NOx Adsorbers for Heavy Duty Truck Engines – Testing and Simulation

N. Hakim, J. Hoelzer, Y. Liu

Detroit Diesel Corporation - DaimlerChrysler Powersystems

This feasibility study of NOx adsorbers in heavy-duty diesel engines examined three configurations (dual-leg, single-leg and single-leg-bypass) in an integrated experimental setup, composed of a Detroit Diesel Class-8 truck engine, a catalyzed diesel particulate filter and the NOx absorber system. The setup also employed a reductant injection concept, sensors and advanced control strategies.

The study included the development of thermal and empirical NOx absorber characteristic models. These models were further applied to the development of regeneration strategies and were used for a comparative performance analysis of the three NOx adsorber configurations.

The reported steady-state experimental and simulation results show relatively high NOx conversion efficiencies, with various levels of fuel economy deterioration. Further, the findings confirm that the development of acceptable regeneration and desulfation control logics are a major technical challenge for practical NOx absorber system applications. These logics are further complicated by factors such as engine transient operation, drivability and durability.

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Presentation Outline

- Experimental Plan
- Simulation
- Experimental Results
- Conclusions

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- **Experimental Plan**
  - **Single Leg**
  - **Dual Leg**
  - **Single Leg with Bypass**
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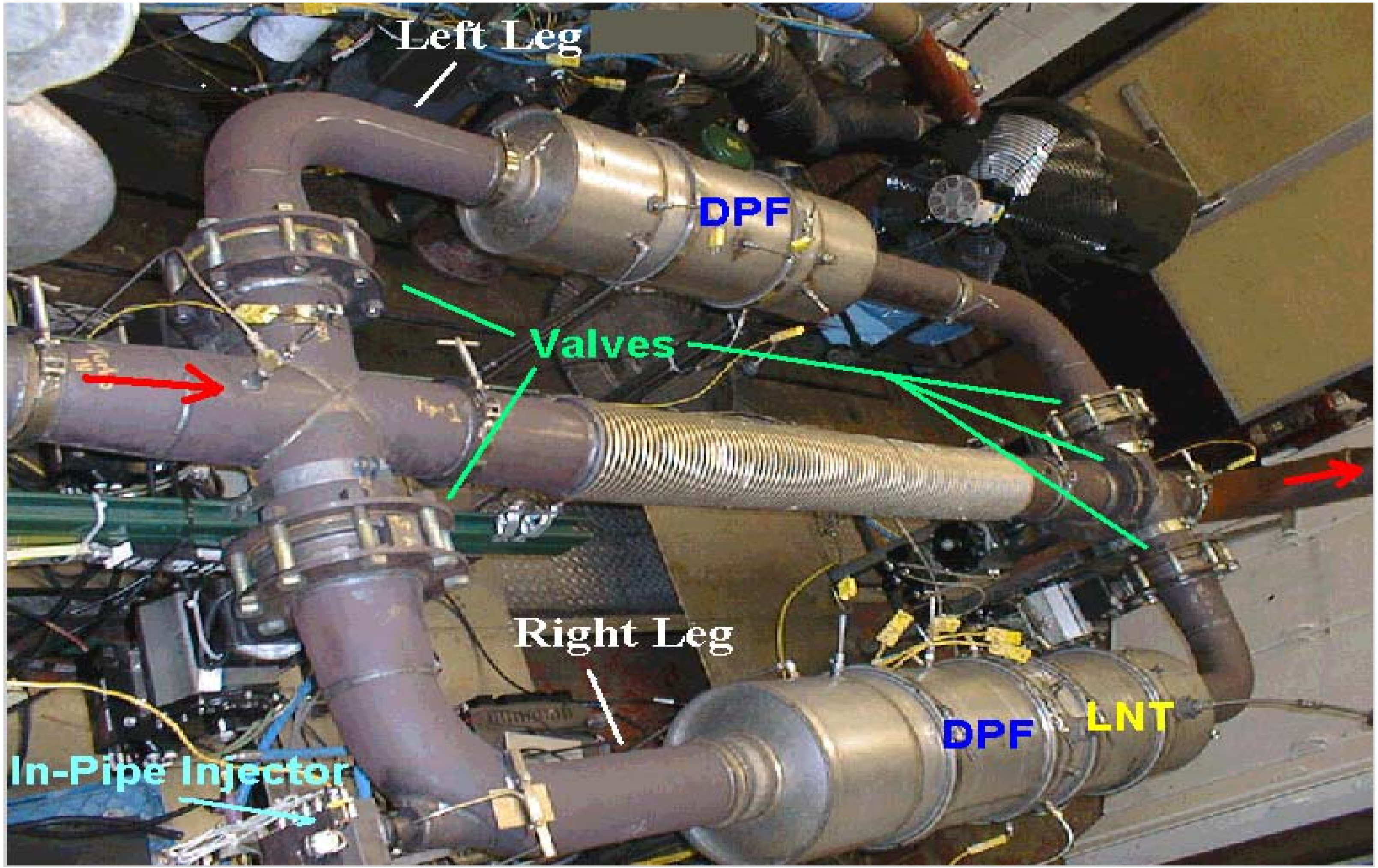
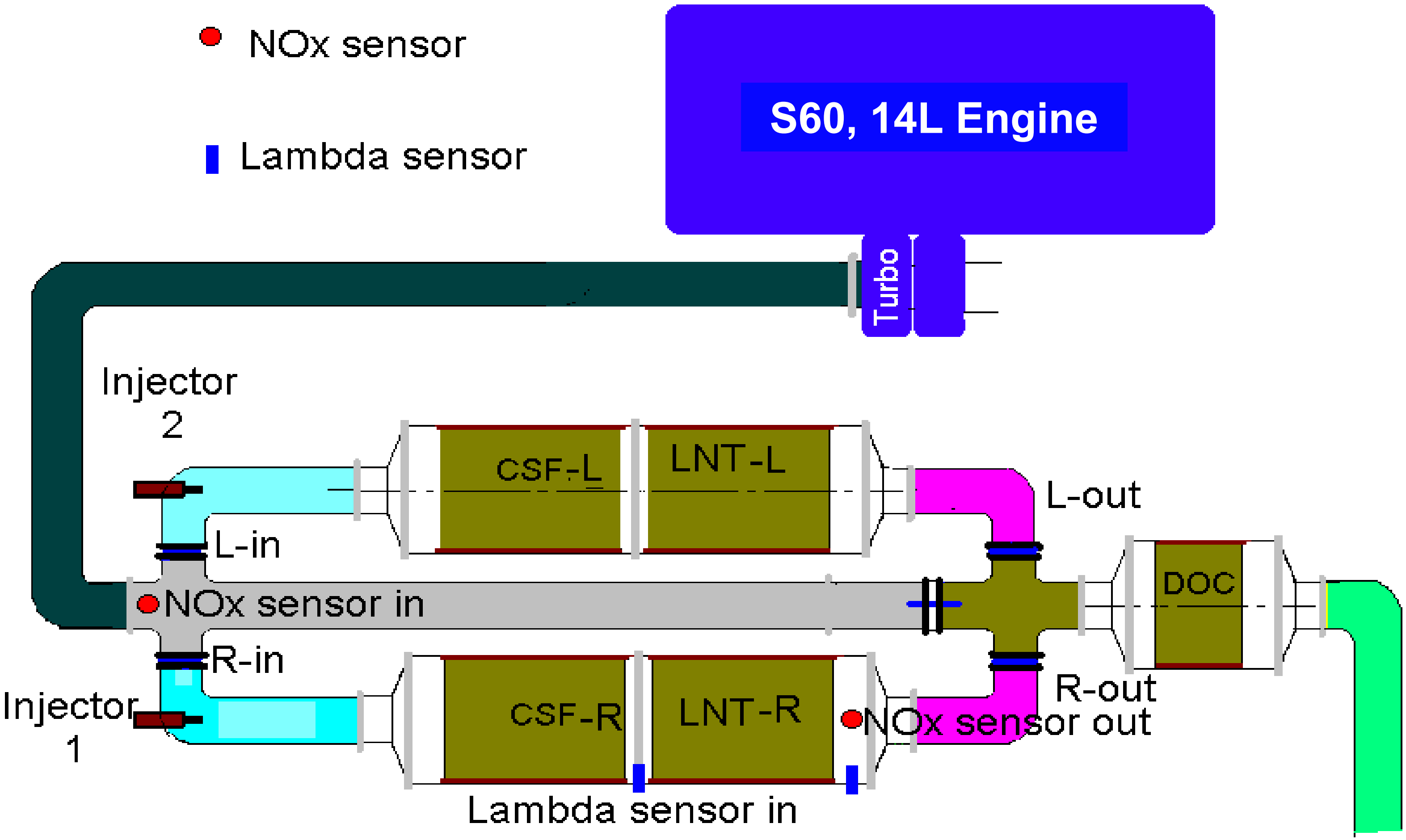
Test Setup



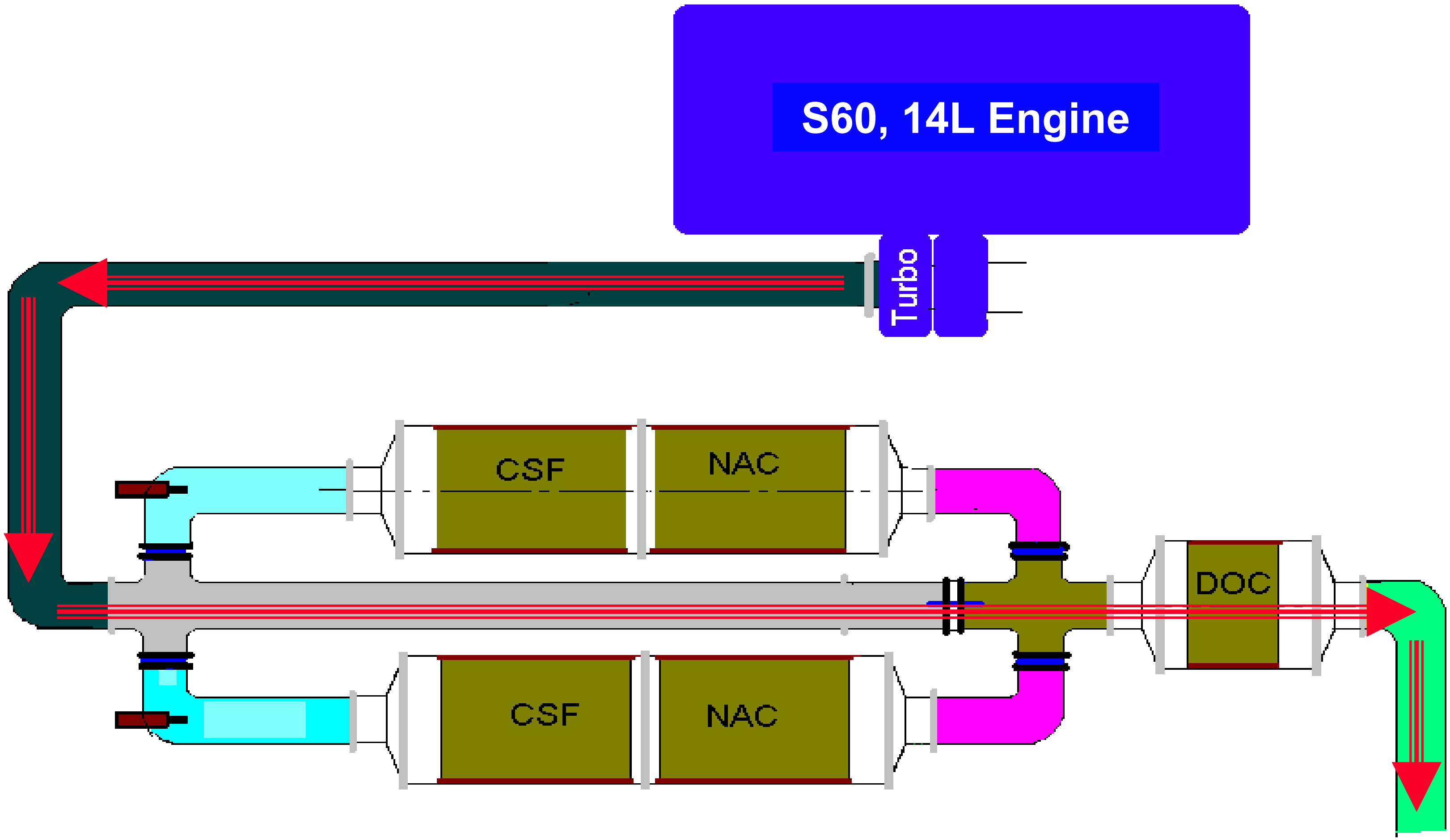
Test Setup Schematic



A.T. System Configurations and Catalysts

Configuration / Catalyst & In-Pipe injector	Dual Leg	Single Leg	Single Leg bypass
DPF	45.6 L	22.8 L	22.8 L
	100 cpsi, 11.25” * 14”		
NOx Adsorber	39 L	19.5 L	19.5 L
	300 cpsi, 11.25” * 12” (2*6”)		
DOC	9.8 L	9.8 L	9.8 L
Post-Engine Injector	Yes	No	Yes

Engine Baseline Test Configuration



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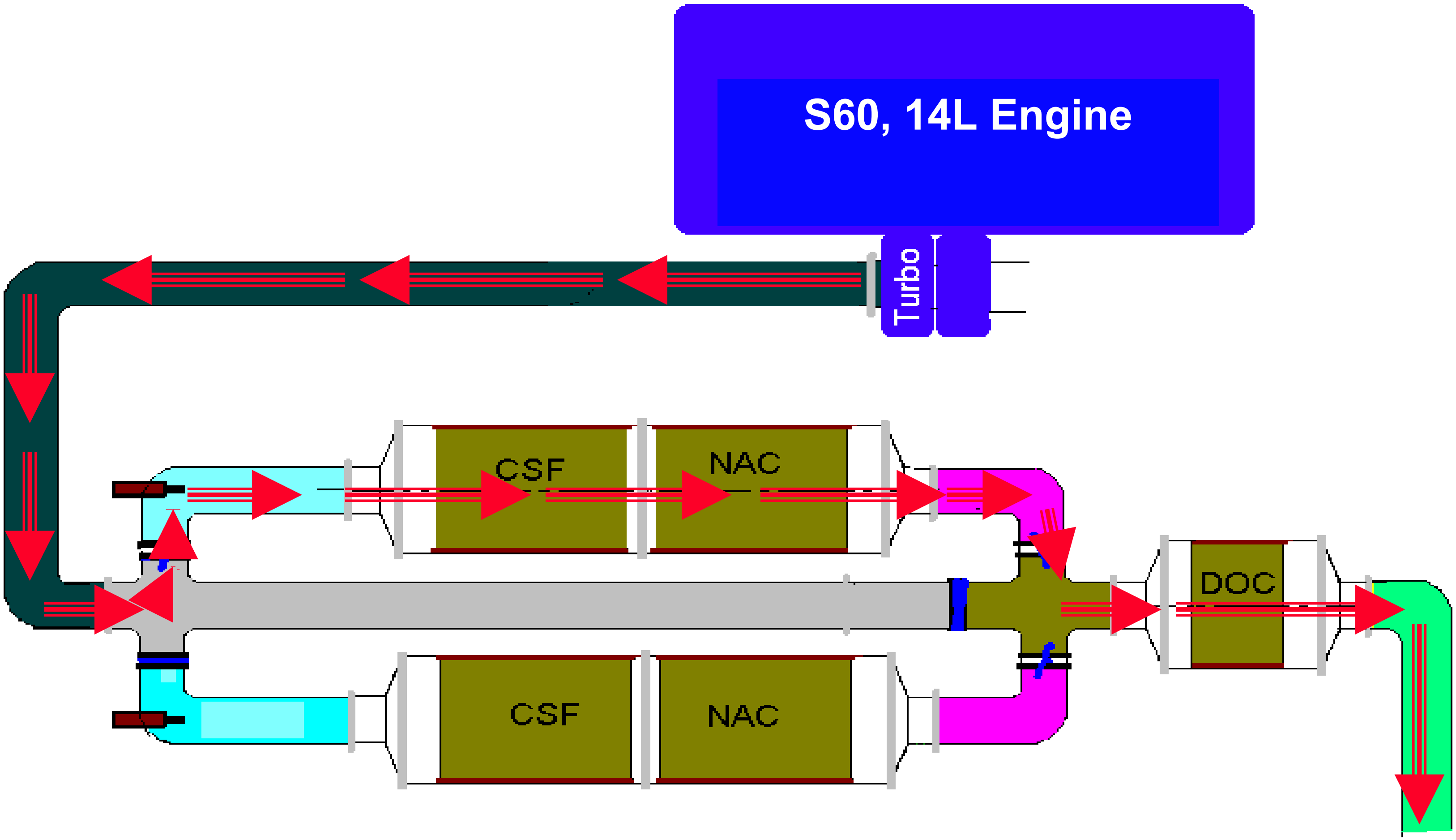
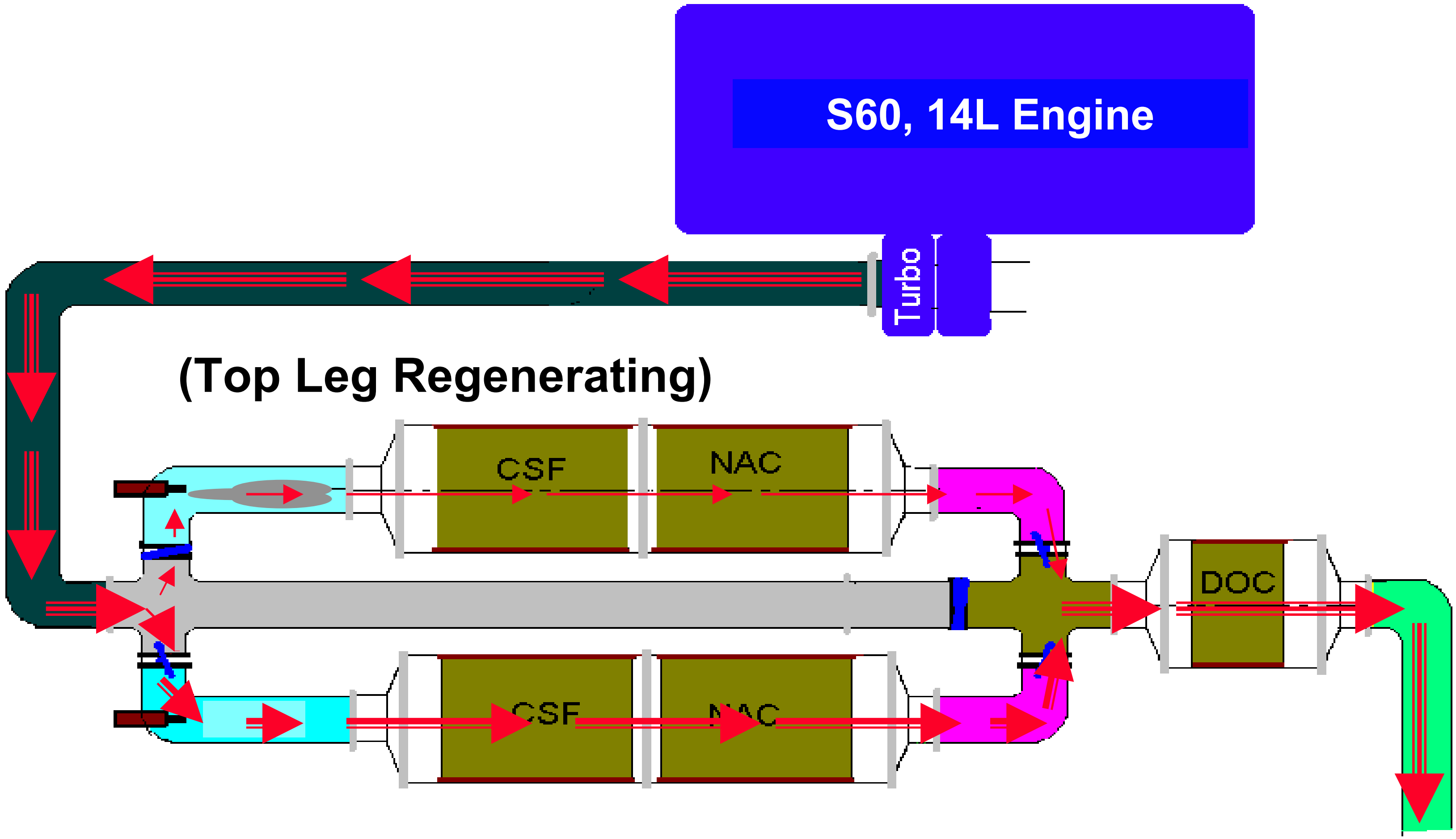
Single Leg Configuration



Dual Leg Configuration



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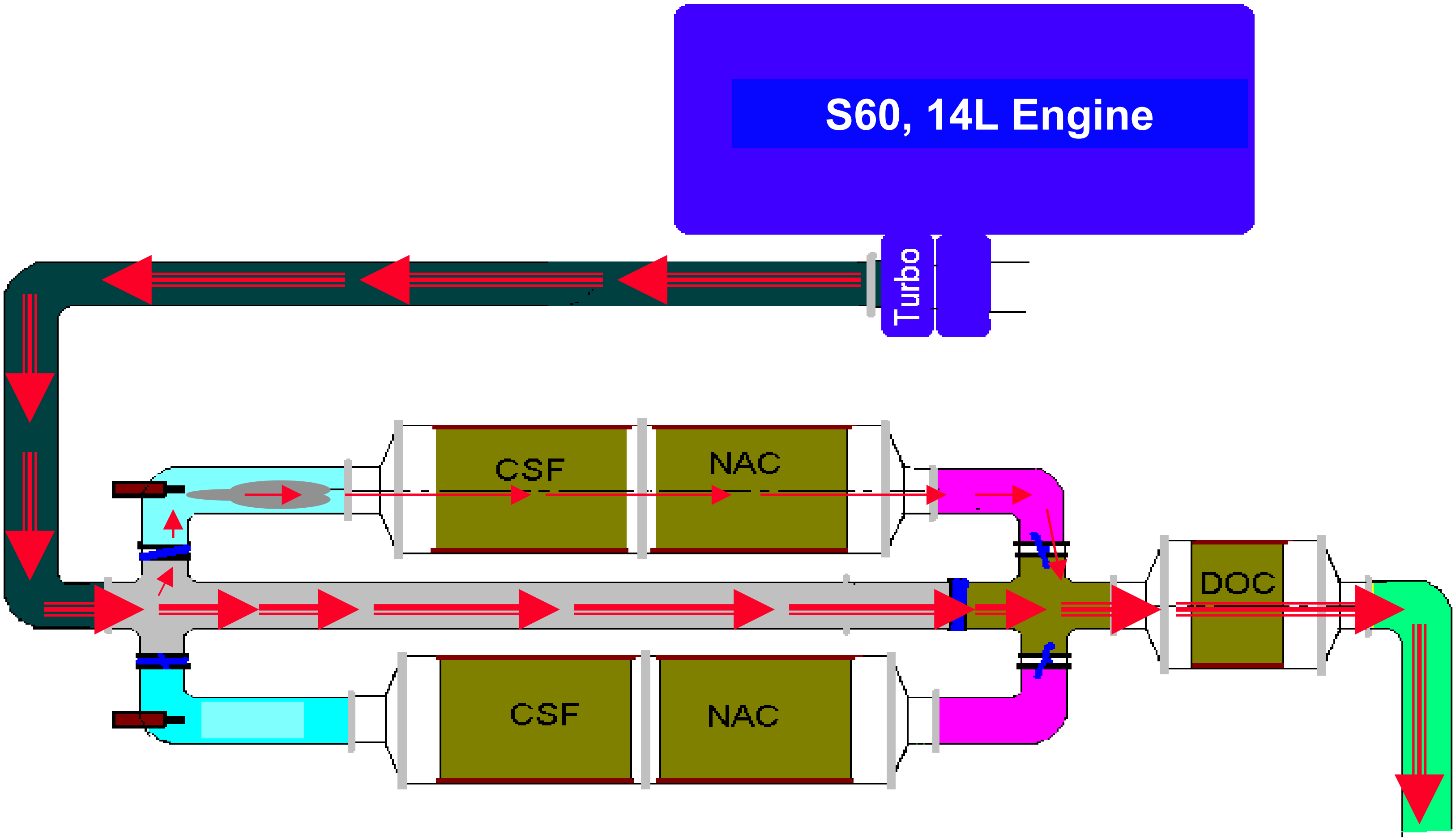
Single Leg with Bypass Configuration (Regeneration)



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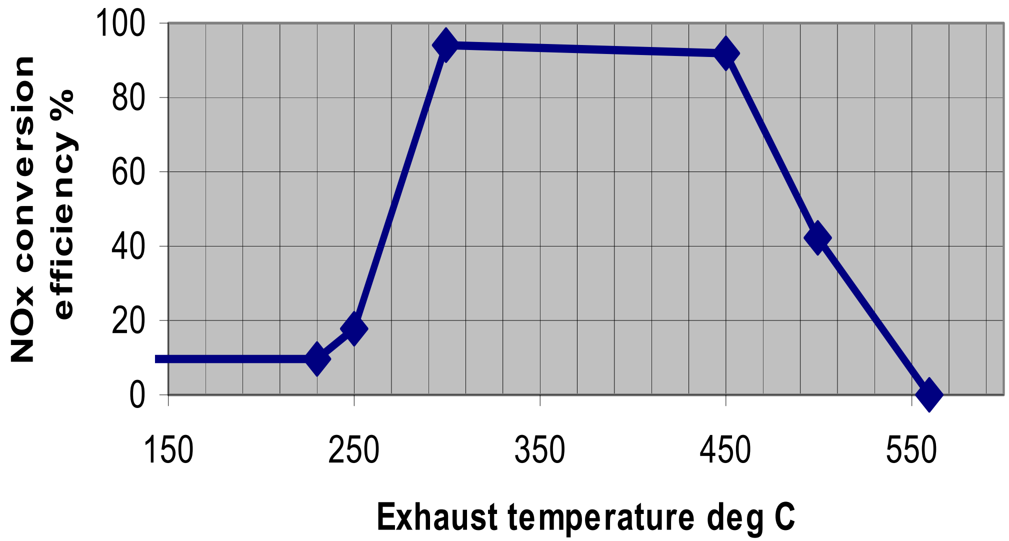
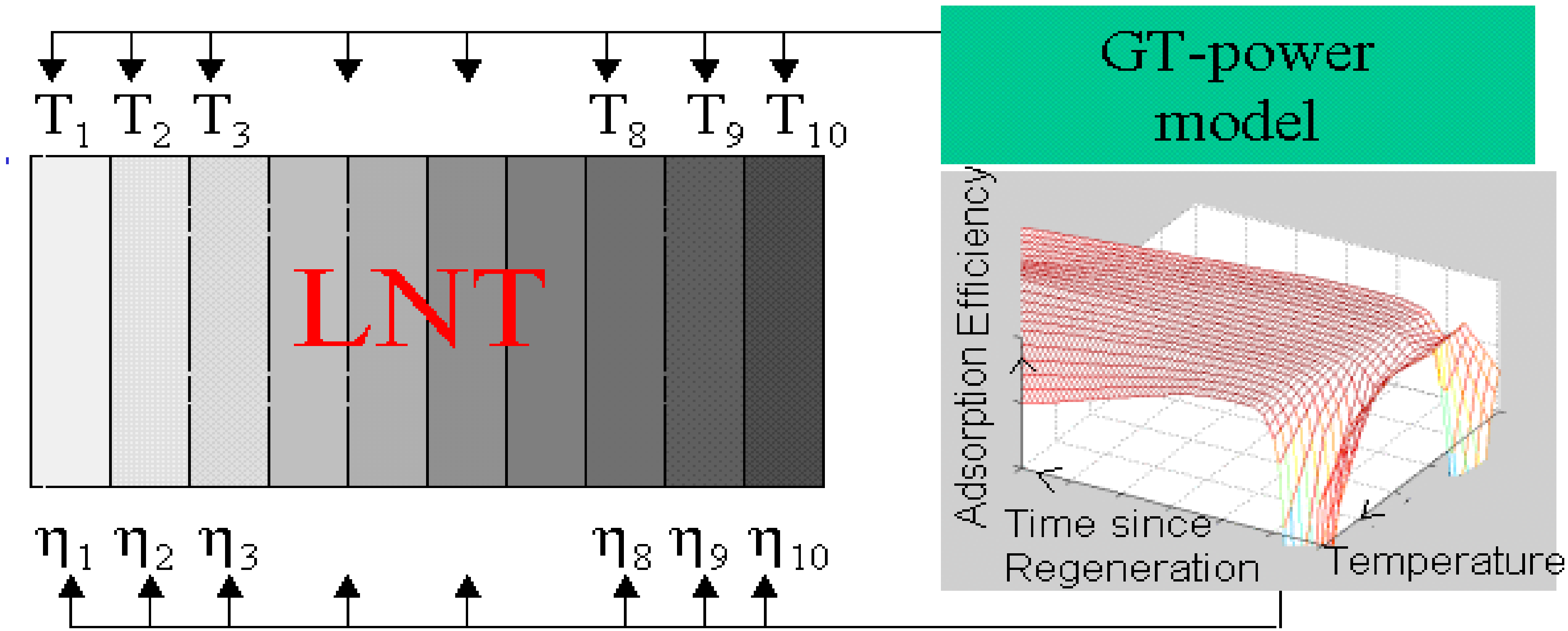
NOx Adsorber Efficiency



High NOx reduction efficiency within the catalyst temperature range

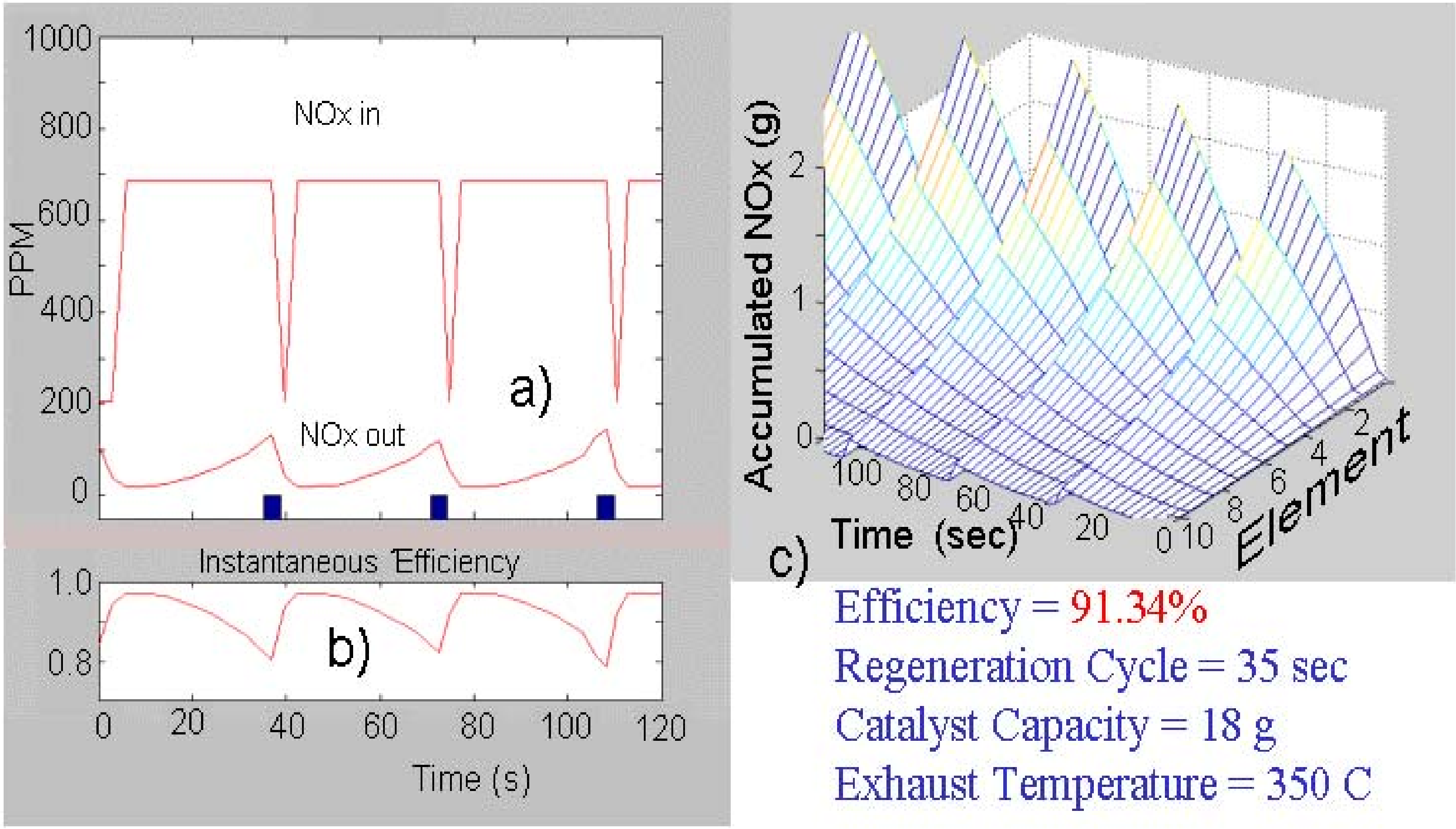
One-D Empirical Model



$$\eta_{overall} = 1 - \prod_{i=1}^{10} (1 - \eta_i)$$

at a time step

NOx In, Out Level and Adsorption inside LNT (Steady State)



Efficiency = 91.34%

Regeneration Cycle = 35 sec

Catalyst Capacity = 18 g

Exhaust Temperature = 350 C

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Single Leg Control Strategy

- Target: Lambda < 1 and Torque smoothness.
- Approach
  - Turbo vane position used to force maximum EGR mass into intake, reducing inlet air mass. This will reduce BTRQ.
  - Advanced BOI to compensate for the BTRQ drop.
  - More FPC to increase richness of exhaust.

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Single Leg Results*

ESC Mode	A50	B25	B75	B100
Rich/Lean, (sec)	3/69	5/145	5/80	7/53
NOx conv. %	72 (Rich time fixed)	77 (Rich time fixed)	88 (Target: lowest NOx out level)	78 (Target: Lowest NOx out level)
FEP %	1.0	1.2	2.05	1.2

* Fresh Catalyst

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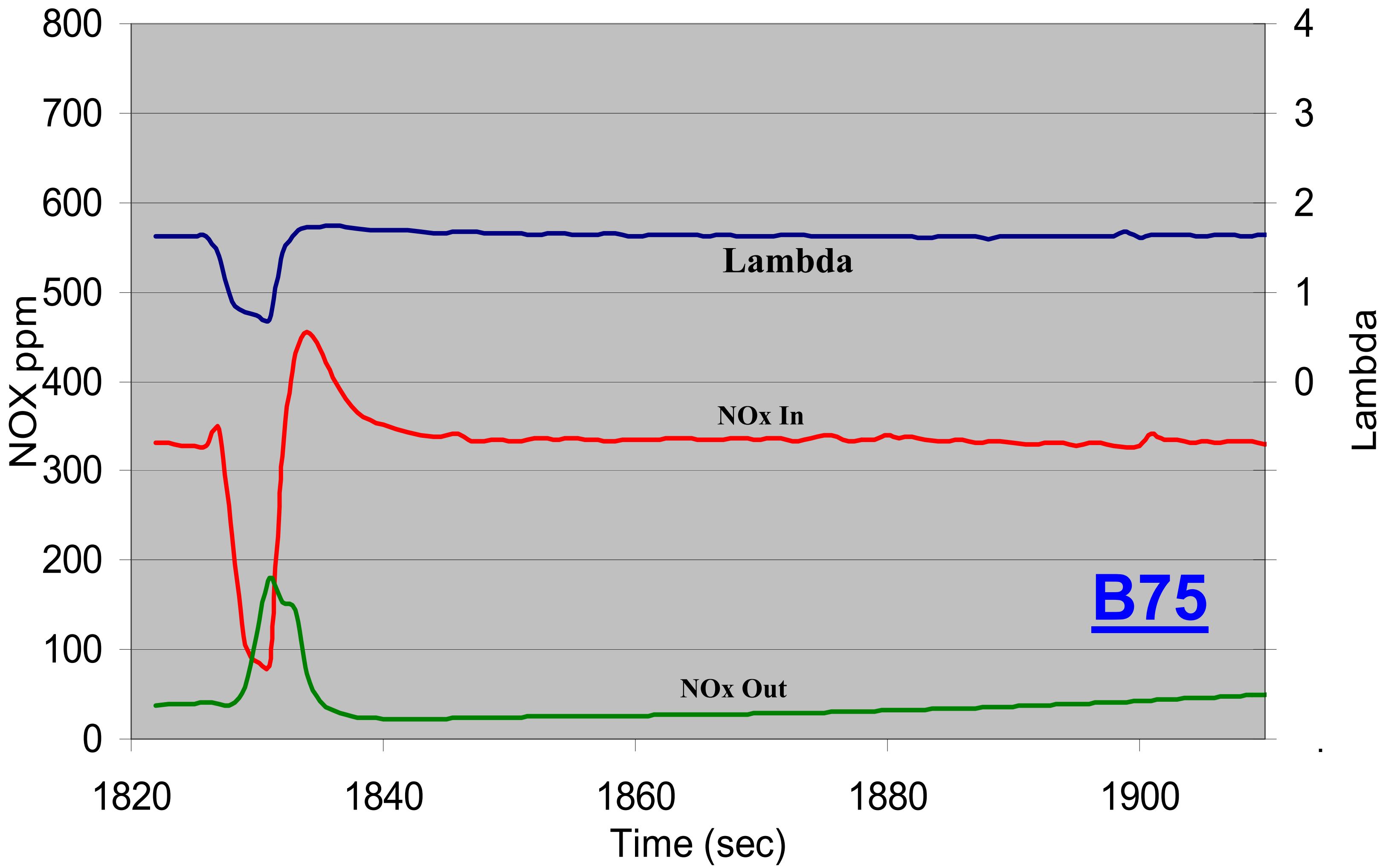
Single Leg Data



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Dual Leg Results*

Conditions	EURO III ESC Mode							
	A25		A50		A75		B50	
Valve Setting(sec)	Close	Open	Close	Open	Clos e	Open	Close	Open
	58	58	52	52	58	58	54	54
SSV(1/hr)	4280	38520	6196	55760	9360	84241	9258	83318
Inj duration	3 sec		3 sec		3 sec		3 sec	
Temp in, C	319		353		427		382	
NOx, ppm (g/hphr)	210(2.36)		440(2.67)		480(2.62)		330(2.28)	
Conv Eff, %	92.4		96		94		90	
FEP, %	5.9		3.2		1.9		2.3	

*Fresh Catalyst - Half System Operation

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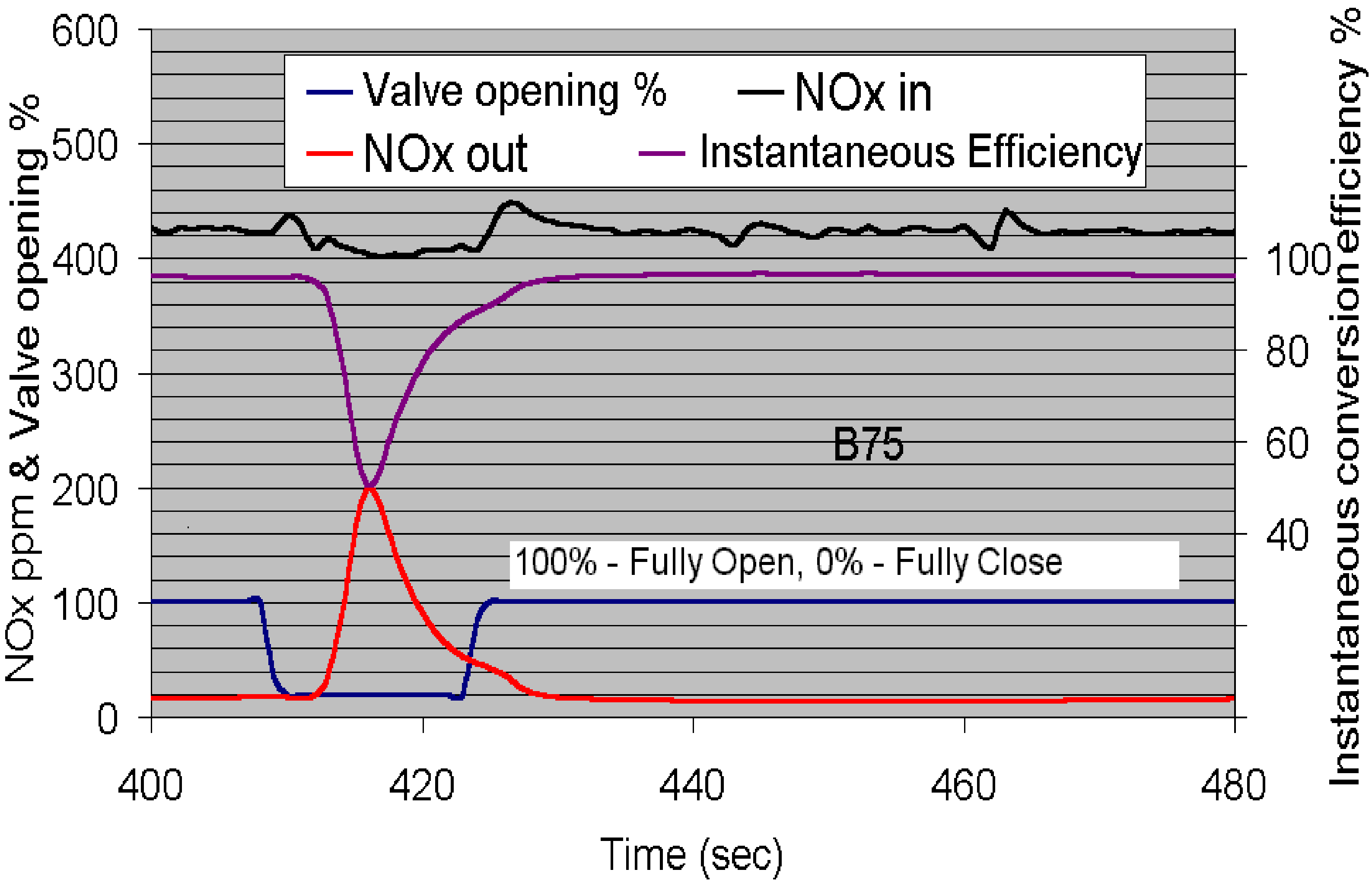
Single Leg with Bypass Results *

Conditions	EURO III ESC Mode							
	A25		A75		B25		B75	
Valve Setting(sec)	Close	Open	Close	Open	Close	Open	Close	Open
	15	140	15	100	15	140	15	100
Inj duration	3 sec		3 sec		3 sec		3 sec	
Temp in, C	319		427		343		392	
Conv. Eff, %, Across LNT	92.0		92.5		91.0		92.5	
Conv. Eff, %, Overall	83.0		80.4		82.0		80.4	
FEP, %	4.0		1.5		3.0		1.3	

* Fresh Catalyst

Test Results - Single Leg with Bypass*



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Conclusions-Single Leg

- The simplest A.T. configuration, but engine management and performance is challenging.

- Issues:
  - The "Ideal" Lambda curve shape when rich.
  - Driveability (Torque Variation)
  - Durability(Liner Temperature, cylinder pressure, turbocharger, …)
  - Transient control (Closed loop control on Torque and Lambda)
  - Desulfation

Conclusions- Dual Leg

- The most complex A.T. configuration, but least core engine management modification involved.

- Issues:
    - Valve mechanism and mechanical durability.
    - Space claim.
    - Secondary fuel injection system.
    - Multiple catalyst reliability.
    - Transient Control.
    - Desulfation.

Conclusions- Single Leg with Bypass

- A compromise between the single-leg and dual-leg systems.
- Has some common features and challenges of each.

Concluding Remarks

- A steady state NOx adsorber regeneration cycle can be designed using a NOx sensor and a Lambda sensor.
- Development of transient regeneration control logic is an order of magnitude more difficult, especially for the single leg system.
- Based on simulation, FTP NOx conversion will be only ~ 50% for the single leg system.
- Thermal stress on the cylinder kit and turbocharger during regeneration cycling must be addressed.