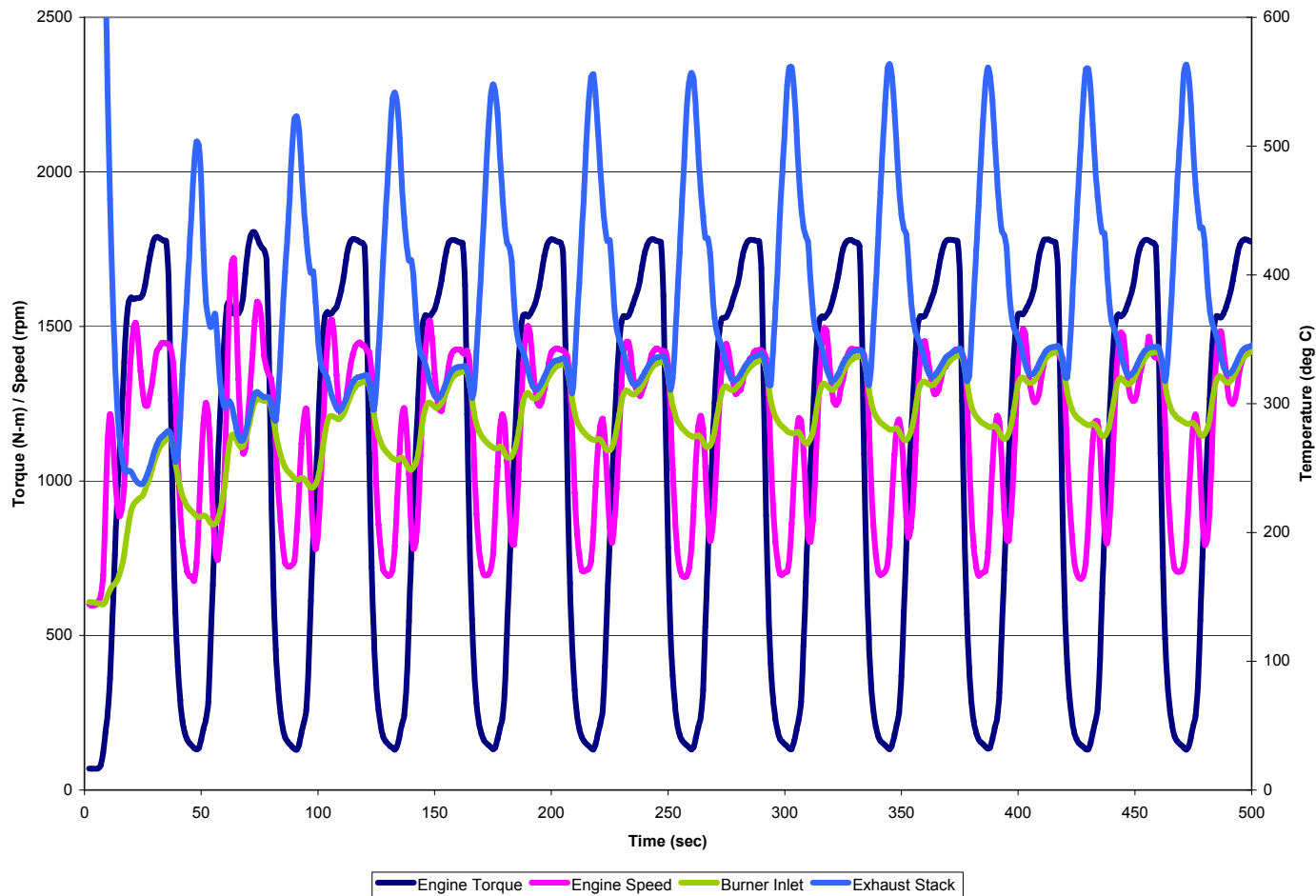
Transient Testing

Free Accel – No Load



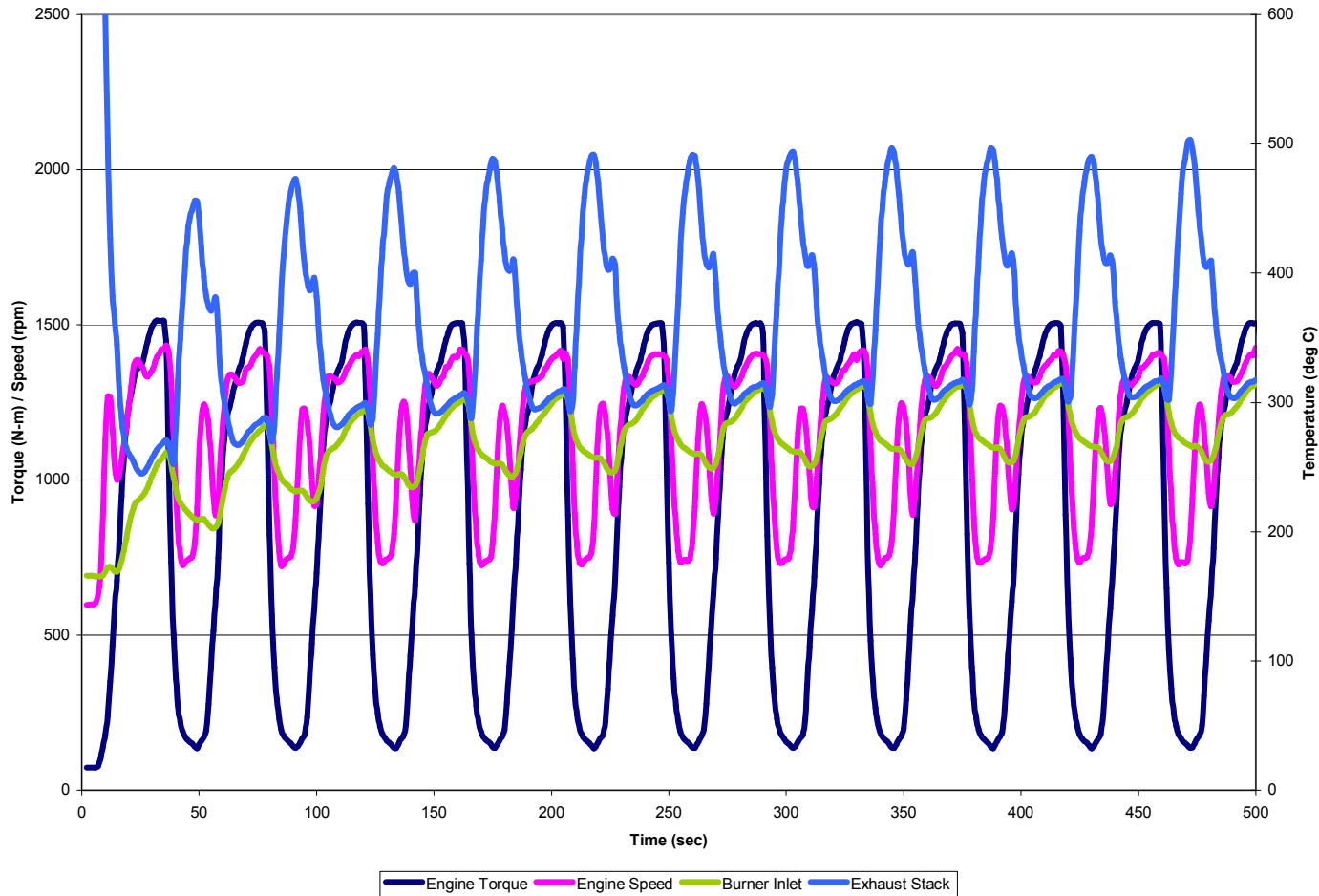
| Mode | Speed (rpm) | Torque (N-m) |
|-----------|-------------|--------------|
| torque2 | trans | trans |
| freeaccel | trans | trans |
| torque1 | trans | trans |
| EURO 7 | 1040 | 339 |
| AC 1 | 600 | 0 |
| AC 2 | 600 | 339 |
| AC 3 | 1200 | 84 |
| AC 4 | 800 | 0 |
| AC 5 | 800 | 339 |
| AC 7 | 1000 | 0 |
| AC 8 | 1000 | 339 |
| | 600 | 152 |
| | 600 | 287 |
| | 800 | 152 |
| | 800 | 287 |
| | 1000 | 152 |
| | 1000 | 287 |
| | 1200 | 152 |
| | 1200 | 287 |
| | 1420 | 152 |
| | 1420 | 287 |
| | 1420 | 373 |
| | 1700 | 152 |
| | 1700 | 287 |

Torque 1 – Quasi-Step



| Mode | Speed (rpm) | Torque (N-m) |
|-----------|-------------|--------------|
| torque2 | trans | trans |
| freeaccel | trans | trans |
| torque1 | trans | trans |
| EURO 7 | 1040 | 339 |
| AC 1 | 600 | 0 |
| AC 2 | 600 | 339 |
| AC 3 | 1200 | 84 |
| AC 4 | 800 | 0 |
| AC 5 | 800 | 339 |
| AC 7 | 1000 | 0 |
| AC 8 | 1000 | 339 |
| | 600 | 152 |
| | 600 | 287 |
| | 800 | 152 |
| | 800 | 287 |
| | 1000 | 152 |
| | 1000 | 287 |
| | 1200 | 152 |
| | 1200 | 287 |
| | 1420 | 152 |
| | 1420 | 287 |
| | 1420 | 373 |
| | 1700 | 152 |
| | 1700 | 287 |

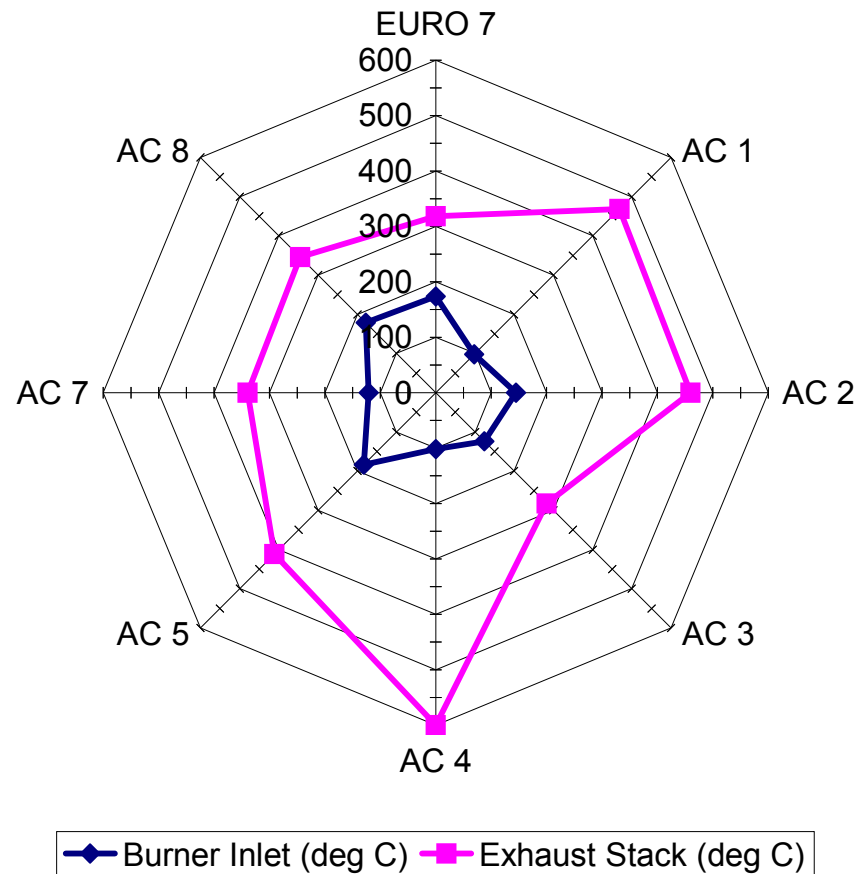
Torque 2 – Quasi-Ramp



| Mode | Speed (rpm) | Torque (N-m) |
|-----------|-------------|--------------|
| torque2 | trans | trans |
| freeaccel | trans | trans |
| torque1 | trans | trans |
| EURO 7 | 1040 | 339 |
| AC 1 | 600 | 0 |
| AC 2 | 600 | 339 |
| AC 3 | 1200 | 84 |
| AC 4 | 800 | 0 |
| AC 5 | 800 | 339 |
| AC 7 | 1000 | 0 |
| AC 8 | 1000 | 339 |
| | 600 | 152 |
| | 600 | 287 |
| | 800 | 152 |
| | 800 | 287 |
| | 1000 | 152 |
| | 1000 | 287 |
| | 1200 | 152 |
| | 1200 | 287 |
| | 1420 | 152 |
| | 1420 | 287 |
| | 1420 | 373 |
| | 1700 | 152 |
| | 1700 | 287 |

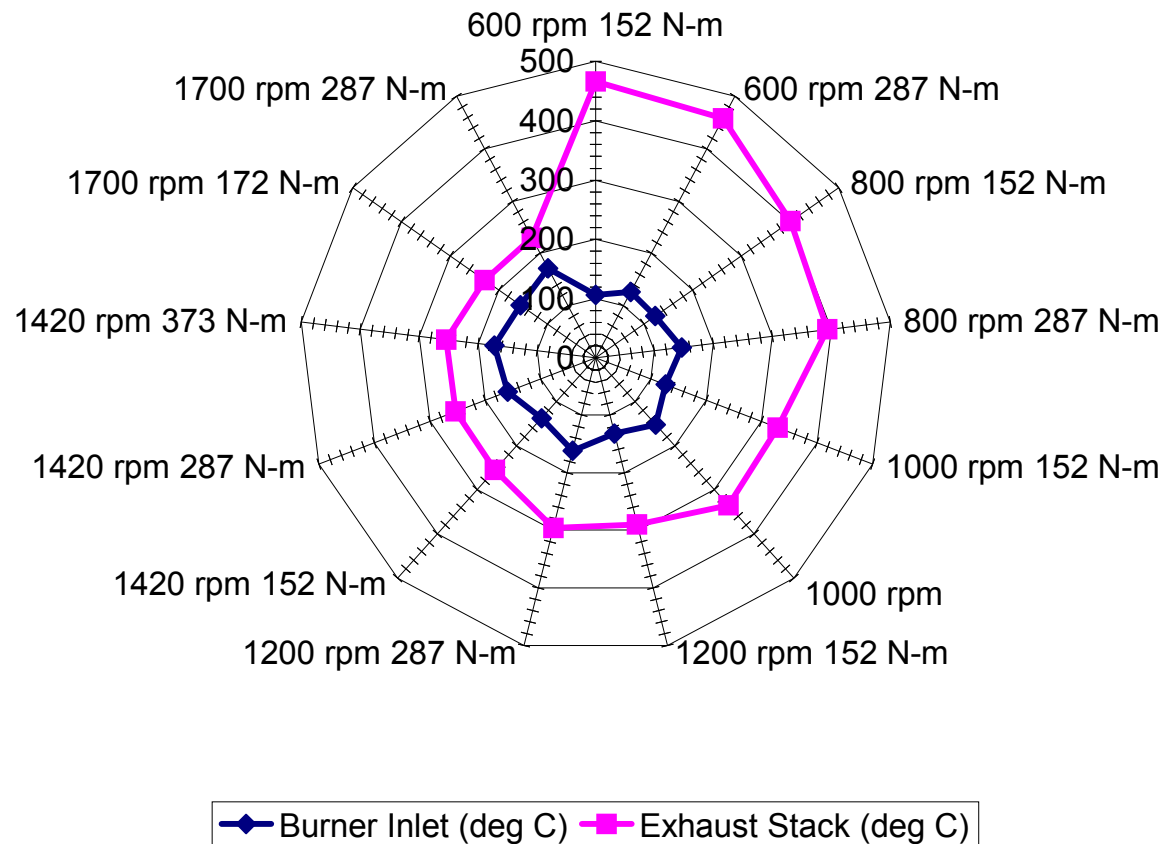
Steady State Testing

Temperature Characteristics



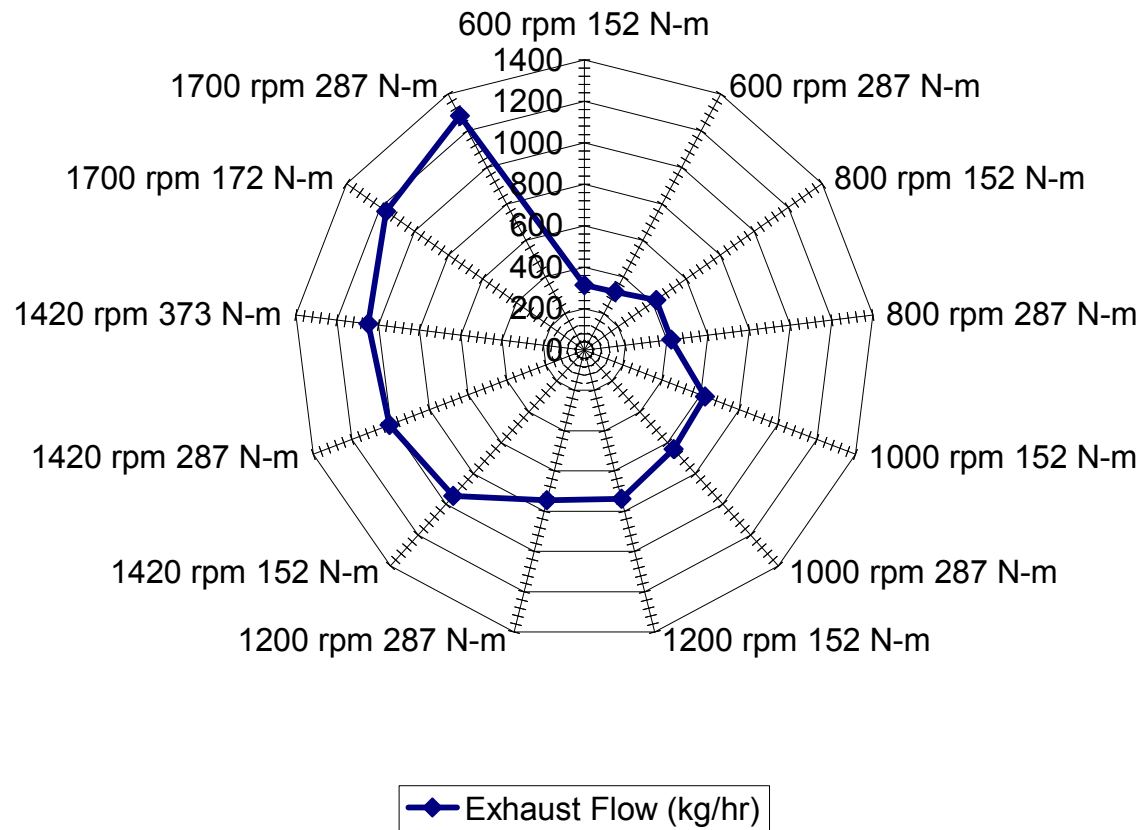
| Mode | Speed (rpm) | Torque (N-m) |
|-----------|-------------|--------------|
| torque2 | trans | trans |
| freeaccel | trans | trans |
| torque1 | trans | trans |
| EURO 7 | 1040 | 339 |
| AC 1 | 600 | 0 |
| AC 2 | 600 | 339 |
| AC 3 | 1200 | 84 |
| AC 4 | 800 | 0 |
| AC 5 | 800 | 339 |
| AC 7 | 1000 | 0 |
| AC 8 | 1000 | 339 |
| | 600 | 152 |
| | 600 | 287 |
| | 800 | 152 |
| | 800 | 287 |
| | 1000 | 152 |
| | 1000 | 287 |
| | 1200 | 152 |
| | 1200 | 287 |
| | 1420 | 152 |
| | 1420 | 287 |
| | 1420 | 373 |
| | 1700 | 152 |
| | 1700 | 287 |

Temperature Characteristics



| Mode | Speed (rpm) | Torque (N-m) |
|-----------|-------------|--------------|
| torque2 | trans | trans |
| freeaccel | trans | trans |
| torque1 | trans | trans |
| EURO 7 | 1040 | 339 |
| AC 1 | 600 | 0 |
| AC 2 | 600 | 339 |
| AC 3 | 1200 | 84 |
| AC 4 | 800 | 0 |
| AC 5 | 800 | 339 |
| AC 7 | 1000 | 0 |
| AC 8 | 1000 | 339 |
| | 600 | 152 |
| | 600 | 287 |
| | 800 | 152 |
| | 800 | 287 |
| | 1000 | 152 |
| | 1000 | 287 |
| | 1200 | 152 |
| | 1200 | 287 |
| | 1420 | 152 |
| | 1420 | 287 |
| | 1420 | 373 |
| | 1700 | 152 |
| | 1700 | 287 |

Flow Characteristics



| Mode | Speed (rpm) | Torque (N-m) |
|-----------|-------------|--------------|
| torque2 | trans | trans |
| freeaccel | trans | trans |
| torque1 | trans | trans |
| EURO 7 | 1040 | 423 |
| AC 1 | 600 | 0 |
| AC 2 | 600 | 423 |
| AC 3 | 1200 | 84 |
| AC 4 | 800 | 0 |
| AC 5 | 800 | 423 |
| AC 7 | 1000 | 0 |
| AC 8 | 1000 | 423 |
| | 600 | 152 |
| | 600 | 287 |
| | 800 | 152 |
| | 800 | 287 |
| | 1000 | 152 |
| | 1000 | 287 |
| | 1200 | 152 |
| | 1200 | 287 |
| | 1420 | 152 |
| | 1420 | 287 |
| | 1420 | 423 |
| | 1700 | 152 |
| | 1700 | 287 |

Thermal Enhancer Summary

- 250-350 deg C Exhaust Management
- Vaporized Hydrocarbon Generation
- Catalyst Enabler Independent of Duty Cycle
- Airless System
- Compact Package