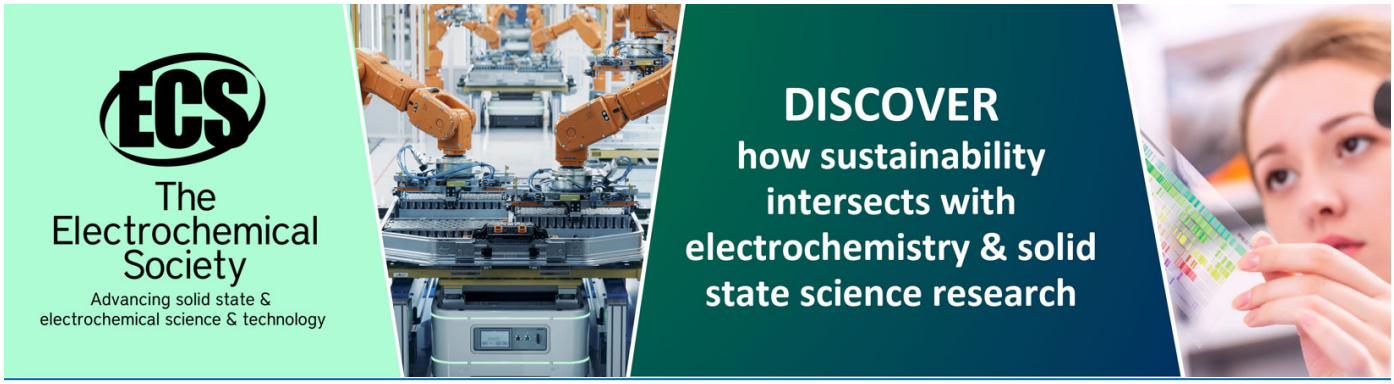
About methods to reduce emissions of turbo charged engine gasoline direct injection



About methods to reduce emissions of turbo charged engine gasoline direct injection

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Abstract: The paper aims to analyse and explain new methods applied on gasoline direct injection to reduce gas emissions and greenhouse effect. There are analysed the composition of emission inside the engine and which are the most harmful emission for the environment. Will be analysed the methods and systems which have a contribution to decrease emissions produced by the mixture of air and fuel. The paper contains details about after treatment systems which are designed to decrease gas emissions without any other negative consequence on the environment.

1. Introduction

In our days for automotive industry the objective is to create engine with low fuel consumption and low emission to reduce the pollution and greenhouse effect. Also it is necessary to raise the performance of the engine which is reflected in horse power and torque. Gasoline Direct Injection or shortly GDI is a complex technology able to reduce fuel consumption, it is more efficiently and it has a good reliability.

Emissions produced by automotive are a really problem in urban zone because the density of vehicles are higher than extra-urban zone. Emissions inside the engine appear because of the air fuel mixture and the combustion which is not perfect. This mixture is not totally burned and from here result pollutants like carbon monoxide CO, hydrocarbons HC, nitrogen oxides NO_x. Also GDI producing mechanical particles which are dangerous for humans. It is necessary to study each emission, to discover why these emissions appear inside the engine and to find solution and methods to combat and reduce the quantity of them. Now we will analysis each emission to see the composition and why is present in the engine.

1.1 Analysis the composition of emission inside the gasoline direct injection engine

Carbon monoxide CO

Carbon monoxide is a very poisonous gas which appears in cylinder. It is very harmful for engine and for environment because cannot be detected by smelling or colour. This gas it is produced by the incomplete burning of air fuel mixture inside the engine.

In composer of carbon monoxide is one atom of carbon and one atom of oxygen. If these two atoms are connected togheter they create a very harmful gas.

What causes carbon monoxide poisoning from vehicles?

- problems at injection system on GDI;
- mixture is to rich (more gasoline then air);
- operating vehicle with a defective emission system.

Hydrocarbons HC

The most representative hydrocarbons are petroleum ethers, benzene, acetone, chloroform, esters and phenols. These petroleum goods are volatiles and they exist in nature under vapour form.

The main hydrocarbons resulting in exhaust gases of automotive are benzene, toluene and xylenes. What makes appear hydrocarbons inside the engine with direct injection?

- in combustion chamber exist crevasses which can store unburned mixture in compression process and this mixture remain unburned because the flame cannot enter in these crevasses;
- when intake and compression process have place the fuel can be absorbed in the oil film and after combustion process the fuel absorbed in oil film is released which means apparition of hydrocarbons;
- incomplete burning of fuel mixture;

Others cases can be lean fuel mixture, improper ignition timing, low cylinder compression.

Nitrogen oxides NO_x

At temperatures over 2000° C, the oxygen and nitrogen combine between them resulting in nitrogen oxides. The nitrogen oxide becomes stabile and is not possible to separate in N_2 and O_2 when temperature is dropped. Nitrogen oxide NOx is caused by high temperature which appears at high speeds. Also this type of emission creates the smog which is reflected in a greenhouse effect.

Mechanical particles

Gasoline direct injection produces mechanical particles which are harmful for people and environment. These particles are presented in gasoline and appear after mixture air fuel is burned. The number of them depends from gasoline, injection pressure and load.

1.2 *Methods and systems to reduce emissions produced by incomplete combustion*

To reduce the value of emissions produce by the engine is necessary to implement complex systems which help to improve the performance of the engine and to protect the environment.

For Gasoline Direct Injection GDI systems used to reduce the quantity of emission are:

- Three Way Catalyst TWC;
- Exhaust Gas Recirculation EGR;
- Gasoline Particulate Filter GPF;

1.3 Three Way Catalyst TWC

A three way catalytic is a component which makes part from treatment system of exhausted gases.

This system is able to reduce dramatically the quantity of exhaust gases which are harmful for the environment. To realise this request the catalytic converter should be able to achieve next requests:

- reduction catalyst;
- oxidation catalyst.

The reduction catalyst is made of platinum and rhodium while the oxidation catalyst is made of platinum and palladium. Both the catalysts have a ceramic honeycomb structure.

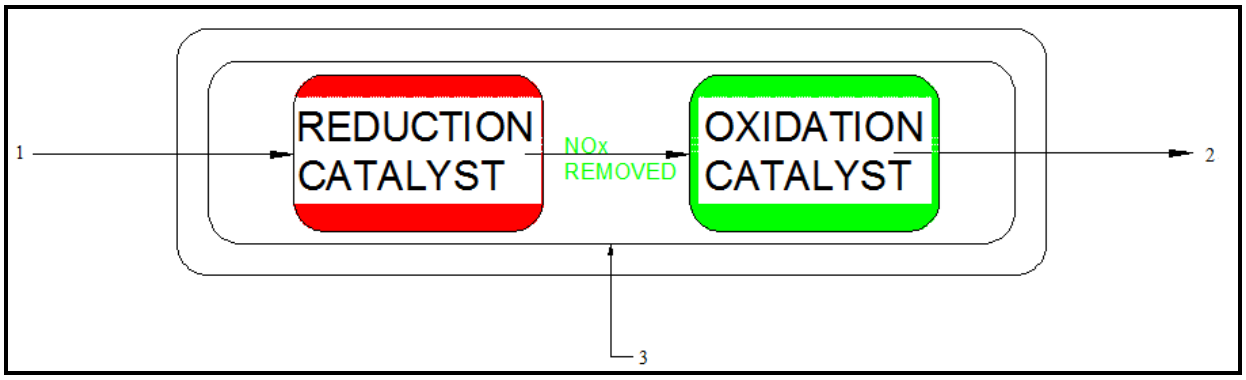

Figure 1. Three ways catalytic converter.

In figure 1 is presented how a 3-ways catalytic converter works. After combustion have place in cylinder the CO, NOx and HC are evacuated on exhayust way. They enter in convert noted wiht 1. First phase is reduction catalyst which contains Platinum and Rhodium. With these materials nitrogen are oxigen are separated in N_2 and O_2. The others emissions enter in oxidation catalyst which converts CO in CO_2 and HC in CO_2 and H_2O. On the exit on 3-ways catalyst can be found CO_2, H_2O, NO_2 noted in figure with number 2. All these reaction have places in ceramic honeycomb structured catalyst noted with 3.

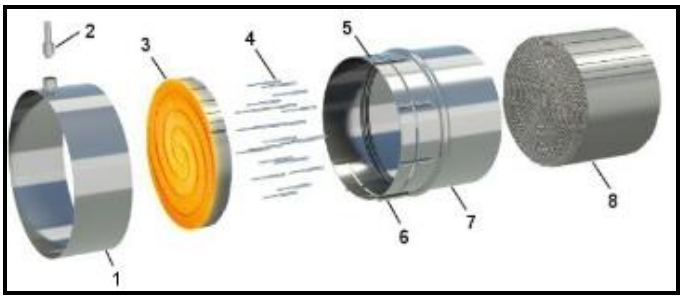

Figure 2. components of a three ways catalyst [1].

1- Exterior metallic shell;
2- Electrical connector;
3- Warm plate;
4- Fixing elements;
5- Metallic case;
6- Holding elements;
7- Interior metallic shell;
8- Catalytic converter.

Tabel 1. Efficiency of the catalyst.

The eficiency of tree ways catalytic converter at optimal temperature (conversion process)		
Hydrocarbons HC	Carbone monoxide CO	Nitrogen oxides NOx
50...90 %	90...99 %	90...99%

The reaction who have place in a reduction catalyst are:

$$2NO - N_2 + O_2 \quad (2.1.1)$$

$$2NO_2 - N_2 + 2O_2 \quad (2.1.2)$$

The reduction catalyst separate nitrogen and oxigen from the oxide of nitrogen.

The oxidation catalyst converts carbon monoxide CO and hydrocarbons HC in the gases into carbo-dioxide CO_2 and water H_2O.

The following reaction takes place when the exhaust gases pass over the oxidation catalyst:

$$2CO + O_2 - 2CO_2 \quad 2.1.3$$

$$HC + O_2 - CO_2 + H_2O \quad 2.1.4$$

The maximum efficienty of the catalytic converter is obtain when air/fuel mixture is stoichiometric. To do that it si necessary a closed loop control for air/fuel mixture.

1.4 Exhaust Gas Recirculation EGR

Exhaust Gas Recirculation is a system who permits to reintroduce the exhaust gases resulting from burning back to the admission manifold. This procedure drives to reduce significantly the quantity of NO_x.

In gasoline engine the EGR is used more to meet the fuel economy standard and to respect the values imposed by regulations.

This system drop the combustion temperature by replacing of oxygen surplus resulting from exhaust gases. First EGR system was installed on internal combustion engine in 1973. In our day the EGR system is present on almost all gasoline direct injection because reduce dramatically the value of nitrogen oxides improve the performance of engine and reduce the fuel consumption.

In principle there are two types of EGR:

- low pressure EGR
- high pressure EGR

1.4.1 Low pressure EGR. In figure 3 is presented how a low pressure EGR works. With blue line is the admission manifold. Air enters in compressor C which is compressed to a higer pressure and then the compressed air enters in intercooler or charge cooler to reduce the temperature of the air and increse the density to have better mixture. Ther the air enter in cylinder when will create the mixture with fuel. After all processes the mixture is evacuated in exhaust manifolg represented in figure with red line.

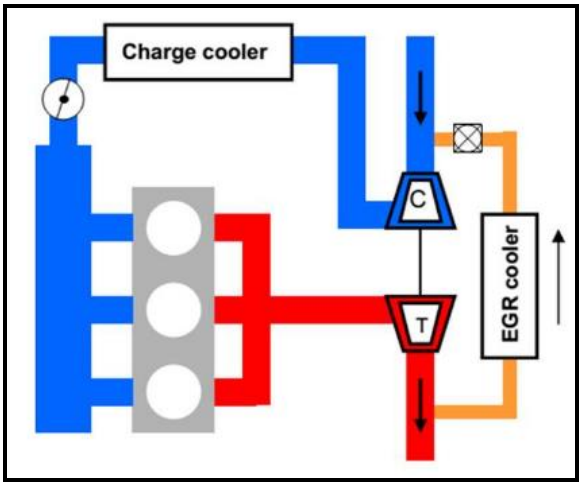

Figure 3. Low pressure EGR [2].

The low pressure EGR takes the exhauste gases after turbine T. That means the exhaust gases are at a low pressure because the energy of these gases are consumed to drive the turbine T. The exhaust gases are also cooled like air.

1.4.2 High pressure EGR. In figure 4 is presented how a high pressure EGR works. The priciple is quiet same like low pressure EGR the difference is only on exhaust manifold. Exhausted gases are introduced in EGR system before turbine T.

The EGR system is used at low and medium speeds. On high loads the vavle close the EGR pipe and gases are not introduced it EGR system.

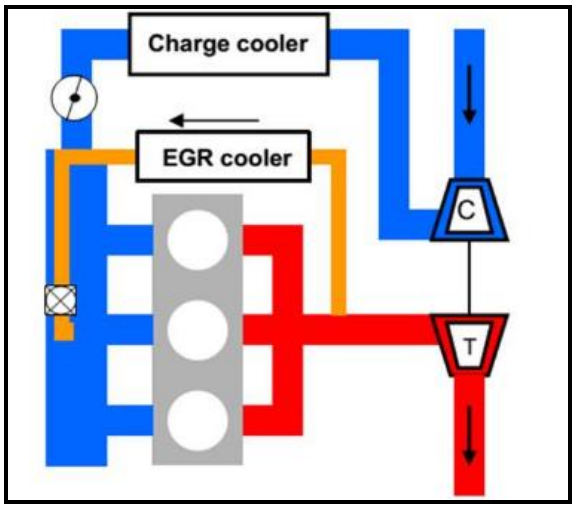

Figure 4. High pressure EGR [2].

The main advantage of EGR system is resulting in a lower nitrogen oxide emissions up to 47% but have many disadvantages like increased engine noise, contamintate the oil fim by reintroducing burned gases back to cylinder also reduce the quality of mixture. The system can be blocked by the depositing of emission inside of and can affect very seriously the functioning of valve which permit to reintroduce the burned gases.

1.5 Gasoline particulate filter GPF

The gasoline particulate filter GPF is a component mounted on exhaust manifold before or after three way catalyst. The roll of this is to eliminate the mechanical particle which result from combustion of mixture.

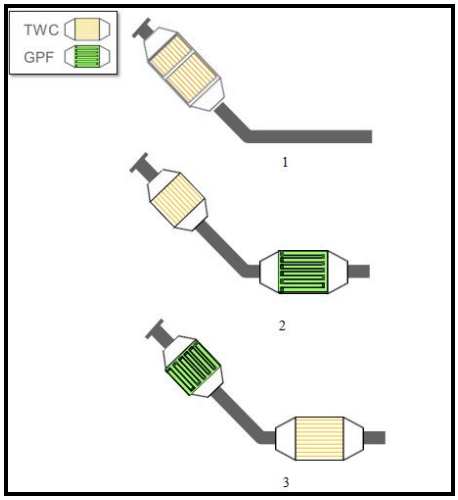

Figure 5. Installing the GPF on exhausting [2].

1- solution without GPF;
2- solution with GPF installed after TWC;
3- Solution with GPF installed before TWC.

Majority of gasoline particulate filter GPF are manufactured from porous ceramic material in honeycomb structure. Volume of GPF depends about the flow of burned gases. If the displacement of the engine is higher the volume of GPF is necessary to be higher.

The request of GPF are very severe, this type of system must be able to meet next requirements:
- filtration of particles with diameter of 0.01 μm;
- reduce the resistance flow of exhausted gases;
- particles filtration in proportion of 95%;
- high temperature resistance until 1050° C.

Particle are retained in GPF which means at some number of kilometers the GPF must be regenerated. The regeneration of GPF means to burn all the particles.

The regeneration process can be effectuated with 2 methods:
- installing one injector on exhaust manifold;
- division of fuel injection and delay the injection.

First method supposed to install one injector on exhaust manifold. When the regeneration of GPF is necessary gasoline in injected on exhaust manifold and because of the presence of oxygen and burned gases have place a combustion which will help to burn all the particles inside from GPF. The temperature inside of GPF take value between 800 and 1000° C.

The second method supposed to delay the injection which means the combustion will take place in GPF.

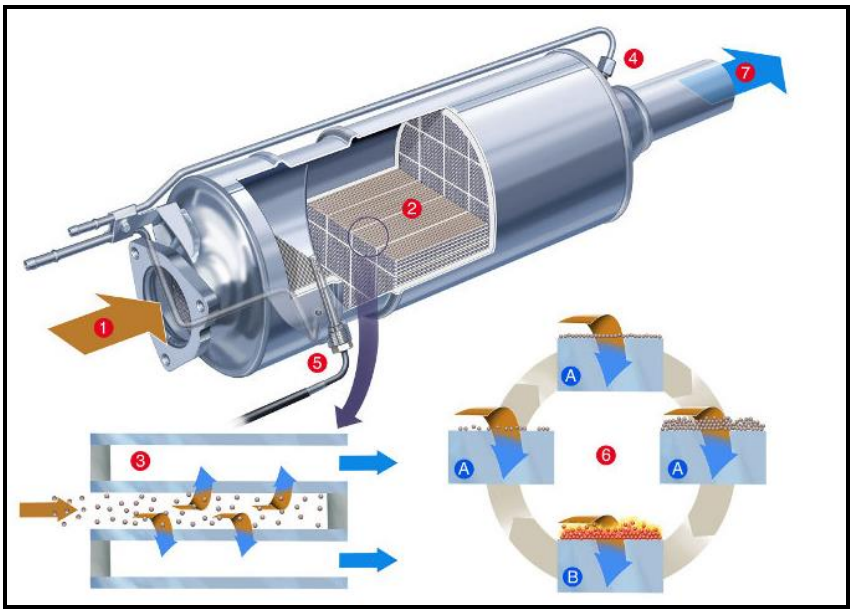

Figure 6. Cross section through GPF and the phases of regeneration [1].

1- Burned gases;
2- Cross-section through filter;
3- The method to retain particles;
4- Pressure sensor after particles filter;
5- Temperature sensor
6- Phases of regeneration:

A – retain of particles;

B – burn of particles and regeneration;

7 – burned gases without particles.

This second method is the most usable because is not necessary to have an extra injector which means the cost of production are lower and the fuel consumption is reduced.

To maintain the good functioning of gasoline particulate filter the customer should respect some indication provide by manufacturer. Customers should respect the interval of regeneration, the quality of oil. The driver is informed by an indicator on dash board when GPF must be regenerate.

If these requests are not respected the gasoline particulate filter will be damage rapidly and the customer will support all costs.

In table 2 are presented some OBD error which occurs in gasoline particulate filter if is not regenerate or some sensors have malfunctions.

Table 2. OBD errors regarding gasoline particulate filter.

Code	Description
P2002	Gasoline particulate filter efficiency under limit
P2003	Gasoline particulate filter efficiency under limit
P242F	Gasoline particulate filter is clogged
P2452	Gasoline particulate filter error on differential pressure sensor circuit
P2453	Gasoline particulate filter error on differential pressure sensor circuit signal out of limits
P2454	Gasoline particulate filter error on differential pressure sensor circuit signal under minimum limits
P2455	Gasoline particulate filter error on differential pressure sensor circuit signal over maximum limits
P2456	Gasoline particulate filter error on differential pressure sensor circuit signal discontinue
P2458	The period of gasoline particulate filter regeneration was not respected
P2459	The frequency of gasoline particulate filter regeneration is not correct

In some interval gasoline particulate filter is necessary to be regenerated to eliminate the particles accumulated inside of the GPF. The driver is informed on dash board when is necessary to make the regeneration of gasoline particulate filter. To do that driver must not stop the engine and should go on the highway to regenerate the filter. If this process is interrupted gasoline particulate filter will be clogged and then will be damage. Also the engine may suffer injuries if this process is not finished correctly.

2. Experimental results

In the next graphics is presented the efficiency of after treatment and systems who can reduce the quantity of emissions for gasoline direct injection engines. Are analyzed the value of nitrogen oxides, hydrocarbons and carbon monoxide.

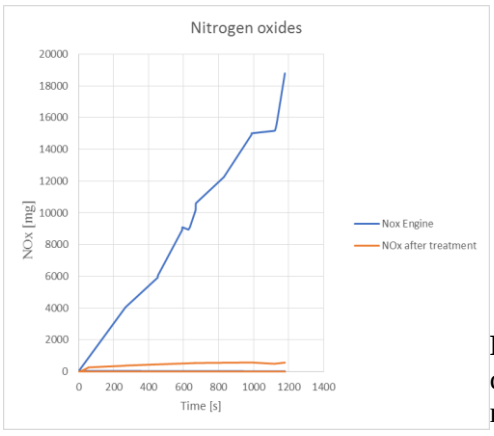

Figure 7. Efficiency of catalyst regarding nitrogen oxides.

In figure 7 are representing the values of nitrogen oxide before and after treatment.

With blue line is the value of NO_x before treatment and with orange line are the values of NO_x after treatment. In this graphic it is possible to see better the efficiency of catalyst. The difference between treatments is significant.

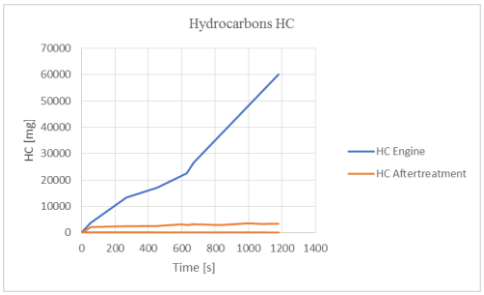

Figure 8. Efficiency of catalyst regarding hydrocarbons.

The catalyst is able to reduce significant the values of HC. The efficiency of catalyst regarding hydrocarbons values can be seen in figure 8.

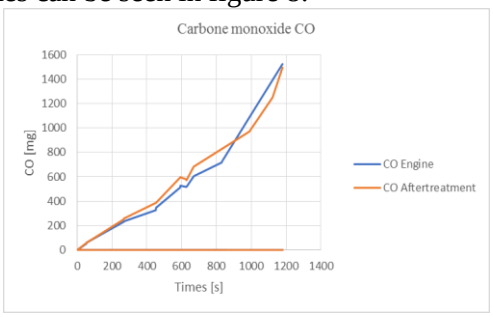

Figure 9. Efficiency of catalyst regarding carbon monoxide.

In figure 9 is representing the efficiency of catalyst regarding carbon monoxide.

3. Conclusions

To ensure the European reglementations about limits of emissions which refers at EURO 6 the after treatment systems on turbocharged gasoline direct injection is necessary to implement a complex mechatronic system. The complexity of after treatment systems installed on gasoline direct injection are necessary to be monitored by an advanced and complex device named OBD to give information about functionality of engine and after treatment equipment. To obtain high performance regarding dynamicity, pollution and fuel consumption suppose high investigation regarding the functionality between engine and all after treatment systems.

4. References

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