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Tesis

**SCR exhaust aftertreatment system
for D13C engines**

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SCR exhaust aftertreatment system for D13C engines

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Abstract— This article provides information about the operation of the SCR exhaust aftertreatment system in D13C engines. Nowadays, atmospheric pollution has been one of the main problems of our society, even though most of this pollution occurs in cities with heavy congestion, in which most vehicles emit polluting gases such as CO₂ and NO_x, the latter is formed by nitric oxide (NO) and nitrogen dioxide (NO₂), therefore this type of gas is very harmful to the person, which is why a technology was developed to mitigate this pollution problem. The SCR technology also called Selective Catalytic Reduction uses the AdBlue solution, which is an additive combined with an infusion of urea to treat nitrogen oxide in order to comply with the exhaust emission standards applied to Euro 5 trucks. The AdBlue solution is injected into the exhaust gases before they pass through the catalytic converter, thus the additive converts the NO_x into nitrogen gas and steam. In order to meet Euro 5 requirements, about 5-6% dilution of the reagent is required in correlation to the volume of fuel available.

Keywords— *AdBlue, Euro 5, SCR aftertreatment system.*

I. INTRODUCTION

Currently, alternative internal combustion engines are producers of toxic gases sent into the environment by the energy source they use for their operation, which is the combustion of a petroleum-based hydrocarbon (1), therefore, combustion-generated nanoparticles are present in exhaust aftertreatment systems in a size range of approximately 1 to 1000 nm (2).

Sustainability is the key driver of powertrain transformation for mobile and stationary solutions. It requires the reduction of both greenhouse gas emissions and pollutant emissions. In this respect, for the mobility sector, internal combustion engines have to compete with battery electric vehicles and fuel cell electric vehicles (3). Modern combustion engines are therefore already highly optimized and further substantial reduction of fuel consumption is technologically increasingly difficult, making alternative approaches mandatory (4).

A combustion strategy to reduce these emissions was investigated with a single-cylinder diesel engine mixing NH₃

gas into the intake air. It was also found that an early pilot injection of diesel fuel reduced NH₃ and unburned N₂O emissions, while HC and CO emissions increased (5). The impact of different concentrations of ferrocene nanoparticles to diesel and B30 base fuels on the performance, combustion characteristics and CO₂ and NO_x emissions of a compression ignition engine is also investigated. A 4-stroke, air-cooled, single-cylinder, air-cooled compression-ignition engine was used to perform these experiments (6).

On the other hand, increasing the use of natural gas in heavy-duty engines is beneficial for reducing greenhouse gas emissions from power generation and transportation. However, converting compression-ignition engines to spark-ignition engines with natural gas can increase methane emissions without costly aftertreatment (7). On the other hand, gasoline compression ignition (GCI) is a promising way to achieve high thermal efficiency and low emissions by taking advantage of conventional diesel engine hardware (8).

This is why exhaust aftertreatment systems are crucial to ensure real-world motor vehicle NO_x emission limits (9). Thus, exhaust aftertreatment systems have been present in motor vehicles for decades and have contributed to reducing their impact on the environment and people. Most of them for oxidation or reduction of harmful particulate and smoke emissions (10).

II. METHODOLOGY

To reduce NO_x emissions, SCR is widely used in many exhaust gas cleaning technologies (22), as we will see below:

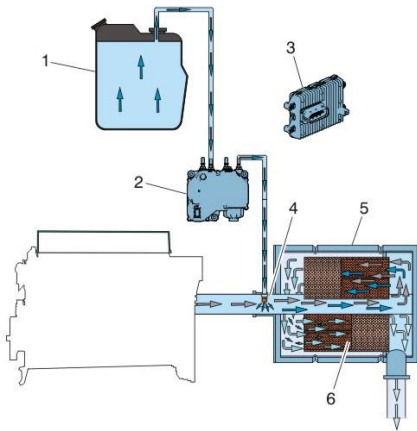


Fig. 1. SCR system flow diagram with its components. Taken from Volvo trucks portal

Table I. SCR system components

| N° | System components |
|----|-------------------------------------|
| 1 | AdBlue tank |
| 2 | Pump unit |
| 3 | Aftertreatment Control Module (ACM) |
| 4 | Metering valve |
| 5 | Silencer |
| 6 | Catalytic converter |

Reagent system overview

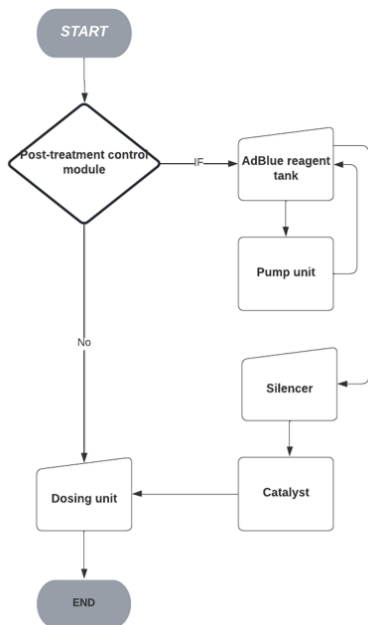


Fig. 2. Flow diagram of the purification principle for exhaust gases. Own elaboration

The AdBlue reagent solution is injected into the exhaust gases in atomized form, upstream of the catalytic converter. The

injection precision is controlled by the engine management system ECM (Engine Control Module), which ensures optimum emission reduction for all operating conditions. The heat of the exhaust gas rapidly decomposes the AdBlue reagent into ammonia and carbon dioxide. Ammonia is the active compound and the most important ingredient in the chemical process that takes place in the catalyst, where NOx is converted into harmless nitrogen gas and water vapor. This chemical reaction takes place at a combustion temperature above 190°C. The SCR catalyst cannot be repaired or replaced as a single unit. The complete muffler unit must be replaced if necessary.

Post-treatment system

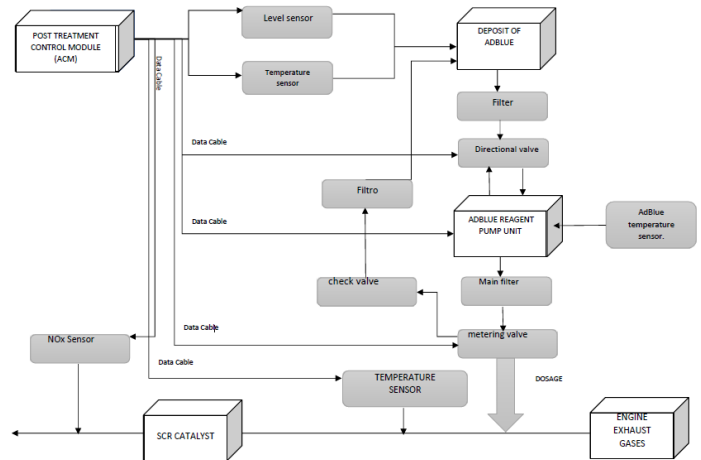


Fig. 3. Block diagram of the system overview. Own elaboration

All sensor signals are checked electronically when the ignition is switched on for plausibility. The temperatures of the AdBlue urea tank, ambient air and pump are monitored. At low temperatures, the system is subjected to a warm-up stage before activation. If all conditions are met (plausibility), the system will enter the pressure build-up phase when the engine starts, i.e., the pump will also start and the SCR system can take advantage of the higher exhaust gas temperature (17). In the pressure build-up phase, the pump sucks AdBlue urea from the tank. The air in the system is forced out through the check valve and a short opening of the metering valve. The pump speed is ramped up to the maximum. The pressure regulator then regulates the system by varying the speed of the pump motor. There will be a constant overflow circulating through the dosing valve into the reservoir to maintain a stable pressure in the system.

AdBlue tank

Most new diesel vehicles need AdBlue to reduce emissions of nitrogen oxides (NOx) so it is an important part of the combustion process cycle (12). AdBlue is filled in a separate tank in the vehicle that is completely separate from the fuel system, also the AdBlue for the SCR system has to be refilled regularly (18). The AdBlue solution tank is made of plastic or

stainless steel and is available in different sizes as shown in the figure below:

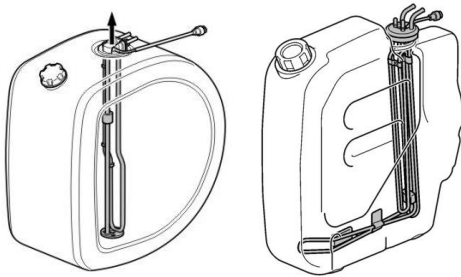


Fig. 4. Steel tank with heating coil or plastic tank for AdBlue solution. Taken from Volvo Portal Trucks.

Both tanks are equipped with a breathing function to equalize pressure changes. The plastic tank is of the older model, equipped with a level sensor and with a float in the modern model. The steel tank has a tank armature with a float. At the bottom there is a drain plug so that the AdBlue solution can be emptied, if necessary, e.g. during cleaning work, replacement of the level sensor, etc.

Heating

As the AdBlue solution freezes at -11°C , the tank has a heating circuit that brings coolant from the engine. On the frame, close to the tank, there is a solenoid valve that regulates the coolant flow. In addition, the hoses connecting the tank and the pump unit are electrically heated and the hose connections are additionally insulated. The AdBlue urea in the tank and pump is heated with a coolant heating coil. The coil is controlled by the coolant heating solenoid and is located in the frame. The temperature sensor value and the ambient air temperature determine whether the heating valve has to be activated or not. The hoses are electronically heated, and the current strength used depends on the ambient air temperature.

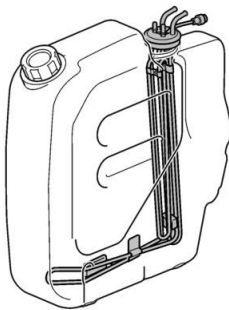


Fig. 5. Steel tank with heating coil or plastic tank for AdBlue solution. Taken from Volvo Portal Trucks.

AdBlue reagent pump unit

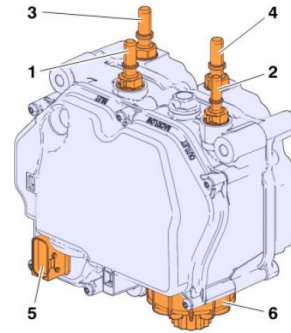


Fig. 6. AdBlue reagent pump unit

Tabla II. Components of the pump unit.

| | |
|---|-------------------|
| 1 | Admission |
| 2 | Outlet |
| 3 | Antifreeze inlet |
| 4 | Antifreeze outlet |
| 5 | ACM connection |
| 6 | Filter box |

Among the components of the pump, we have: The pump, filter body, cooling control valve, temperature sensor and pressure sensor. The pump is switched on when all the activation conditions are met, and oxygen plays an important role in the absorption of the reactant and in the reaction process (21). The working pressure of the pump is about 5 bar. When the engine is stopped the pump empties the system of AdBlue solution, which is pumped back to the tank. This takes about 90 seconds.

AdBlue filter housing

After the pump, the AdBlue solution passes through a filter body that greatly assists the aftertreatment system (13) and is located in the pump body. These have also become essential to comply with regulations (19). The body consists of a paper filter [1] that purifies the AdBlue solution from dirt particles. In the filter there are two porous rubber rings [2] that protect the filter body if the paper freezes in case of very low temperatures. The filter with the rubber rings is replaced as a spare part when necessary. The filter is sealed with an O-ring [3]. In the filter body cover [4] there is an electric heating element [6] of typed insert. This element is released when changing the filter. Before changing the filter, the filter housing must be drained with the drain screw [5]. Wait 90 seconds before opening the drain screw to allow time to pump the AdBlue solution back into the tank. Particulate filters can also be retrofitted on older engines (25).

Note! In the intake pipe to the pump unit, there is a strainer [7] which is cleaned when necessary and replaced if damaged.

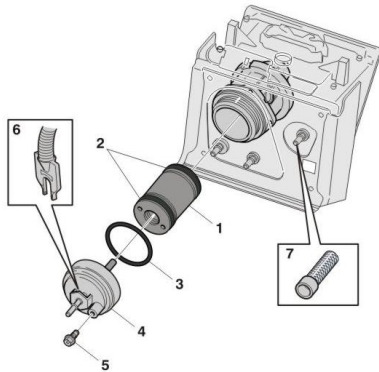


Fig. 7. AdBlue filter box with its respective components. Taken from Volvo Portal Trucks.

Catalyst

The catalyst consists of a ceramic structure with several small ducts coated with an active substance. Atomized AdBlue solution is injected into the exhaust pipe upstream of the muffler and mixed with the hot exhaust gases. The AdBlue must evaporate as quickly as possible because the gaseous state of this substance (mainly ammonia) is involved in the chemical reduction taking place in the catalyst (14). When the exhaust gases pass through the SCR catalyst, it accelerates the reaction between ammonia and nitrogen oxides in the exhaust gases. The end product is harmless nitrogen gas and water vapor. Finally, the ammonia in the exhaust gas is captured through the catalyst (23). The catalyst cannot be reconditioned or replaced separately. The low SCR inlet temperature is the predominant reason for the high NOx emission (15).

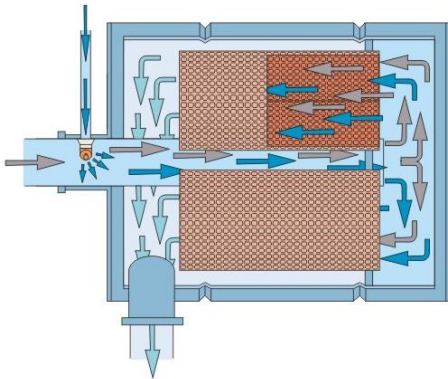


Fig. 8. SCR catalytic converter. Taken from Volvo Portal Trucks.

Dosing unit

The dosing unit has a dosing valve or injector that injects the AdBlue solution at 5 bar (500 kPa) pressure into the exhaust

gas before it reaches the catalytic converter. The amount of AdBlue solution depends on engine speed and load and is regulated electronically from the engine management system (EMS). No injection takes place if the AdBlue solution temperature is below $-7\text{ }^{\circ}\text{C}$ or exceeds $85\text{ }^{\circ}\text{C}$, overheating of the injectors can have a major influence on the operation of the SCR system (11). The efficiency of the catalyst reaction is affected by the distribution of the injectors (24). The metering valve is protected from the hot exhaust gases by a heat shield and an air bag. In addition, the metal body is cooled by the circulating AdBlue solution, which withstands a maximum of $85\text{ }^{\circ}\text{C}$. Further studies are needed concerning the heating temperature of the AdBlue injector, respectively the possibility of cooling it when it overheats (16).

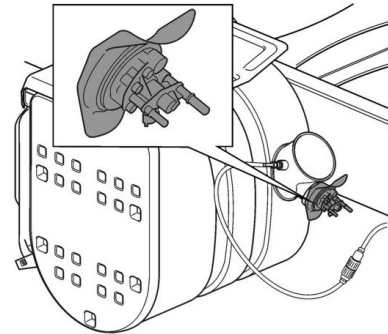


Fig. 9. Location of the metering unit. Taken from Volvo Portal Trucks.

III. RESULTS

Thanks to this exhaust aftertreatment system, a drastic change in the reduction of monoxide in the exhaust gases emitted by those vehicles of previous years that did not have the SCR system could be evidenced, and now almost all Euro 5 vehicles use the SCR system that consumes AdBlue to reduce NOx emissions (20) as shown in the figure below:

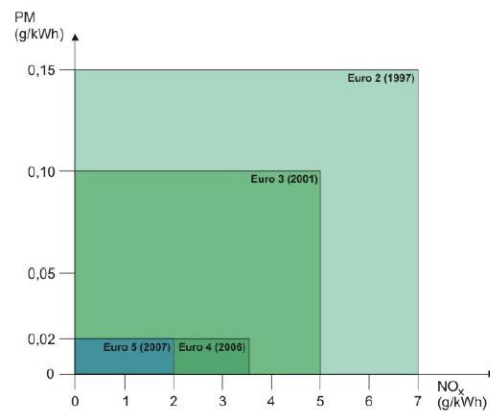


Fig. 10. Reduction of exhaust emissions. Taken from Volvo Portal Trucks

The invariable advance of the Euro 5 standard, has always sought to improve the condition of the air making an implementation in the various fleets of many vehicles of different makes and models to be able to condition renewed

technologies that help clean the carbon monoxide gases in the exhaust of all these types of vehicles.

It is also important to clarify that the Euro 5 standard applies to different types of engines such as gasoline and diesel engines. Which have different ratings, but that does not affect the level of requirement.

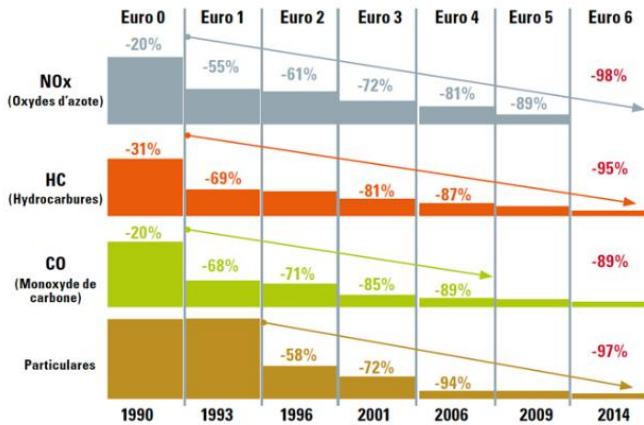


Fig. 11. Gas reduction with the implementation of each of the Euro standards. Taken from Autocrash Magazine

A. Fuel efficiency

It helps to optimize fuel efficiency and prolong engine life, as well as reduce vehicle maintenance costs.

B. AdBlue Durability

AdBlue is sensitive to temperature extremes to some extent, both hot and cold. The solution freezes at -11.5°C / 12.2°F . The proportion of AdBlue can be reduced if the temperature exceeds 30°C / 86°F . However, it should be noted that AdBlue® is not destroyed by freezing, once melted it retains its concentration and quality. The solution should not be stored in direct sunlight.

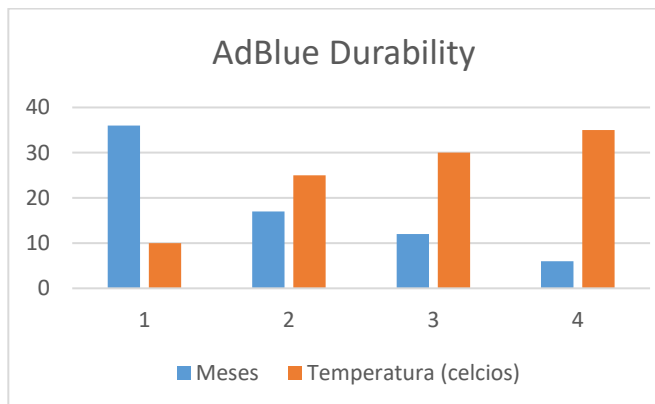


Fig. 12. Durability of AdBlue in months at constant temperature. Own elaboration.

IV. CONCLUSIONS

The following are some conclusions about the performance of the SCR treatment system:

- The effectiveness of the system at different temperatures was proven thanks to the devices that compose the system which help to obtain an ideal temperature for its good operation. As well as the availability of an exhaust aftertreatment system that is durable and highly efficient could help to adapt this type of technology to smaller vehicles.

- The injection quantity of the Adblue solution is regulated by the engine control unit with the help of information from the dosing control unit, i.e. the current values of the combined level and temperature sensor in the tank, the pressure sensor and temperature sensor in the pump unit, and the dosing valve upstream of the catalytic converter. Diagnosis and programming is carried out with the vehicle's diagnostic socket.

- With SCR technology, exhaust aftertreatment is done by adding an AdBlue solution that is injected into the exhaust gases before they pass through the catalytic converter. The AdBlue causes the nitrogen oxides to be converted into nitrogen and water vapor, natural substances in our environment. To meet Euro 5 requirements, approximately 3-4 % AdBlue is needed in relation to the amount of fuel. The Euro 5 engine has been developed for more efficient combustion levels and its control unit calculates the optimum amount of AdBlue solution to be injected in relation to the current load and engine speed..

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