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IMPROVED EFFECT OF PRELIMINARY FUEL TREATMENT IN SELF-IGNITION ENGINES

Key words

Diesel engines, fuel injection system, catalytic fuel treatment.

Summary

The research and development of self-ignition engines presently focuses on the reduction of the emission of toxic compounds into the atmosphere and on lowering fuel consumption. These objectives can be reached by the application of fuel injectors fitted with a fuel preheating system directly into the injector body. Furthermore, some of the results obtained prove that engine efficiency is enhanced when preliminary catalytic fuel treatment is applied. Research is continued on combining the thermal and catalytic methods of fuel treatment, which can be done within the injector.

Introduction

Recently, the main directions of developments in internal combustion engines have been related to the reduction of toxic compound emission into the environment and more effective fuel consumption. Although designs of engines and their systems have reached certain limits in terms of operating process parameters and possible control of these processes, future standards of exhaust gas toxicity and fuel consumption are expected to be even stricter. Efforts to meet the standards are aimed at the application of electronic systems to control the characteristics of fuel injection, producing stechiometric fuel-air mixtures, devices for exhaust gas purification such as catalytic reactors, filters and others. However, attention is paid to the use of these solutions in the design of the combustion chamber, the injector equipment and the exhaust system. These engine components directly relate to the combustion and the reduction of the toxic compounds produced. It should be underlined that a systematic approach to the ecological and economic problems of combustion engines has to cover two areas: what we burn and what we reduce. In fact, the process of combustion is the most important link in the associated chain of phenomena. Proper combustion is what principally affects engine efficiency and the level of toxic compound emission. Although the oxidation and reduction of these compounds – exhaust gas purification – are equally important, these processes directly depend on what is fed into the combustion chamber, i.e. on the chemical and physical parameters of fuel and air.

It is known that the process of combustion in self-ignition engines, particularly its second stage – kinetic combustion – is characterised by rapid pressure increase and is interrelated with the first stage – time of ignition delay. The phenomena both stages are the main causes of engine revolution reduction and its mechanical and thermal loads. Therefore, self-ignition delay time is needed for such phases to ready fuel for ignition, which includes fuel droplets till they partially or completely evaporate, heating the produced fuel vapours to the self-ignition point, preliminary fuel oxidation reaction leading to self-ignition. Therefore, both the initial stages and the entire combustion process can be improved by treating the fuel while it is delivered to the combustion chamber.

Physical parameters of fuel in self-ignition engines are basically defined by such quantities as density, viscosity and surface tension; these strictly affect the droplet diameter as well as the shape and range of the atomised fuel jet stream. This in turn is related to the first combustion stage – self-ignition delay. Fuel chemical parameters depend on the structural composition of hydrocarbons, of which paraffins C_nH_{2n+2} make up the most numerous group. It should be underlined that in certain conditions, i.e. in the presence of a catalyst, some reactions may take place that result in converting paraffins into olefin hydrocarbons C_nH_{2n}, releasing hydrogen particles. Hydrogen is a factor reducing the self-ignition time, due to its high diffusion coefficient in air, its ability to ignite, and its fast combustion rate, plus a wide range of fuel mixture flammability. Considering these facts, one can state that appropriate preparation of fuel by changing its physical and chemical parameters may improve the cost-effectiveness and ecological impact of self-ignition engines.

1. The process of preliminary fuel treatment

Advantageous changes in the physical and chemical parameters of fuel are possible through preliminary treatment carried out directly before its injection into the combustion chamber. This will include simultaneous heating and contact of the fuel with a catalytic material placed in the injector body. It should be noted that fuel treatment before it is discharged by the injector pump or before it gets into the injector may significantly change the characteristics of fuel injection. This is connected with the changes in the fuel's physical parameters, which may cause increased leaks in the precision pairs of fuel injectors and wave changes in high-pressure pipelines. The literature on the subject shows that, in certain research centres at home and abroad, the research on preliminary, thermal fuel treatment has not always brought positive results. In some cases [2, 3], the improvement of operational and ecological parameters of self-ignition engines was attained only in certain load ranges; whereas, according to [4], improvement is obtained at loads up to 50% of rated power output, while for higher loads, fuel consumption and emission of toxic compounds increase. The obtained results refer to the use of fuel heaters before the fuel injection pump and the injector, which, as mentioned before, changes the fuel injection characteristics. For this reason, the application of preliminary fuel thermal treatment in conjunction with catalytic treatment directly in the injector body, excluding the precision pairs, eliminates the shortcomings of the above mentioned solutions.

Practically, such fuel treatment immediately before fuel injection into the combustion chamber took place in the injector body in which additional passages had been made delivering fuel to the under-needle space; one of these – ring passage – was situated in the lower, most heated part of the injector body. Additionally, catalytic material was deposited on the passage surfaces. In order to increase the contact area between the fuel and catalyst, there were pieces of pressed wire covered with a layer of catalytic material placed in the passages. Figure 1 presents a diagram and the components of a fuel injector (atomiser) with the fuel heating system. As shown in the diagram, fuel from the injection pump is delivered through passage 3 to the ring passage 4 and further through the passage to the under-needle fuel space.

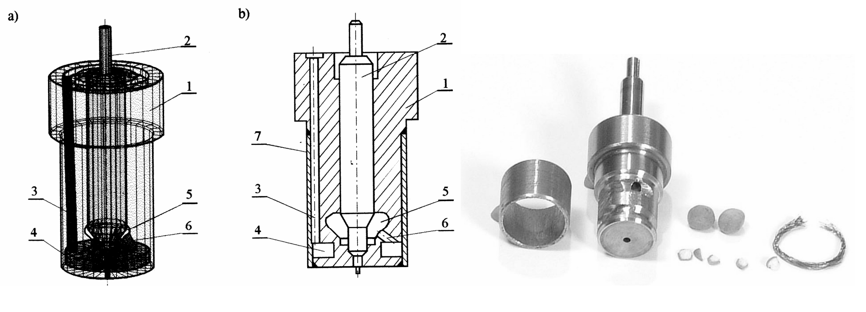
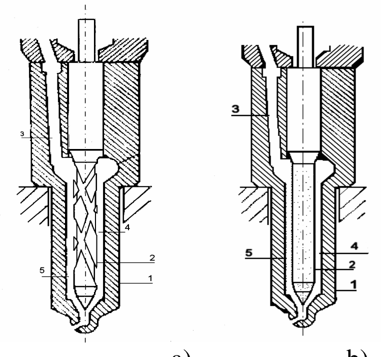


Fig. 1. Diagram (a), cross-section (b) and elements of an injector (c) including the fuel heating system: 1 – nozzle holder, 2 – needle, 3 – inlet passage, 4 – ring passage, 5 – under-needle space, 6 – connecting passage, 7 – external skirt

The above process of preliminary fuel treatment refers to pintle injectors, in which the construction of a nozzle holder allows for fuel heating passages covered with catalytic material deposited on their surfaces. However, new developments in self-ignition engines clearly show that direct fuel injection prevails, in which the injection process is basically carried out by multi-point injectors. Their construction makes it practically impossible to employ the fuel heating system as shown in Figure 1. In this case, preliminary fuel treatment is possible if the fuel flow in the gap between the holder and needle is much more turbulent (Fig. 2). Depositing a catalyst on turbulizing elements and on the lower, hottest part of the injector is sufficient for satisfying the basic requirement for catalytic and thermal treatment of fuel in self-ignition engines.



a) b)

Fig. 2. Increased area of contact between catalyst and flowing fuel in a multi-point injector body: a) – injector with turbulizing passages on the non-working part of the needle, b) – injector with rough surface on the non-working part of the needle; 1 – nozzle holder, 2 – needle, 3 – inlet passage 4 – gap, 5 – catalytic surface, 6 – turbulizing passages

Basic problems that have to be solved for the thermal-catalytic fuel treatment to be implemented are connected mainly with the determination of allowed changes in fuel temperature in the injector body, problems of the catalyst effect on the fluid jet stream, the methods of increasing the temperature of the injected fuel and the catalyst deposition on injector elements.

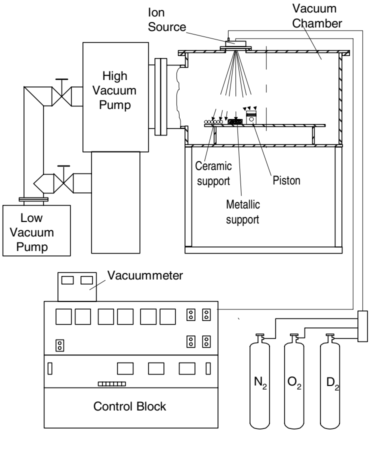
2. Catalyst deposition on fuel injector elements

As mentioned before, operational and ecological properties of the self-ignition engine can be improved by initial chemical reactions such as dehydrogenation. In this case, these reactions are possible due to the contact of fuel with a catalytic material that enhances the effectiveness of the process in increased temperatures. The combination of the two processes – fuel heating and its contact with a catalyst can be achieved directly in the injector body, including the heating system whose elements are covered with a catalytic material.

At present, catalysis is said to be a phenomenon in which a relatively small amount of a substance called a catalyst brings about an increase in the reaction rate. A reaction rate can be accelerated by directing it onto one of a few thermodynamically possible routes of the reaction and is characteristic of a lower energy barrier. A catalyst does not change the chemical balance. Catalyst activation centres react only with reactors in a multi-stage process, forming temporary transition states, with the catalyst regeneration in the last stage. Catalyst regeneration may be complete or partial, the former being connected with deactivation [1].

One of the conditions for the correct activity of a catalyst is the sufficient exposition of its area. In the injection systems of self-ignition engines, such exposition of the catalyst area is limited due to the small dimensions of fuel passages in which catalytic treatment can take place. For this purpose, this author has proposed filling heating passages with pressed wires on which catalytic material was deposited. Furthermore, the non-working part of the atomiser needle located in the under-needle space was used. The catalyst can be deposited on this element when its surface is first made rough. On the one hand, greater roughness increases the area of contact between flowing fuel and the catalyst. On the other hand, it causes turbulence in the fuel flow, which additionally increases fuel – catalyst contact.

Of a number of methods of catalyst deposition on injector elements, the method of electro-discharge alloying was chosen for the non-working elements of the injector needle (Item 2, Fig. 1). The method of ion implantation on the elements of fuel heating system passages (Items 3 and 4, Fig. 1) and additional elements placed in the passages was also chosen. Figure 3 presents a diagram and general view of the facility for catalytic material deposition on fuel injector elements.



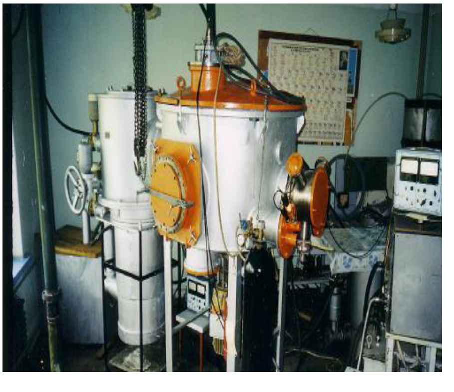


Fig. 3. General diagram and view of the facility for ion implantation

3. Experimental research

Research on thermal and catalytic treatment of fuel was performed at the brake test stand. The diesel engine used was a two-cylinder self-ignition engine (2C8.5/11, rated power 8.8 kW, revolutions per minute – 1500 min^{-1}, piston diameter – 85 mm, piston stroke 110 mm, with a vortex combustion chamber of the Ricardo Comet MrcV type (Fig. 4); its choice was due to the use of pintle injectors in which the fuel heating system can be designed.

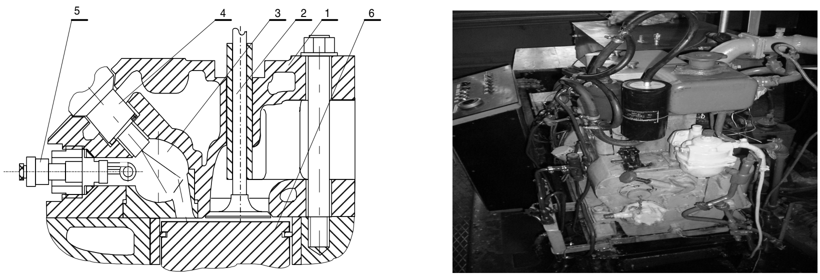


Fig. 4. Cross-section and view of a two-cylinder self-ignition engine: 1 – head, 2 – valve, 3 – vortex chamber, 4 – injector, 5 – glow plug, 6 – piston

Figure 5 presents the results of experimental research on the proposed method of thermal-catalytic fuel treatment carried out at a test stand with a one cylinder engine.

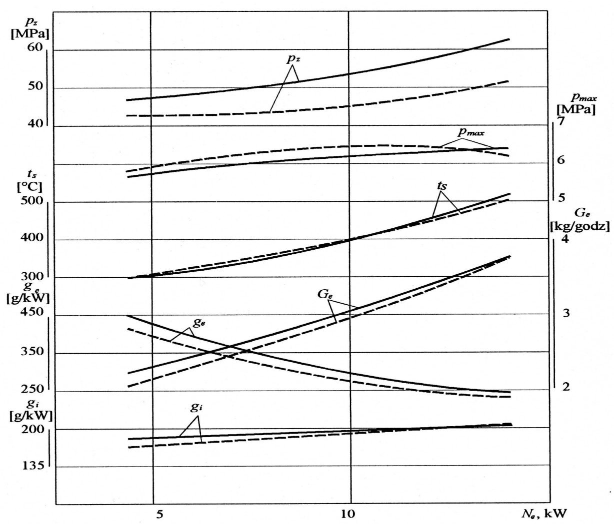
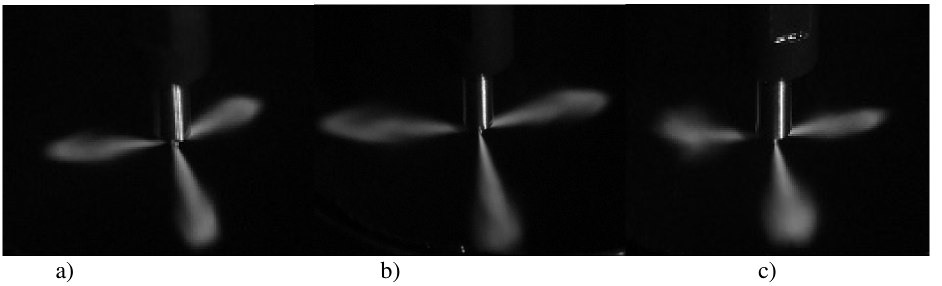


Fig. 5. Results of research on the application of thermal-catalytic fuel treatment
--- - thermal fuel treatment; - - - - - - thermal-catalytic treatment

Laboratory tests of multi-point injectors (Fig. 2) were done on a bench equipped with a standard stroboscope and consisted in recording the jet stream of fuel injected into the surrounding area and comparing the stream developments created by classic and modified injectors. Figure 6 displays photographs of fuel jet streams from the tested injectors. It should be noted that the turbulization of fuel flowing in the injector gap noticeably improves the fineness of fuel jet droplets, their range and angle of spread. This indicates that the self-ignition delay time can be reduced and the operational and ecological parameters of self-ignition engines with direct fuel injection can be improved.



a) b) c)

Fig. 6. Fuel jet streams produced in injectors: a – standard, b – with rough surface of non-working part of the needle (Fig. 2, b), c – with a turbulizer in the non-working part of the needle (Fig. 2, a)

Conclusions

Experimental research has shown that the application of preliminary thermal and catalytic treatment of fuel before its direct injection into the combustion chamber reduces the unit consumption of fuel as well as the amount of toxic compound emissions into the environment. Further research on the problem will focus on the process of preliminary thermal and catalytic fuel treatment in engines with direct injection; since, in such injectors, the treatment can be applied using the non-working part of the needle where fuel-catalyst interaction is possible.

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Recenzent:
Janusz MYSŁOWSKI

Zwiększenie oddziaływania wstępnej obróbki paliwa w silnikach z zapłonem samoczynnym

Słowa kluczowe

Silnik z zapłonem samoczynnym, aparatura wtryskowa, katalityczna obróbka paliwa.

Streszczenie

W artykule przedstawiono analizę procesów termodynamicznych zachodzących w korpusie wtryskiwacza paliwowego wyposażonego w układ podgrzewania paliwa, w którym umieszczono materiał o działaniu katalitycznym. Wyniki badań analitycznych wskazują na możliwość zwiększenia efektywności pracy silnika z zapłonem samoczynnym przy jednoczesnym zmniejszeniu emisji związków toksycznych do otoczenia.