

Biodiesel Effects on U.S. Light-Duty Tier 2 Engine and Emission Control Systems – Part 2

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ABSTRACT

Raising interest in Diesel powered passenger cars in the United States in combination with the government mandated policy to reduce dependency of foreign oil, leads to the desire of operating Diesel vehicles with Biodiesel fuel blends.

There is only limited information related to the impact of Biodiesel fuels on the performance of advanced emission control systems. In this project the implementation of a NO_x storage and a SCR emission control system and the development for optimal performance are evaluated. The main focus remains on the discussion of the differences between the fuels which is done for the development as well as useful life aged components.

From emission control standpoint only marginal effects could be observed as a result of the Biodiesel operation. The NO_x storage catalyst results showed lower tailpipe emissions which were attributed to the lower exhaust temperature profile during the test cycle. The SCR catalyst tailpipe results were fuel neutral. The engine-out emissions formation showed increased NO_x and decreased HC emissions with the Biodiesel blend. The observed effect specifically on NO_x was up to 10% increase with the B20 blend. There was some impact on fuel economy which was attributed to higher combustion efficiency resulting in approximately 2% improved fuel economy with Biodiesel. There was no measurable impact of Biodiesel operation on the engine mechanics including fuel injection system.

INTRODUCTION

Due to advancements in Diesel engine technology light-duty Diesel powered vehicle are becoming more popular in the U.S. In addition to the increased interest in light-duty Diesel vehicles the phasing in of stringent Tier 2 emissions standards for this vehicle class has lead to the necessity of emissions control systems (ECS) on these vehicles. Concurrently, increasing fuel prices have rejuvenated interest in bio-fuels, such as Biodiesel, as a means to displace demand for petroleum-derived fuels.

Selective catalytic reduction (SCR) with urea and NO_x adsorber catalyst (NAC) are the leading technologies for meeting the Tier 2 NO_x emission standards for light-duty Diesel vehicles. Extensive research has been conducted over the past decade focusing on the performance and durability of these technologies in conjunction with conventional fuels [1-8]. Little research has been performed with the intent of gaining an understanding of the impact of bio-fuels, or more specifically Biodiesel, on these ECSs.

Biodiesel is a renewable fuel derived from vegetable oil, animal fat, or waste cooking oil and consists of the methyl esters of fatty acids. It is typically used as a Diesel blending component at levels up to 20 volume percent. A resource assessment indicates that Biodiesel has the potential to displace 5% or more of petroleum Diesel over the next decade [9], and a life cycle analysis indicates that use of B20 reduces life cycle petroleum consumption by 19% [11]. Although little is known about

the potential impacts of these fuel blends on the life and performance of ECSs.

This project evaluates the emissions performance of the NAC or SCR system, combined with a Diesel oxidation catalyst (DOC) and Diesel particle filter (DPF), while operating on ultra-low sulfur Diesel (ULSD) and a blend of ULSD and 20% Biodiesel (B20). A consideration of SCR and NAC chemistry suggests several areas where Biodiesel blends may perform differently than pure petroleum-derived fuels.

HARDWARE AND SOFTWARE DESCRIPTION

The following five chapters provide an overview of the hardware and software components used during the project. The test vehicle and test engines are procured through the U.S. Department of Energy, while all catalyst hardware as well as the urea dosing system is supplied by the Manufacturers of Emissions Controls Association (MECA).

ENGINE HARDWARE

The engine used for this project in the test cell as well as in the vehicle is a 4 cylinder 2.15 l HSDI Diesel engine. The original engine calibration complies with EURO 4 emission standards. The engine utilizes a conventional high-pressure EGR loop, second generation common-rail fuel injection system (1600 bar maximum injection pressure, solenoid injectors) with all actuators electrically controlled. Table 1 lists the main parameters of the test engine.

Table 1: Engine specifications

Engine Power	113 kW at 4000 rpm
Peak Torque	360 Nm at 2000 rpm
Maximum Engine Speed	4700 rpm
Maximum BMEP	21 bar
Cylinder Number and Arrangement	4 Cylinder Inline
Firing Order	1 – 3 – 4 – 2
Valve Train	4 Valve DOHC
Bore to Stroke Ratio	1.0034
Displacement	2.15 l
Compression Ratio	18
Fuel Injection System	2nd Generation Common Rail

ENGINE HARDWARE

The test vehicle is a conventional four door sedan vehicle in the 1700 kg class. It meets the EURO 4 emission standards and is equipped with a catalyzed DPF as standard feature.

Table 2 lists the relevant vehicle features.

Table 2: Vehicle specifications

Criteria	Unit	Value
Vehicle Mass	kg	1700
Air Drag Coefficient	-	0.29
Frontal Surface Area	m ²	2.20
Transmission Gear Ratio	1 st	4.99
	2 nd	2.82
	3 rd	1.78
	4 th	1.25
	5 th	1.00
	6 th	0.82
	Axle	2.65
Tires	Rear	205 / 55 R 16 91 H
	Front	205 / 55 R 16 91 H

CATALYST SPECIFICATIONS

As part of the ECS all catalysts are provided by MECA. Figure 1 shows the system architecture for the NAC as well as the SCR system. The NAC in the upper portion of the graph is located close-coupled, directly after the turbine exit with minimal distance to the catalyst to allow fastest possible heat-up of this NOx treatment unit. In addition the SCR system dimensions are displayed on the bottom as the SCR catalyst which is the critical unit from heat-up perspective is moved to the under-floor location. All the piping between the DOC exit and the SCR inlet is made of dual wall exhaust pipe for increased heat preservation during operation.

Table 3 shows the catalyst specifications for each individual component.

Unit		Volume [l]	Cell Density [cpsl]	PGM loading [g/ft ³]
NAC System	DOC	0.8	400	150
	DPF (AT)	3.3	300	60
	NAC	4.1	400	120
SCR System	DOC	1.23	400	150
	DPF (SiC)	4.1	300	60
	SCR Fe-ZSM-5	4.43	300	N/A

CATALYST SPECIFICATIONS

The design process of the ECS software was aimed to be as modular as possible. Each control module can be easily removed or substituted by an alternative routine. Figure 2 shows the high level structure of the controller which is implemented in the rapid prototyping environment.

The input as well as the output module converts the signals to useful conditions for each side of the controller. The core of the ECS algorithm is within the intervention handler module.

The different intervention requests coming from the State Release Module and a release system are transformed into the corresponding output signals through a patented multi-variable control structure which allows the control of temperature and lambda simultaneously.

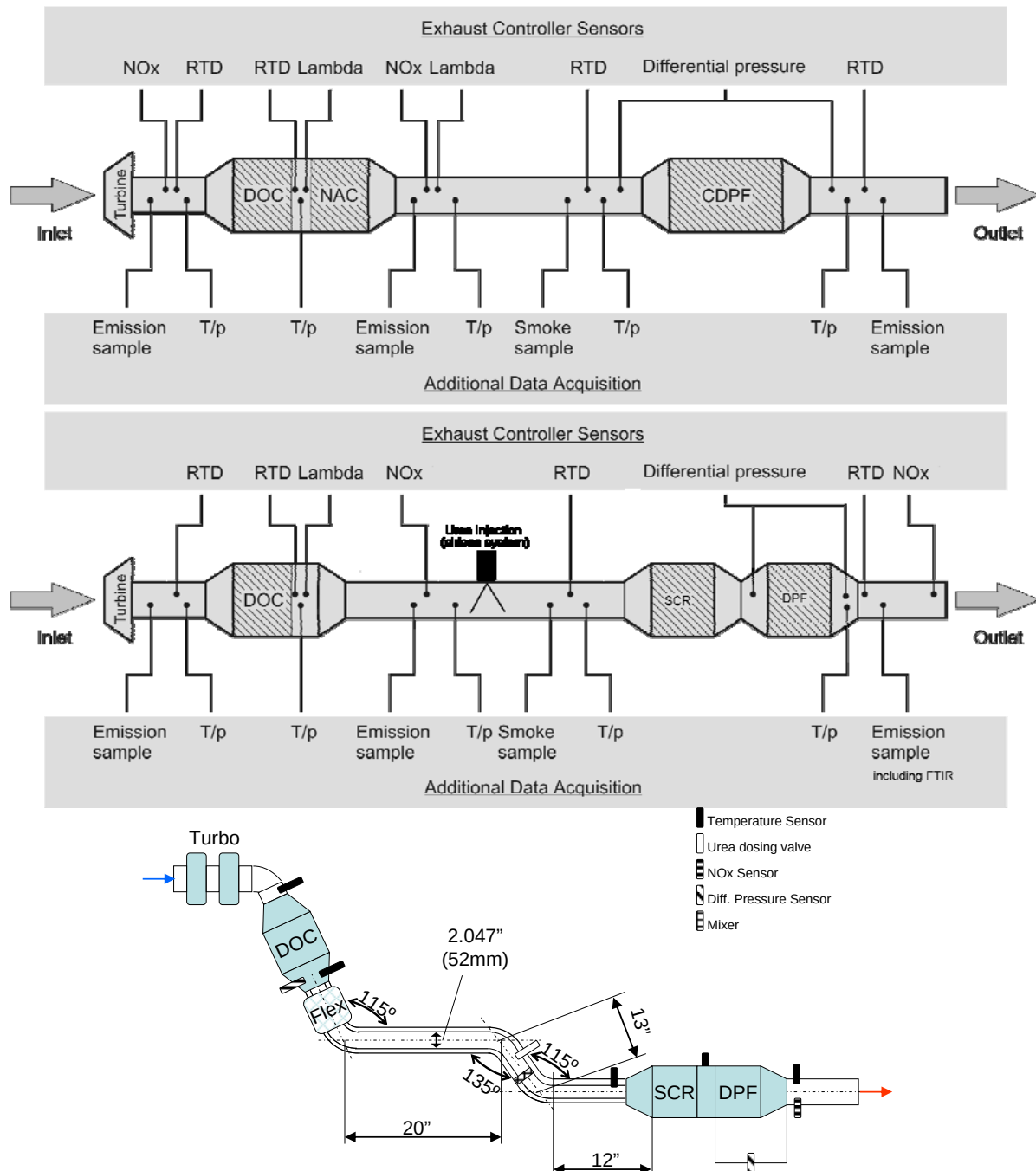


Figure 1: Emission control systems architecture

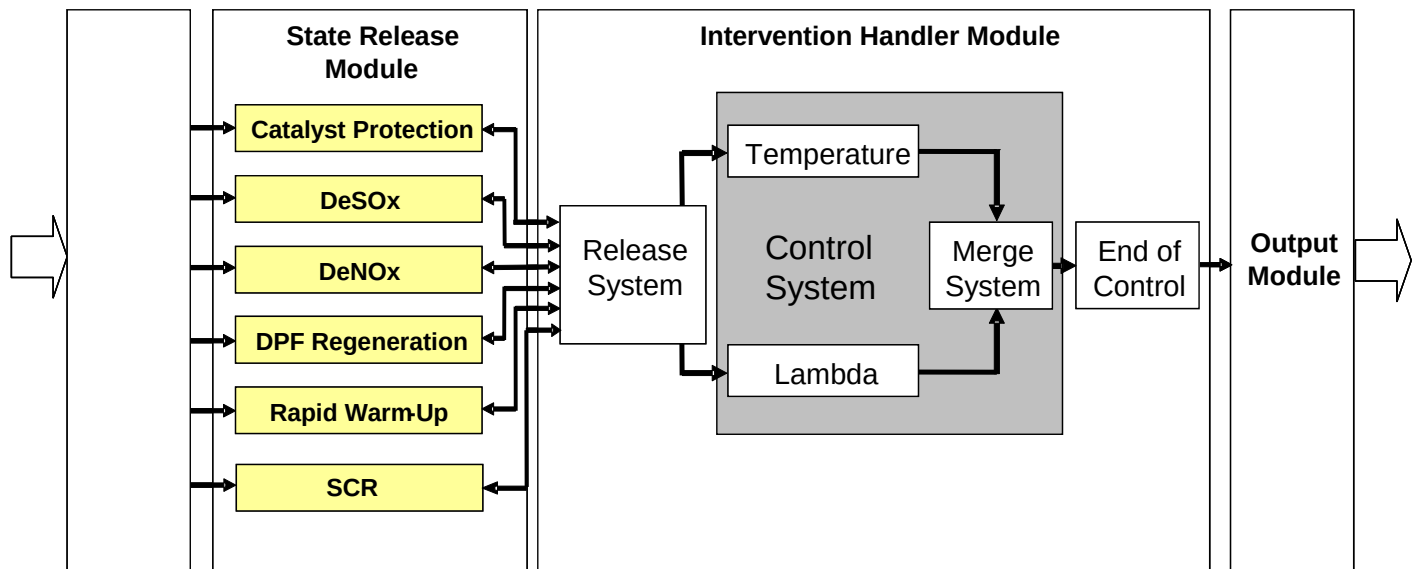


Figure 2: Emission control software architecture

FUEL SPECIFICATIONS

The ultra low sulfur Diesel fuel (ULSD) also called the base fuel was used to blend the 20% by volume (feedstock is soy methyl ester). Table 4 lists the fuel specifications for each tested fuel type. The effects on the fuel specifications as a result of the increased amount of methyl ester become particularly noticeable in the heating value, the cetane number and the oxygen content and of course have secondary effects on the remaining specifications. The Biodiesel fuel blend was based on B100 which met the D6751 specifications. The metal content for Na and K were below detection level of 1 ppm and Ca and Mg were below 0.1 ppm.

Table 4: Fuel specifications

		ULSD	B20
Net Heating Value [ASTM D240]	MJ/kg	42.534	41.522
Cetane Number [ASTM D613]	-	41.4	45.6
Density at 15°C [ASTM D4052]	kg/m3	847.5	852.9
Viscosity at 40°C [ASTM D445]	mm2/sec	2.429	2.685
Carbon [ASTM D5291]	wt%	87.04	85.01
Oxygen [ASTM D5622]	wt%	0.00	2.29
Hydrogen [ASTM D5291]	wt%	12.96	12.70

SCR UREA DOSING SYSTEM DESCRIPTION

The urea dosing system and its control is one of the key components for a successful system conceptualization. The utilized system supplies the urea from a supply unit at 10 bar pressure to a urea dosing valve. A Dosing Electronic Control Unit or DECU controls the system pressure in a closed loop control mode as well as the urea dosing quantity. Figure 3 shows the various subcomponents of the dosing system as well as its installation in the vehicle upstream the catalyst.

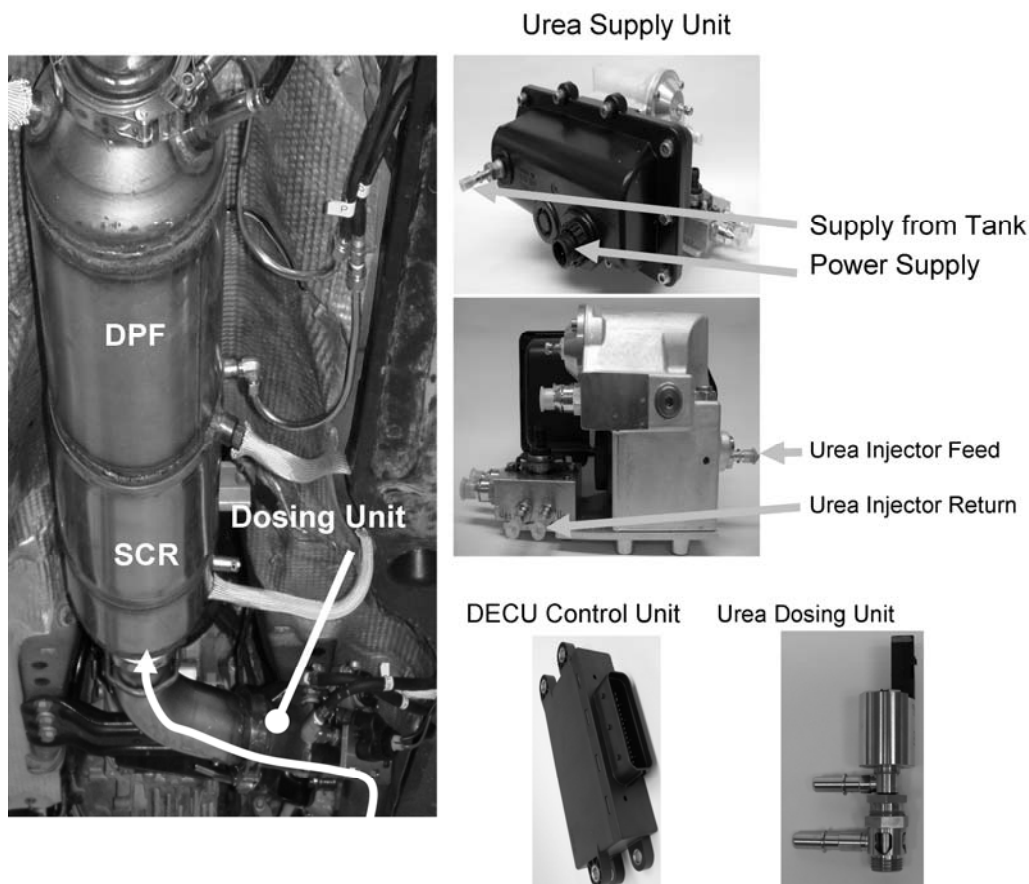


Figure 3: Urea dosing system

DPF MANAGEMENT

The first phase of the development work was the calibration of the temperature control module for the DPF regeneration mode as this serves both NAC as well as SCR ECS. This task has to precede all other activities as the function of the DPF regeneration allows for the safe and continuous operation of all other system interventions. The DPF regeneration strategy development as well as calibration were started under steady-state conditions in the test cell and were ultimately transferred to the vehicle.

As the project goal was the determination of the influences of Biodiesel effects on engine and ECS, a mature emission control calibration, in this case the control of the DPF regeneration, was used to compare the ULSD base fuel with the B20 blend. Figure 4 shows the behavior of the two compared fuel blends at 600°C and 650°C (these tests were conducted in the engine dynamometer test cell). In both cases the DPF was loaded to 5 g/l (5 grams of soot per liter of DPF volume). The soot burn-out rate is calculated based on the feedback signal from the differential pressure sensor. It is evident that at the lower set-point temperature the regeneration rate of the Biodiesel blend is faster compared to the base fuel, as has been observed in

previous studies [10]. This has been attributed to changes in PM morphology and to the addition of oxygen to the PM surface caused by the inclusion of Biodiesel in the fuel. At the higher temperature set-point the differences disappear.

The temperature increase upstream of the DPF was realized through a combination of air- as well as fuel handling parameter variations. The engine out temperature is raised through intake air throttling in conjunction with lowered EGR rates. An early post injection (close to the main injection event) raises the engine out temperature further while a late cycle post injection provides reactants to the DOC which generates an exothermic reaction and controls the temperature at the setpoint level.

The temperature control module was transferred to the vehicle and its performance evaluated under various driving conditions. It was found that during transient operation the control parameters had to be recalibrated in order to obtain stable control of DOC outlet temperature.