

Optimization of Exhaust After-Treatment System (EATS) to BS 6 Emission Level for a Light Commercial Vehicle (LCV) Using Existing BS 4 Engine Results and 1-D Simulation Approach

Ragupathi Soundara Rajan, Vijay Sharma, Ashraf Emran, and Devising Rathod
FEV India Pvt. Ltd.

John Henry Kwee and Thorsten Michaelis-Hauswaldt
FEV GmbH

Thomas Körfer
FEV Group Holding GmbH

ABSTRACT

The emission legislations are becoming increasingly strict all over the world and India too has taken a big leap in this direction by signaling the migration from Bharat Stage 4 (BS 4) to BS 6 in the year 2020. This decision by the Indian government has provided the Indian automotive industry a new challenge to find the most optimal solution for this migration, with the existing BS 4 engines available in their portfolio. Indian market for the LCV segment is highly competitive and cost sensitive where the overall vehicle operation cost (vehicle cost + fluid consumption cost) is the most critical factor. The engine and after-treatment technology for BS 6 emission levels should consider the factors of minimizing the additional hardware cost as well as improving the fuel efficiency. Often both of which are inversely proportional.

The presented study involves the optimization of after treatment component size, layout and various systems for NO_x and PM reduction. The study aims to analyze hardware changes required on the selected BS 4 engine to achieve improved engine out emission levels so as to minimize the Exhaust gas After-Treatment System (EATS) size using 1-D simulations approach.

Normally the after treatment calibration and the engine thermodynamic calibration are performed separately which leads to complexity achieving the optimum fuel consumption and tail pipe emissions at vehicle level. FEV has developed a new strategy in which simultaneous optimization of involved systems like engine level thermodynamics, controls, transmission system and the EATS can be performed, thus arriving at the best engine and EATS configuration.

In this study, the approaches to migrate from BS 4 to BS 6 for a Light Commercial Vehicle (LCV) application have been detailed. For an existing BS 4 diesel engine there can be two different approaches possible to meet the BS 6 emission targets. The first approach involves keeping the existing engine hardware unchanged and arriving at the required EATS, layout and sizing. The second approach involves implementation of engine level internal measures for improving engine-out emission levels and then arriving at a more optimized EATS. The engine level changes considered for this approach does not include any major architectural changes in the hardware. Both the approaches are evaluated on these two factors: a) cost of hardware addition to the existing engine and after-treatment system b) operational fluid cost. No changes into the transmission layout have been considered in this study. Although it was established that increase in the number of gears in the transmission will help reducing the engine out emissions [1].

CITATION: Soundara Rajan, R., Sharma, V., Emran, A., Rathod, D. et al., "Optimization of Exhaust After-Treatment System (EATS) to BS 6 Emission Level for a Light Commercial Vehicle (LCV) Using Existing BS 4 Engine Results and 1-D Simulation Approach," *SAE Int. J. Engines* 10(1):2017, doi:10.4271/2017-26-0119.

INTRODUCTION

Vehicle Specifications

A LCV with a Gross Vehicle Weight (GVW) of 2930 kg has been

chosen for this study with an engine output of 75 kW rated power. The vehicle falls into N1- Class 2 category with a Reference Mass (RM) of 1700 kg. Other specification for vehicle and engine are listed in the [table 1](#) and [table 2](#)



Documents

Document Sharing Hub

Table 1. Vehicle specification

Powertrain arrangement	2 wheel drive / rear wheel drive
Transmission	Manual with 5 forward and 1 reverse gear
Tire Specification	215 / 70 R15
Inertia Class	N1 - Class 2
EATS for BS4	DOC

The engine has to comply with BS 6 emissions by 2020 as per the proposed legislation from Government of India. Table.2 shows the specifications of the engine considered in this study. The base BS 4 compliant engine is a 3 cylinder inline engine having a high pressure (HP) cooled EGR, 1600 bar common rail system, Compression Ratio (CR) of 16.5 and an active waste gate controlled turbo charger. Currently closed coupled DOC is used to meet the BS 4 emission legislation.

Engine Specifications

Table 2. Engine specification

Swept volume	1500 cc
Arrangement	Inline 3 cylinder
Number of valves / cylinder	4
Injection system	Unit pump based common rail injection system
Turbocharger	Waste gate
EGR	Cooled high pressure EGR with pneumatic control
Rated power	75 kW @ 4000 rpm

The current exhaust system layout on the vehicle is shown in fig.1. The turbocharger mounted on the exhaust manifold has a close coupled diesel oxidation catalyst for reduction of HC and CO from the engine out exhaust.

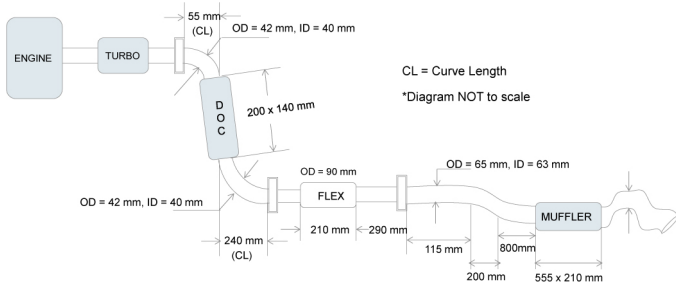


Figure 1. BS 4 Exhaust layout

The vehicle being a LCV has a length of more than 4 m, has no major layout constraints for routing of the exhaust systems underneath the vehicle. Fig.2 compares the limits of exhaust emissions between BS 4 and BS 6 legislations. The NO_x needs to be reduced by 68.2 % to 105 mg/km and PM by 88.8 % to 4.5 mg/km. Addition of particulate number of 6.0×10^{11} included in BS 6 legislation. The current BS 4 emissions are achieved by engine out measures besides oxidation

catalyst, whereas the BS 6 limits necessarily require a massive exhaust gas after treatment system with DeNO_x and PM reduction at the vehicle level.

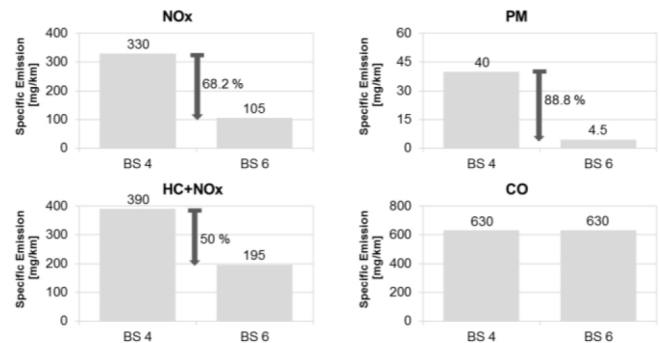


Figure 2. Comparison of exhaust emission legislation

The limit for CO has been kept unchanged while the HC limits have been relaxed in the draft BS 6 draft notification with a share of 54:46 ratio between NO_x and HC respectively. This is a substantial step in reduction of emissions by skipping BS 5 intermediate level. In additional CO_2 targets also need to be considered in the vehicle development.

EXHAUST GAS AFTER-TREATMENT MEASURES

Diesel Particulate Filter

The particulate number limit notified by Government of India for BS 6 legislation makes it mandatory to use DPF [6]. Soot separators originally used with industrial sector to separate soot from the exhaust were later thought to be used in automotive applications. Due to its size and packaging, it was not considered as a viable option to adapt directly to the vehicular application. Later the regenerative particulate filters evolved for vehicular application. Depending on the material and design, it is classified into combination of ceramic & sintered with close & open filters. The most common type of particulate filter is a ceramic honeycomb filter. It has small pores sufficient enough to filter every small particle from the exhaust gas. In order to keep the back pressure to the engine minimum, these filters were sized over, for example the filter for a passenger car application is more or less ~ 1.5 times the size of the engine capacity.

Fig.3 shows a reduction of 99 % particles through the DPF, which has PN levels even better than the engine inlet levels. With course of vehicle life, the accumulated soot needs to be cleaned or filter has to be replaced. Typically the DPF needs regeneration at around 500 -1000 km for such type of vehicles [3]. Generally it is not practical to have the vehicle in the work shop for DPF cleaning, hence automated regeneration or soot burning is necessary. For regeneration the inner temperature of DPF has to be increased to around 600°C , which typically being done by a regeneration controller and optimized thermal management. This is a discontinuous type of DPF regeneration. In another DPF regeneration strategy commonly known as continuous regeneration technique, the regeneration temperatures can be brought down to around 300°C . The process involves cleaning on the upstream DOC or LNT not only oxidizes CO & HC but also

converts NO to NO₂. This NO₂ then oxidizes the stored soot in the DPF located downstream. This is called CRT (Continuous Regeneration Trap). The CRT effect also supports the discontinuous DPF regeneration system used generally on smaller vehicles [3].

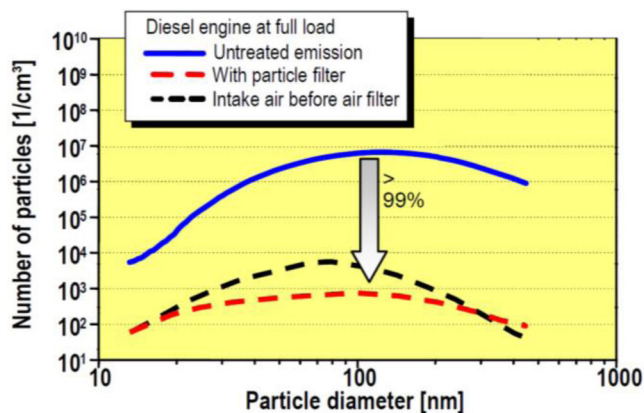


Figure 3. Particulate number level[3]

NO_x Treatment in the Exhaust Gases

EGR has been used to control the NO_x produced inside the cylinder from the time of implementation of BS 3 emission legislations and the same trend continuing till BS 4 legislations for the considered N1-Class2 vehicle category. But the stringent BS 6 limits of 105 mg/km for NO_x and 4.5 mg/km for PM makes it challenging to reach the targets with only EGR based approach, without the use of any DeNO_x system in the exhaust. There are two widely acceptable DeNO_x solutions available in production today a) Lean NO_x Trap or NO_x storage catalyst or NO_x adsorption catalyst (LNT) b) Selective Catalytic Converter (SCR) [2] [9].

LNT systems are basically NO_x adsorbing catalytic converters which do not use any active reducing agent. The LNT catalyst can adsorb NO_x and can be regenerated to reduce the accumulated NO_x from it. During the adsorption process the nitrogen oxides in the exhaust reacts with the metal oxide base to form nitrates. The adsorbing base materials are generally alkaline, alkaline earth metal or carbonates [3] [8]. When the storage capacity of the base material is filled, all the metal oxide is converted to metal nitrates. In the presence of hydro carbon, the metal nitrates are broken leaving the original metal oxide. The NO_x desorbed in the process gets reduced by CO/HC produced during rich event into CO₂ and N₂ as shown in fig.4. The NO_x adsorption generally happens between the LNT brick temperatures of 150 °C to 450 °C [8]. There is an undesirable reaction occurring in LNT system which is formation of metal sulfates due to oxidization of sulfur oxides in the exhaust gas. This causes a slow reduction in LNT's DeNO_x efficiency and requires a desulfurization event with temperature around 600 °C [3] [5] [8] [9].

On the other hand, SCR systems involve the addition of a separate reducing agent such as ammonia into the exhaust. The reducing agent is injected with the help of injection systems in front of the SCR catalyst which is generally Fe or Cu based zeolites or Vanadium oxides (V₂O₅). Typically NH₂CONH₂ is used as reducing agent which is a mixture of 32.5 % water and 67.5 % urea [3]. This mixture reacts to form ammonia when injected into the exhaust gas. This

ammonia reduces the NO_x in presence of the catalyst to form N₂ and H₂O. The NO_x conversion efficiency is dependent also on the temperatures in the SCR catalyst, as shown in fig.5.

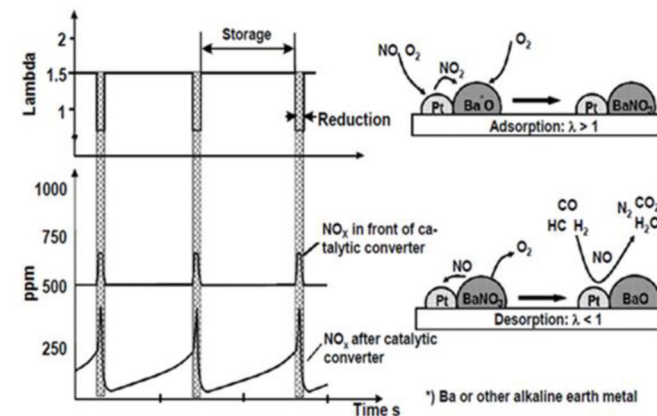


Figure 4. Chemical reactions at Lean NO_x Trap [3]

The space flow velocity which is the flow rate divided by the catalyst volume is also very important which defines the dwell time of the exhaust gas inside the catalyst. A slower space velocity will yield a higher efficiency due to more time available for the reaction [3]. LNT system achieve higher DeNO_x efficiency at relatively lower exhaust temperatures as compared to the SCR system, thus providing higher performance during the initial phase of the MIDC cycle when the catalyst temperatures are lower in case of passenger cars and LCV's. SCR system uses external reducing agent (urea) which require a separate dosing system (urea tank, dosing pump, dosing injector, control unit etc.) making the system costly as compared to LNT system [9].

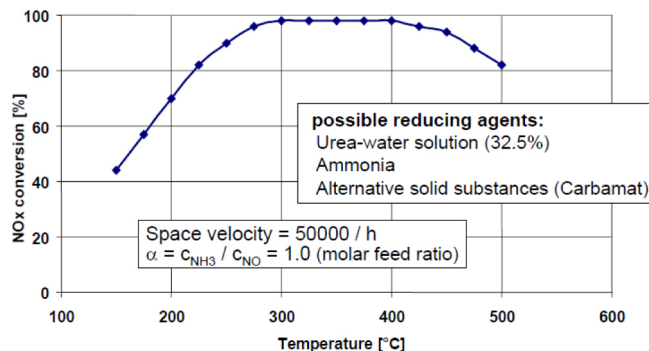


Figure 5. SCR - NO_x conversion characteristics [3]

SCR system is also not ideal with respect to packaging on the vehicle with separate requirement of urea mixing length in front of the SCR catalyst and making provision for the urea tank. The LNT system requires short rich engine operating regeneration events which causes fuel penalty on the other hand the SCR system has additional urea consumption. There is also some slippage of ammonia from the SCR catalyst which produces foul smell in the exhaust and may require an extra slip catalyst to bring the slippage within limits. The SCR system also has issues in the sub-zero operations when the urea-water mixture may freeze [3]. The LNT systems are typically preferred for engine below 2 L / 2.2 L swept volume for meeting BS6 emission limits with Modified Indian Driving Cycle (MIDC) due to lower exhaust temperatures involved, lower overall system cost and ease of