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CATALYTIC TREATMENT IN DIESEL ENGINE INJECTORS

KATALITYCZNA OBRÓBKA PALIWA WE WTRYSKIWACZACH SILNIKA O ZAPŁONIE SAMOCZYNNYM*

The aim of the study proposed and carried out by the authors was to assess the impact of using platinum as a catalyst carrier in the fuel injector diesel engine with the direct fuel injection for emissions of toxic substances in the exhaust gases into the atmosphere and specific fuel consumption. Experimental studies were carried out on a test bench equipped with a 359 engine and a hydraulic brake with complete measurement apparatus. During the tests the engine worked by external speed characteristics. The analysis of the study showed that it is possible to reduce emissions of toxic compounds into the environment and to reduce specific fuel consumption through the use of catalytic coatings in the diesel engine fuel injector.

Keywords: *combustion engine, toxin emission, fuel treatment, injectors, fuel injection modeling.*

Celem zaproponowanych i przeprowadzonych przez autorów badań była ocena wpływu zastosowania nośnika katalitycznego w postaci platyny we wtryskiwaczu paliwowym silnika z zapłonem samoczynnym z bezpośrednim wtryskiem paliwa na emisję substancji toksycznych w gazach wylotowych do atmosfery oraz jednostkowe zużycie paliwa. Badania eksperymentalne zostały przeprowadzone na stanowisku hamownianym wyposażonym w silnik 359 oraz hamulec hydrauliczny z kompletną aparaturą pomiarową. Podczas badań silnik pracował według zewnętrznej charakterystyki prędkościowej. Analiza przeprowadzonych badań wykazała, że istnieje możliwość ograniczenia emisji związków toksycznych do otoczenia oraz zmniejszenie jednostkowego zużycia paliwa poprzez zastosowanie powłoki katalitycznej we wtryskiwaczu paliwowym silnika ZS.

Słowa kluczowe: *silnik spalinowy, emisja substancji toksycznych, obróbka paliwa, wtryskiwacze, modelowanie wtrysku paliwa.*

1. Introduction

Development of internal combustion engines in recent years has been directed at improving the environmental and economic operating parameters. Environmental parameters of the engine are related to the emission of toxic substances into the atmosphere in the exhaust gases, whereas economic ones are connected with fuel consumption. Requirements related to reducing emissions of toxic substances into the atmosphere and a reduction in fuel consumption become more stringent each year [1]. In order to fulfill them, electronics systems that control the course of fuel injection characteristics and devices for emission control in the form of catalytic converters in exhaust systems were used. Research on the use of catalysts in the engines combustion chambers has been also conducted. These solutions are used in engine parts, which are directly related to the combustion and the reduction of toxic compounds produced, that is in the injection apparatus, combustion chamber and exhaust systems [2, 5]. Engine working process is associated with the process of combustion of a mixture of fuel and air. This cycle consists of: preparing a mixture for combustion, combustion and emission control. The key step in this chain of events refers to the preparation of the mixture for combustion.

The combustion process of a mixture of fuel and air in the combustion chamber of the diesel engine consists of several stages. The analysis undertaken in this work concerns the first and also the most important phase, which is the ignition delay period. This is the time which includes the moment of appearance of the first drops of fuel in the combustion chamber until their self-ignition. It has a direct influence on the kinetic combustion, which is the second stage. The objective is to ensure that the ignition delay period was as short as possible. The longer it takes, the more fuel is accumulated in the cylinder, and it causes the combustion in the second period takes place rapidly, causing a high rate of pressure build [25].

The main physical parameters of the fuel in diesel engines are: density, viscosity and surface tension. They have a direct impact on the droplet diameter, the shape and the scope of jet fuel spray and they are related to the ignition delay period. Whereas, chemical parameters of the fuel depend on the structural composition of the hydrocarbons, where the most numerous group represent paraffin hydrocarbons C_nH_{2n+2}.

Chemical properties of the fuel can be changed by the paraffin dehydrogenation, that is some reactions may occur in the presence of catalyst, as a result of which the paraffins are converted into hydrocarbons of the C_nH_{2n} olefin group with the hydrogen molecule emission. In turn, hydrogen, due to the high diffusion coefficient in the air, a large capacity to the ignition and the high combustion rate as well as wide flammability limits of the mixture, reduces the ignition delay period under the conditions in the combustion chamber. Taking these facts into account, it can be concluded that the proper preparation of fuel in the form of changes in its physical and chemical parameters can improve both economic and ecological indicators of diesel engine work [9].

The favorable change of physical and chemical parameters of the fuel is possible by pretreatment of the fuel, conducted immediately before its injection to the combustion chamber in its contact with the material of the catalytic action in the nozzle holder. Thus, the authors made an attempt to assess the impact of a catalytic carrier, that is platinum used in the fuel system, on the combustion process in a diesel

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl*** engine, which has a direct impact on fuel consumption and emissions of toxic substances. This issue is currently not being used in engines.

2. Analysis of the literature on the subject of the paper

Currently, catalysts have not found their applications in the injection apparatus of diesel engines . However, the analysis for combustion and the use of materials for catalytic action in the combustion chamber and the exhaust system provide a powerful application of catalysts in fuel injection systems. [3, 4, 6, 7, 10, 14, 15, 16, 17, 19, 21, 22, 24].

Analysis of the available research literature indicates that one of the possible ways to change the physical parameters of the fuel before its atomization into the combustion chamber is the thermal method. Combustion of the heated fuel enables to control the initial period of combustion, and thus lets to reduce the maximum pressure in the combustion chamber and the speed of their growth. Moreover, it leads to reducing further noise and increasing durability of the engine. As the study results show, heating the fuel to 230°C (503 K) helps to achieve a marked reduction in the rate of pressure rise in the cylinder, in addition there is the decrease in smoke and the reduction of specific fuel consumption [12]. Increase in fuel temperature accelerates the reaction of fuel cracking in the combustion chamber and due to the shortening the fuel heating time it causes shortening the ignition delay period [9].

Different method was heating the fuel in the tank due to the installation of electric heaters [9]. In this way of the thermal impact on fuel (heating fuel in the tank) it is possible to obtain almost any temperature, however, it should be considered that the steam conveying the injection pump will be working under different conditions by changing the viscosity and density of the fuel. The elimination of this problem is possible using the heating system in the high pressure, but in this case the possibility of pressure changes in the pipes and the fuel injection characteristics (other operating conditions in the injector) should be taken into account [11]. This is confirmed by the results conducted so far, in which the desired effect is not achieved throughout the whole range of engine load [6]. It should be noted that while the engine is powered with fuel, heated in front of the injection pump or fuel injector, a partial improvement in the engine was achieved, but it concerned only certain working conditions, and the results did not indicate the stability of their achievements. In addition, the registration of the indicator diagram and the characteristics of the fuel injection showed a marked change in relation to the graphs of a conventional engine. That fact can explain the failure to apply the thermal pretreatment of the fuel in engines, although many authors emphasize possibilities to improve their work with this way of impact on the physical parameters of the fuel. Other method of increasing the temperature of injection fuel is he annular channel located at the bottom of the jet block. The fuel flowing this way receives the heat from the most heated part of the discharge jet and the other thermodynamic state is atomized into the engine combustion chamber. It should be noted that with such a distribution of the heating system, the adverse impact of changes in physical parameters of the fuel on plunger and barrel assembly: nozzle holder – needle is completely eliminated. There is possibility to use catalytic converter in annular channel which activities could change chemical fuel parameters due to dehydrogenetion of hydrocarbons [13].

The catalytic treatment of the fuel in the combination with the heat treatment may be carried out in pintle injectors with the location of the catalyst in the discharge jet cooling system, whereas in the multi-hole injectors – on the imprecise part of the needle.

3. Research objectives

The aim of the study was to determine the impact of the catalytic coating in the diesel engine injector with the direct fuel injection on emissions of toxic substances into the air and the specific fuel consumption. This article is about the testing the emissions of nitrogen oxides, carbon monoxide, smoke and carbon dioxide emissions of the diesel engine by introduction of a platinum catalyst on the part of non-working injector needle. The tests were carried out on the engine test bench. During the tests the engine worked according to external speed characteristics in the revolutions frequency of 1200 – 2700 min^{-1}. Engine test bench have been carried out with the following engine configuration: injection timing of 18.5°, ejaculation pressure of 22 MPa (factory pressure setting).

The measurements were made in steady state conditions at selected points on the external characteristics of the velocity. Test items were factory fuel injectors and fuel injectors imposed on the catalyst imposed on non-working part of the needle.

4. Analysis of the temperature in the multi-hole injector nozzle

In order to determine the fuel temperature during its flow in the multi-hole injector (Fig. 1) the equations of the heat transfer and fluid flow through the tubular channel were used and the heat exchange by transmissivity was established [18, 23].
Fuel characteristics:

- Fuel absolute weight $\gamma = 840$ kg/m^3
- Specific heat $c = 2140$ J/kg·K
- Thermal conductivity $k = 0,1433$ J/m·s·K
- Heat transfer coefficient $\lambda = 165$ W/m^2·K

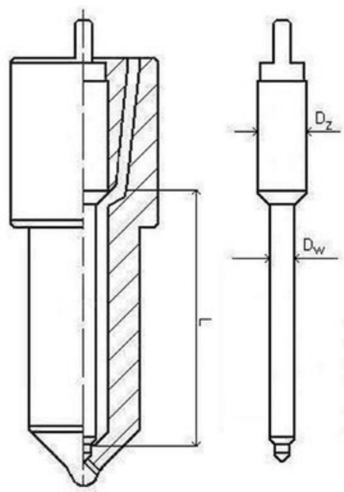


Fig. 1. Schematic of multi-hole injector

Injector characteristics:
$D_z = 0,005$ [m]
$D_w = 0,0045$ [m]
$L = 0,0\ 275$ [m]
$g_v = 0,0000094$ [m^3/s]

Mathematical model of the multi-hole fuel injector proposed by the authors:

The duration of one cycle of the fuel injection:

$$T_w = \frac{120}{n} \quad [s] \tag{1}$$

The volume of the fuel injected within one injection:

$$V_0 = T_w \cdot g_v \ \ [\mathrm{m}^3] \tag{2}$$

The fuel which flows around the injector needle forms a ring around it (in cross section). In order to facilitate the calculation of the heat exchange between the walls of the injector nozzle and the fuel, the conversion of the ring cross-section into a circular cross-section is necessary.
Cross-sectional area of the fuel pillar:

$$P_1 = \frac{\pi}{4}(D_z^2 - D_w^2) \quad [\mathrm{m}^2] \tag{3}$$

Equivalent channel diameter:

$$D_1 = \sqrt{\frac{\pi}{4}P_1} \ \ [\mathrm{m}] \tag{4}$$

Equivalent channel volume:

$$V_1 = P_1 \cdot L \ \ [\mathrm{m}^3] \tag{5}$$

The number of fuel doses per volume of the fuel injector nozzle channel:

$$j = \frac{V_0}{V_1} \tag{6}$$

Fuel injection time:

$$\tau = \frac{\phi}{720}T_w \ \ [\mathrm{s}] \tag{7}$$

where φ – rotation angle of crankshaft
Length of the segment corresponding to a dose of a specific fuel volume l:

$$l = \frac{L}{j} \ \ [\mathrm{m}] \tag{8}$$

Lateral surface area of the liquid column of the length l *filling the* channel f *:*

$$f = \pi \cdot D_1 \cdot l \ \ [\mathrm{m}^2] \tag{9}$$

The volume of the fuel pillar on the length l:

$$V_s = l \cdot P_1 \ \ [\mathrm{m}^3] \tag{10}$$

Fuel charge mass relating to the length l:

$$m = V_s \cdot \gamma \ \ [\mathrm{kg}] \tag{11}$$

Fuel rate in the channel:

$$u = \frac{l}{\tau} \ \ [\mathrm{m/s}] \tag{12}$$

Reynolds number:

$$\mathrm{Re} = \frac{2D_1 u}{\nu} \tag{13}$$

To read the value of the kinematic viscosity in the graph (Fig. 2) the temperature of the fuel T_0 is needed:

$$T_0 = \frac{T_{pi} + T_{sci}}{2} \ \ [\mathrm{K}] \tag{14}$$

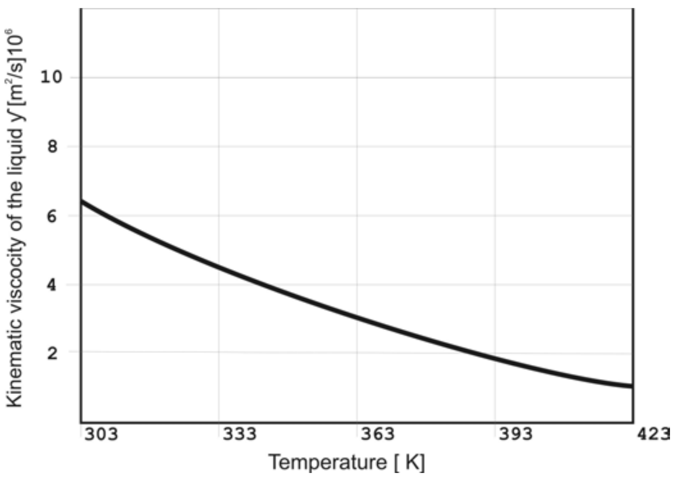


Fig. 2. Changing the viscosity of the fuel according to the temperature

Prandtl number for the fuel flowing into the channel section calculated by the arithmetic average of the temperature of the wall and fluid:

$$\mathrm{Pr} = \frac{\nu \cdot c \cdot \gamma}{\lambda} \tag{15}$$

Heat transfer coefficient of the flow through the channel:

$$\alpha_i = 0{,}023\frac{\lambda}{2D_1}\mathrm{Re}^{0{,}8}\,\mathrm{Pr}^{0{,}4} \tag{16}$$

Factor related to the geometry of the channel:

$$\eta = \frac{2}{D_1} \tag{17}$$

Factor related to the physical properties of the fuel flow:

$$\beta_i = \frac{\alpha_i}{c \cdot \lambda \cdot u} \tag{18}$$

Factor related to the heat transfer coefficient between the wall of the atomizer and the fuel flowing into the channel:

$$\Theta = 0{,}9993 \cdot e^{-2\eta\beta_i} \tag{19}$$

The fuel temperature after the flow through the selected channel segment:

$$T_{dyni} = T_{sci} - \Theta \cdot (T_{sci} - T_{pi}) \ \text{[K]} \tag{20}$$

The amount of heat supplied to the fuel during its stay in the atomizer channel:

$$Q = k \cdot f \cdot (T_{sci} - T_{pi}) \cdot (T_w - \tau_w) \ \text{[J]} \tag{21}$$

Increase in fuel temperature during the downtime on the selected section of the channel:

$$\Delta T_i = \frac{Q_i}{m \cdot c} \ \text{[K]} \tag{22}$$

The final temperature of the fuel at the outlet from the selected section of the channel t_{ki}:

$$T_{ki} = T_{dyni} + \Delta T_i \ \text{[K]} \tag{23}$$

Growth of the fuel temperature over the entire length of the channel:

$$\Delta T_k = T_{ki} - T_{pi} \ \text{[K]} \tag{24}$$

The aim of the analytical researches was determining the temperature inside fuel injector, because one should to make a perfect match equivalent catalytic converter. The calculation shown that the fuel temperature in the injector nozzle is about 343 K. The analysis for the literature there is the possibility of using platinum as the catalytic converter in temperature condition in the Diesel injector [20].

5. Research characteristics

The object of the research was multi-hole injectors of the 359 diesel engine and the direct fuel injection shown in Fig. 3 and 4 [7].

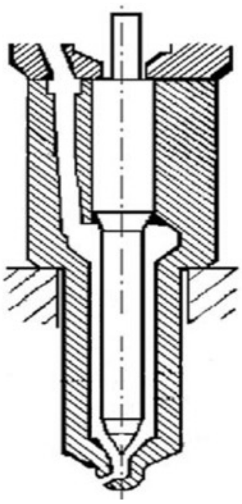


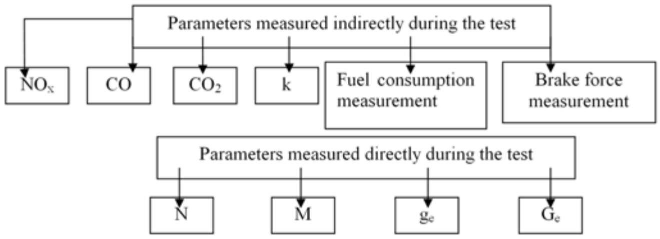
Fig. 3. Schematic of the multi-hole injector cup of the 359 engine

On the non-working part of the needle in the injector the catalytic coating in the form of platinum was applied, as it is shown in Fig. 4 [9]. Based on analysis of the literature it was found that the most appropriate catalyst due to the temperature in the injector cup is platinum [8].

Fig. 4. Needle with the catalytic coating applied on the non-working part [8]

6. Methods for testing

Researches has been made by using schema:



Engine power was calculated from the formula:

$$N = \frac{n \cdot P}{1160} [kW] \tag{23}$$

The engine torque was calculated from the relationship:

$$M = 8,231 \cdot P [Nm] \tag{24}$$

Specific fuel consumption was calculated from the formula:

$$g_e = \frac{3600 \cdot 103}{t \cdot N} [\frac{g}{kWh}] \tag{26}$$

Where:

- NO_x – nitric oxides,
- CO – carbon monoxide,
- k – opacity factor,
- N – engine power,
- M – engine torque,
- g_e – specific fuel consumption,
- n – engine speed,
- P – brake force,
- t – time of the fuel flow in the meter,
- 103 – fuel weight in metrology device [g].

Engine researches have been made in the laboratory with 359 engine. The toxins measurements have been carried out by using MDO opacimeter and IMR 1500 fumes analyser.

7. Description of the studies

The research was carried out on laboratory by using Bosch Common Rail CRIN injectors 0445120219. The aim of laboratory researches was fuel injection stream observation with the use of stroboscope. Fig. 5 and 6 put forward the injection fuel stream to the combustion chamber.

Fig. 5. Stream of the fuel injected in the factory injector

Fig. 6. Stream of the fuel injected in the injector with the catalytic coating applied

The laboratory researches enabled the observation of injection fuel stream. It is noticed on fig. 6 that injection fuel stream on injector with catalytic converter is dispersed. Catalytic fuel treatment interfere in chemical not physical. The injector has been used by 135 MPa injection pressure and 1000 µs injection time. Fuel dosage for conventional injector is 364,12 mm^3/H and for injector with a fuel pretreatment is 366,24 mm^3/H. The range of correct injector parameters for 135 MPa injection pressure and 1000 µs injection time is 370,5 +/− 11,5 mm^3/H. There is possibility to improve the process of coming into combustible mixture through better mix fuel and air.

The aim of this study was to analyze the engine workflow and its economic and environmental operating parameters using conventional injectors and the injectors with the catalytic coating applied on the non-working part of the needle.

Fig. 7 and 8 shows the results of 359 engine running on two types of the injectors.

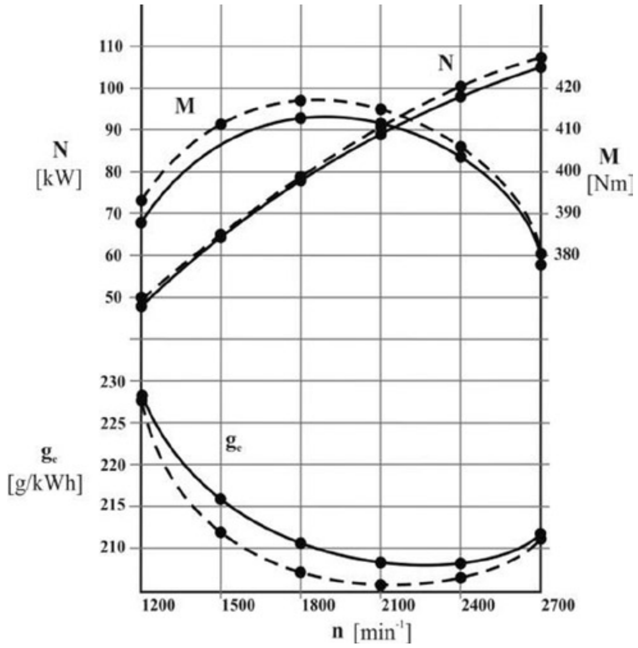


Fig. 7. Comparison of the basic parameters of the 359 engine work on two types of the injectors with the factory set engine: continual line – conventional injector, dotted line – injector with the fuel pretreatment

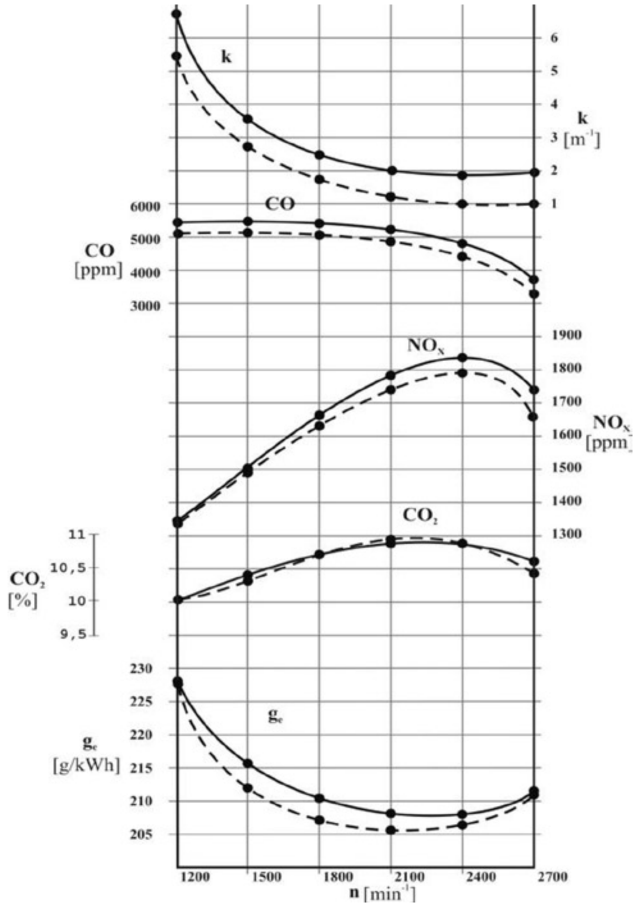


Fig. 8. Comparison of ecological and economic parameters of the 359 engine on two types of injectors with the factory set engine: continual line – conventional injector, dotted line – injector with the fuel pretreatment

Fig. 7 shows the results of the 359 engine in the form of external speed characteristics. During the study the engine power (N), engine torque (M) and the specific fuel consumption (g_e) were recorded.

It is noticed using platinum catalytic converter improved torque in whole range of engine speed. The power increase begins from 2100 min^{-1} engine speed. Catalytic converter influence on reducing individual fuel consumption and for engine speed 1800 min^{-1} was 205 g/kWh.

Fig. 8 shows the results of the 359 engine in the form of external speed characteristics. During the study the smoke (k), carbon monoxide (CO), nitrogen oxides (NO_x), carbon dioxide (CO_2) emissions and the specific fuel consumption (g_e) were recorded.

8. Conclusions

The analysis of the literature research, as well as the analytical and experimental studies for the application of the fuel pretreatment in diesel engines allow to formulate the following conclusions:

- beneficial reduction of the ignition time can be achieved by reducing the energy activation, using the phenomenon of catalysis, which implies the use of materials having a catalyst in the injection system;
- based on mathematical model the Best catalytic converter working by 343 K temperature is platinum;
- so far, the use of catalysts in combustion piston engines have taken place in the exhaust systems in the form of catalytic converters, there are a few research studies on the use of catalysts in the combustion chamber, there are not any works on the use of catalysts in the fuel injection system;
- an innovative fuel injection system in diesel engines has been proposed in which catalytic fuel processing takes place directly before the spraying, it could be used in all multiholes Diesel injectors as well in Common Rail system;
- a type of catalysts and methods of their application to the fuel injector components have been chosen;
- o the concept and the physical models of multi – hole injections with the system of the catalytic fuel pretreatment have been developed;
- experimental studies on the structural solutions of the fuel injectors equipped with the system for catalytic and thermal fuel pretreatment on the test bench and test stands have been carried out;
- the results of conducted researches show that it has been obtained the improvement of economical and ecological engine work parameters;
- in order to do additional researches of phenomenon in Diesel combustion chamber one should make indication Diesel engine with injectors with the fuel pretreatment;

The aim of the study was to determine the effect of the use of a catalytic coating in the cup of the multi-hole injector in the diesel engine with the direct fuel injection.

Before the selection of a suitable catalyst, the temperature in the cup of the multi-hole injector has been calculated. Then, on the basis of the literature analysis the appropriate catalyst has been selected and its correct operation corresponds with the surrounding in the engine injector. After the test preparation the laboratory and motor tests have been conducted.

During the laboratory analysis, the change in the structure of the injected fuel stream has been observed, using the injectors with the catalytic coating applied on the non-working part of the needle. Engine tests have shown that the specific fuel consumption decreased by about 10%, the smoke decreased by approximately 15% and the carbon monoxide emissions decreased by about 10% across the whole range of the engine speed while the nitrogen oxide emissions decreased by about 8% in the range of 1500 – 2700 rev/min.

To sum up, the studies carried out have shown that the use of the fuel pretreatment system in the form of coating applied on the non-working part of the injector needle in the 359 engine improves its environmental and economic operating parameters.

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