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ENVIRONMENTAL POLLUTION CAUSED BY A DIRECT INJECTION ENGINE

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Abstract

In the paper, the authors made an analysis of mechanisms of the toxic components formation of exhaust gases in the direct injection engines. The genesis as well as the typical engine construction solution with the use of direct injection in diesel engines and these with positive ignition was developed. The typical construction solution of the Common Rail (CR) system, which is one of many elements increasing the purity of exhaust gases, was also presented. The basic advantages of direct injection, especially in case of the positive ignition engine, were also briefly described. Then, the mechanism for the formation of toxic components of exhaust gases in the direct injection diesel engines was presented. Moreover, the definition and dependency on the indicated mean effective pressure were shown, and the closed indicator graph, which is indispensable to calculate values of this pressure, was also (graphically) presented. In this paper, the mechanisms and processes, with the use of which it is possible to reduce the emission of toxic components of exhaust gases, were quoted. The exhaust gas recirculation with the EGR valve, which allows supplying the exact amount of gases to the engine inlet system, is such an example. The advantages of using this type of solutions were described, and a typical construction solution was presented in the diagram. The paper was completed with a conclusion, which emphasised the importance of direct injection on reducing the emission of toxic components of exhaust gases.

Keywords: *combustion engines, air pollution, environmental protection*

1. Introduction

Nowadays, almost all car manufacturers use direct injection in both diesel and petrol engines. Direct injection diesel engines for passenger cars (Fig. 1) appeared at the end of the 80's. One of the Fiat Croma models was the first passenger car with the direct injection diesel engine.

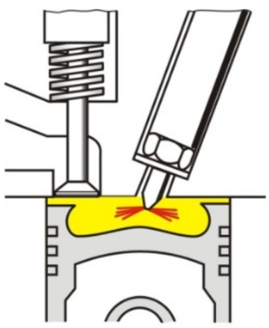

Fig. 1. The implementation diagram of direct injection in the diesel engine [1]

Since 1989, Audi and VW have started to use this technology until it has spread to the entire automotive industry. At the same time, a gradual increase in the injection pressure continued until the common rail (CR) injection system entered production. The CR system generally consists in supplying all cylinders by the common fuel rail. The system includes measuring elements, central control unit, high-pressure pump, pressure vessel, AND injectors – Fig. 2.

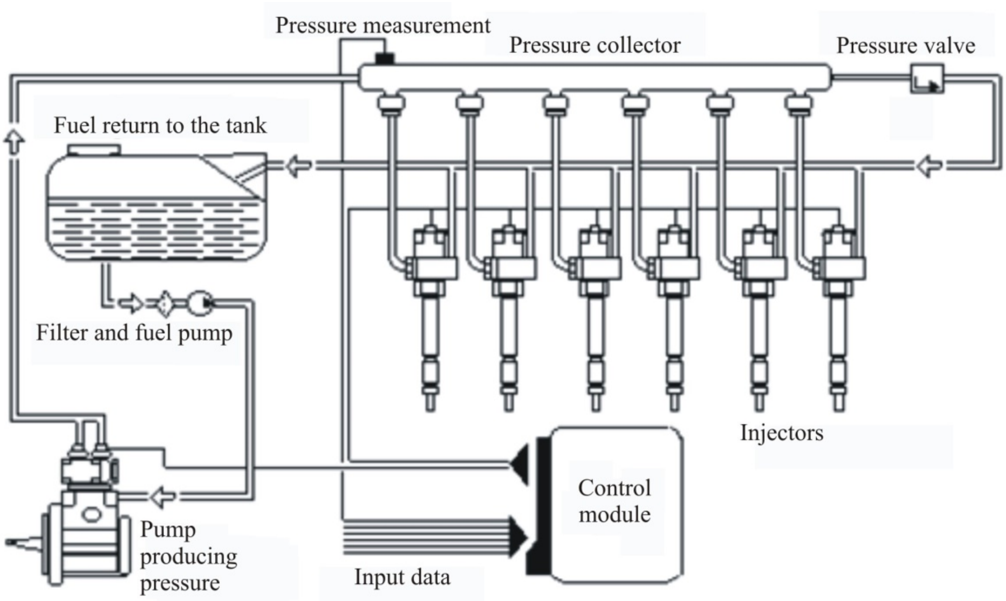

Fig. 2. Diagram of the Common Rail (CR) system

The system operation consists of fuel injection under pressure produced by the pump to the injection collector between subsequent injections, which allows maintaining constant pressure during the entire fuel injection period. The size of the injected fuel dose is dependent on the injector opening time as well as the pressure in the system.

The diesel engine turbocharge became a standard element. These engines occurred to be more durable, they are not subject to heating, and they produce relatively clean exhaust gases.

The direct injection petrol engines are known under the acronym: GDI (Eng. Gasoline Direct Injection) engines. In the GDI engines, the fuel injection is conducted directly into the combustion chamber – Fig. 3. While in case of diesel engines, it has been a standard for many years, it is still a kind of novelty in petrol engines. The first car with direct injection in the petrol engine already appeared in 1954 (Mercedes 300 SL), but the occurrence of next ones (Mitsubishi Carisma) took 43 years.

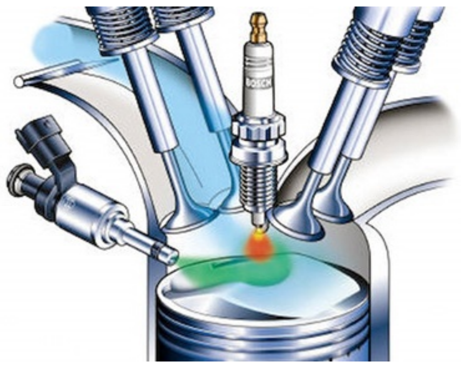

Fig. 3. Direct Injection – the example solution [10]

Direct injection of fuel into the cylinder of the positive ignition engines is considered as a method to increase thermal efficiency and to bring it closer to the efficiency of diesel engines. It is assumed that it will allow obtaining the reduction of fuel consumption between 20% and 25%. However, many construction and operational factors of the engine, which are important in terms of the fuel consumption, such as: elimination of throttling with a throttle, increasing the ratio of compression and extension of the load limits in case of the work with the stratified charge, may have the opposite effect in terms of the exhaust gas emissions. In addition, many of the strategies used to reduce the emission, such as: the use of storage, regenerating catalysts of nitrogen oxides NOx, the post injection of fuel in order to increase the temperature of the catalyst, extending the scope of operation on the stoichiometric mixture, to accelerate the process of the catalyst bleaching during the cold start, have a negative impact on the specific fuel consumption (SFC).

The paper presents the main mechanisms of the formation of toxic components of exhaust gases in relation principally to the hydrocarbon fuel that is currently used in most combustion engines, including the direct injection engines.

3. The specificity of the formation of toxic gases in GDI engines

Direct injection into the cylinders results in increasing the accuracy of the fuel metering and reduction of the emission in case of the cold start and transient states.

In case of diesel engines, where direct injection is commonly used, the formation processes of impurities are highly dependent on the fuel distribution and on the way, in which this distribution varies over time, together with mixing. The mechanism for the formation of toxic components of exhaust gases in the direct injection diesel engines shows the way, in which different elements of the fuel stream, in the premixing as well as controlled mixing phases, during the combustion with the charge swirling, influence the formation of nitrogen oxides NO, hydrocarbons HC, and soot or particulate matter – see Fig. 4.

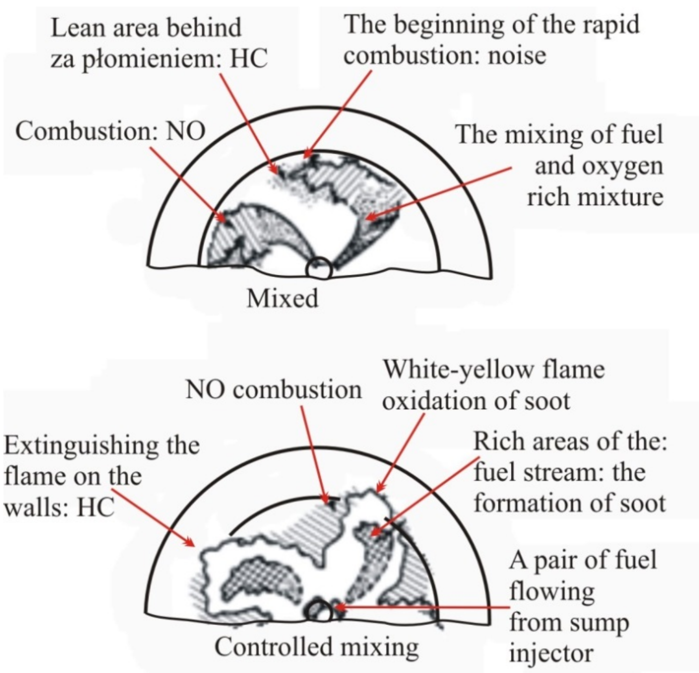

Fig. 4. The mechanism for the formation of toxic components of exhaust gases in diesel engines [7]

In any case, it is important to remember that in the direct injection diesel engines, the procedure of forming toxic components substantially differs from their formation in the positive ignition engines. The main reason is that the fuel in the engine is injected into the cylinder before the start of combustion.

In contrast, the comparison of the emissions of GDI engines with the emissions of PFI (Port Fuel Injection) engines under the cold start shows that in case of the GDI engines, there is a very rapid increase of the indicated mean effective pressure IMEP (unit internal operation) just after the first injections, while the PFI engines must perform about 10 cycles in order to make the engine operate normally. This is due to the formation of a film of fuel on the inlet valves and the walls of the inlet ducts of the PFI engines.

The indicated mean effective pressure is a constant pressure which acting on the piston during the combustion cycle, would work adequately to the actual pressure operation, which acts on the piston during one complete engine cycle. The indicated mean effective pressure is a purely theoretical quantity, which does not occur in a real engine. It is calculated on the basis of the (normal) closed indicator graph – Fig. 5. In addition, it is equal to the ratio of the mean value of W_s field to the cylinder displacement:

$$p_i = \frac{W_s}{V_s} \quad [kPa]. \tag{1}$$

The area of a rectangle p_iVs is equal to the area of the indicator graph, which allows assuming that the work done during one cycle by the changing gas force p_gA is equal to the force work p_iA equally to the piston stroke S.

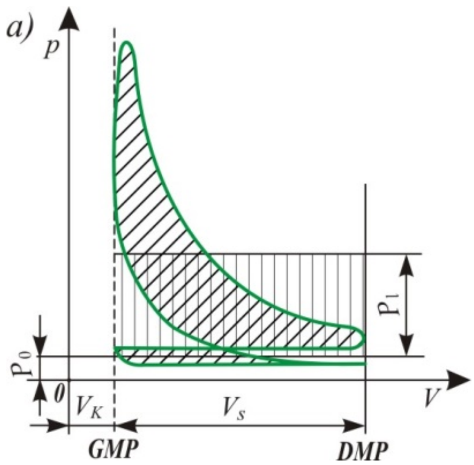

Fig. 5. The indicated mean effective pressure of the four-stroke engine p_i is presented in the closed indicator graph [7]

GDI engines can be subjected to the cold start on the stoichiometric mixture and even a bit lean one. As a result, there is a possibility to reduce emissions of hydrocarbons HC in them. Thus, reducing the emissions of hydrocarbons HC under the cold start and the engine heating is one of the significant benefits in terms of the four-stroke GDI engines. It should be noted that these beneficial features in terms of reducing emissions are highly dependent on the quality of the fuel stream supplied by the fuel injection system. If the appropriate level of the fuel spraying is not achieved during the cold start, then the effects will be much worse than those obtained during the stable operation period.

The HC emission sources during operation of the engine with the stratified fuel charge are different from during operation with the stoichiometric charge. The mechanisms derived from slots and layers of the lubricating oil are of minor importance because the amounts of fuel vapour are much smaller. A greater role is played by the mechanisms such as excessive or too weak mixing. The lower temperature in the cylinder combined with the lean charge also reduces the post-flame oxidation.

The low temperature of exhaust gases impedes the catalytic system operation, and it also excludes the possibility of extensive oxidation of hydrocarbons in outlet ducts as in the PFI engines operating at comparable loads.

The EGR (Exhaust Gas Recirculation) system has a great impact on the emissions of hydrocarbons HC in the GDI engines. Its primary purpose is to reduce the amount of oxygen supplied to the combustion chamber, resulting mainly in the reduction in temperature, slowing down the combustion process and the reduction of nitrogen oxide emissions. The above task is implemented by adding the respective portion of exhaust gases to the inlet system, which simply cause the pollution of air supplied to the combustion chamber. The EGR valve is part of the duct, through which part of exhaust gases is supplied to the inlet system. It decides when and in what amounts these exhaust gases are supplied to the inlet system – see the diagram in Fig. 6.

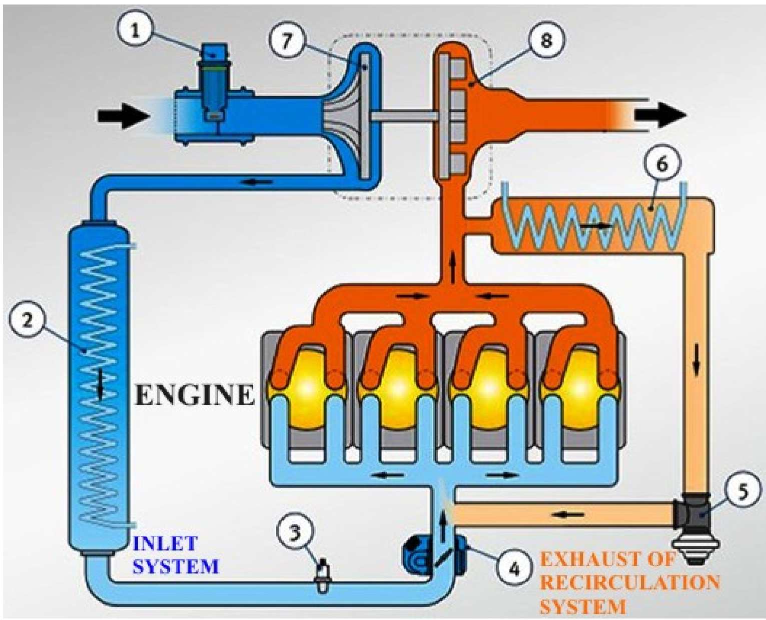

Fig. 6. Diagram of the drive system with an additional exhaust gas recirculation system (EGR) [11]: 1 air flow sensor; 2 − charge air cooler; 3 − charge air temperature sensor; 4 − regulating flap; 5 − EGR valve; 6 − EGR cooler; 7 − turbocharger (compressor); 8 − turbocharger (turbine)

However, the mechanism of the emission reduction is complex and includes the extension of combustion, the combustion phase delay and increased post-flame oxidation. The increased temperature of the incoming air with the use of the hot EGR has the most desirable effect on reducing the HC emission. Adding EGR, despite the elimination of throttling with the throttle, does not intensify the process of flame propagation because the areas of the lean mixture are subject to further dilution with exhaust gases, which smothers the flame.

The conventional positive ignition engine with the lean charge shows the maximum speed of the NOx formation on a slightly leaner mixture than the stoichiometric one.

When the air-fuel mixture becomes leaner, a continuous decrease in the speed of the NOx formation occurs. This decrease is due to the reduction of the maximum temperature in the reaction area. However, in GDI engines that operate with the stratified charge, the temperature in the reaction area is maintained at a constant high level because of the presence of the stoichiometric mixture or even slightly rich one in the area of initiation of the stratified charge combustion. Therefore, the speed of the NOx formation in these areas is high, although the average combustion temperature is lowered. The GDI engines generally operate at higher compression values, which may also affect the increase of the level of the NOx emissions. It also influences the increase of temperature in the cylinder because of the greater compressed charge mass in the cylinder than for the comparable load during operation with throttling with the throttle. The result is that the NOx level in the GDI engines operating without EGR will be generally quite high, even though some GDI engines can operate at the air and fuel ratio of 50:1. The GDI engines show a substantially higher level of the NOx emission at the idling operation than the PFI engines. In fact, combustion takes place locally in conditions of the stoichiometric charge combustion. It is combined with the high temperature and rate of heat release. In the PFI engines, there is a greater amount of the gas exhaust residues during idling control with throttling with the throttle, which causes the reduction in the NOx emissions. In the stoichiometric range of the GDI system operation, the NOx emissions are at the similar level as the emissions of the PFI engines. In relation to the GDI engines, the disadvantage is that in case of the NOx disposing, three-way catalytic converters cannot be used, but other methods, e.g. disposal directly in the cylinder or special systems for the outlet exhaust gas treatment can be applied.

3. Conclusion

The conducted analysis confirmed the legitimacy of using the direct injection of fuel to the combustion chamber. In this regard, many benefits are obtained, from the thermal efficiency and engine efficiency to the reduction of fuel consumption. In addition, it significantly results in reducing the emission of toxic components of exhaust gases during the cold start and transient states. They can also be started in case of the lean mixture, which affects the reduction of emissions of hydrocarbons HC. In addition, the use of the EGR valve, which decides about the amount of gases supplied to the engine inlet system, also affects the emissions of HC, as well as the emissions of nitrogen oxides NOx.

Therefore, the direct injection has many advantages, which are decided about the great popularity of this solution and currently is often used, especially from the time of the occurrence of turbochargers, which provide the maintenance of a high compression ratio.

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