Investigation of the Torch-Ignition in a Lean-Burn Internal Combustion Engine with Catalytic Prechamber

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Abstract

In the present work it is proposed to improve the efficiency of an Otto engine by a substantial increase of the compression ratio, the use of a lean mixture and the introduction of a prechamber with a catalytic insert. A four-cylinder engine Ford FSD 425 was selected for experiments. The modification of Diesel engine to the Otto cycle was performed in by replacing the fuel injectors with prechambers equipped with the catalytic insert and ignition plugs. For this configuration of the engine the geometric compression ratio was in the range _ =15.5-16. Investigation showed that for the engine with torch-ignition the range of stable operation depends on: 1) method of the creation of the torch-ignition, 2) kind of the catalyst and 3) kind of the fuel. The torch-ignition in the prechamber can be created by means of three methods: 1) the spark ignition, 2) pure catalytic ignition and 3) spark-catalytic ignition. The experiments were performed with two kinds of catalysts (Pt and Ni) and unleaded petrol (ON 98 and ON95). Investigation showed that for the engine with the spark-catalytic ignition the range of the stable operation were the widest for the Ni catalyst and ON 98 unleaded petrol ($1.38 < \lambda < 1.65$). In the case of unleaded petrol ON 95 the limits of knock combustion are shift in the direction of a lean mixtures.

Introduction

The aim of the present study is to develop a system of catalytic ignition improving performance of the engine. For many years one of the most important tendencies in development of gasoline engine was combustion of lean mixtures.. However, if the mixture is lean and homogeneous, then the initial flame kernel is weak and the speed of flame propagation is low. The solution proposed here to improve the engine operation is similar to those used in stratified charge engines. It is characterized by the combustion chamber being divided into two parts, i.e. the main combustion chamber and prechamber. However, by contrast with stratified charge engine, the prechamber now is feed with the same as main combustion chamber lean mixture. In order to decrease cycle to cycle variation and to increase local burning velocity, instead of rich mixture in prechamber the catalytic insert is used. A small prechamber with the catalytic insert attached to the engine structure improves considerably the combustion characteristics, thus making possible operation with lean mixtures, higher compression ratios, and high efficiency. In experiments it was found that catalytic ignition either can accompany spark ignition or it can be used as independent source of ignition. In both cases, in comparison with spark ignition, it increased the fuel economy and reduces emission of HC and CO.

Experimental

The principal goals of the present work are:

- to establish a method of determining the catalytic properties of various catalyst and fuels,
- to apply catalyst assisted ignition and combustion in a serial production engine.

The microcalorimeter [1,2] was used to determine the temperature characteristics of a catalyst interacting with a mixture of unleaded petrol vapors with air. The sensitive element of that microcalorimeter is a thin wire, made of the catalytic material to be tested. A heated tube was employed to evaporate the liquid petrol, to create a homogeneous mixture of vapor with air and to keep the initial temperature of the flowing air-fuel mixture at the desired level.

A four-cylinder engine Ford FSD 425 was selected for experiments. The modification of Diesel engine to the Otto cycle was performed in by replacing the fuel injectors with prechambers equipped with the catalytic insert and ignition plugs (Fig.1).. The prechamber is a smaller part of the combustion chamber and in its final version contains only 10 % of the clearance volume. The catalytic insert, which is platinum or nickel wire coil , was suspended on a special hanger screwed into the prechamber. To protect the catalytic insert and to avoid uncontrolled ignition and knock combustion it was necessary to cool the walls of the prechamber with water drawn from the cooling circuit of the engine. The mixture was composed by fuel injection into the inlet manifold just before the inlet valves. For the reported here configuration of the engine the geometric compression ratio was in the range _ =15.5-16.

Results

Investigation showed [1,2,3] that flow of air-fuel mixture in gaseous phase over catalyst changes its temperature as the result of the chemical reactions of fuel and oxygen on its surface. If the temperature of the catalyst T_c and air-fuel mixture T_m exceed temperature of the heterogeneous ignition T_{HI} then the heterogeneous reactions stabilized and the temperature of the catalyst surface increase to the autothermall temperature T_{AT} in the violently way (Fig.3). For the unleaded petrol, octane number ON98, the heterogeneous ignition temperature was $T_{HI} \geq 320^oC$. Further investigation on the heated tube showed that for the condition of experiment, T_m and $T_c \geq 350^oC$ and _ =1.3-0.75, chemical reactions at the surface of the catalyst cause the ignition of the flowing air-fuel mixture. So, catalytic surface ignition begins at temperatures several hundred degrees Celsius lower than the gas phase ignition for the same combustion mixture. Investigation on the heated tube were performed for the conditions of atmospheric pressure and low turbulence.

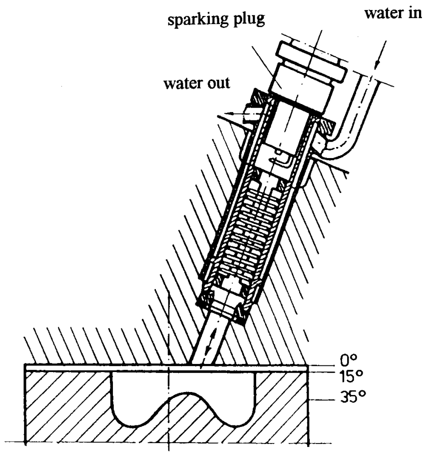

Fig.1 The section sketch of the prechamber and the main combustion chamber.

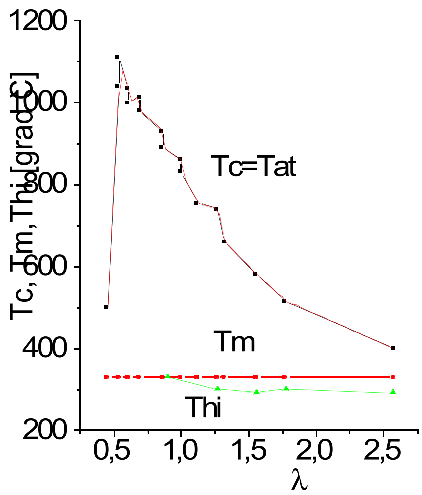

Fig.2 Autothermal temperature (Tat) and heteregeneous ignition temperature (Thi) of the Pt catalyst versus coefficient _ for unleaded petrol NO 98.

In the course of the working cycle of the piston engine the contact between the fresh air-fuel mixture with the catalytic insert is possible only during the compression stroke. During this stroke fresh mixture flows into the prechamber, thus entering into contact with the heated catalyst. After ignition within the region of the spark plug the pressure of the gases in the prechamber increases above the pressure of the mixture in the cylinder and the burning mixture flows back into the main chamber (ignition torch). It is essential that heterogeneous ignition of the mixture should occur on the surface of the catalyst during the flow of fresh mixture, through the prechamber towards the spark plug and back into the main chamber.

In the case of the pure catalytic ignition, ignition-torch is created as a result of the catalytic heterogeneous reactions, only. The combustion process proceed in the range of conditions

$$\lambda_k < \lambda < \lambda_{ce}$$

where: $\lambda_{k,}, \lambda_{ce}$ - air excess coefficient for knocking combustion and for catalytic extinction, respectively.

Investigation showed that for the engine with torch-ignition the range of stable operation depends on:

1) method of creation of the torch-ignition, 2) kind of the catalyst and 3) kind of the fuel.
One can distinguish three methods of creation of torch-ignition:1) for spark ignition $1.4 < \lambda < 1.52$,

2)for spark-catalyst ignition $1.38 < \lambda < 1.65$ and 3) for pure catalyst ignition $1.38 < \lambda < 1.46$.

The experiments were performed with two kinds of catalysts (Pt, Ni) and unleaded petrol (ON 98 and ON95). Specific fuel consumption (ge) and emission of CO, HC and NOx as a function of excess air coefficient λ for the Ni catalyst and ON98 are compared in Fig. 3a,b. The specific fuel consumption (g_e) and the emission of HC and of CO are the lowest for the pure catalyst ignition and then for the spark-catalyst ignition. The emission of HC for pure catalyst ignition is in the range of 0.68-0.82 g/kWh. Combustion of the hydrocarbons fuel are sequential process CnHm-CxHy-CO-CO_2. It means, that at the beginning of the combustion processes catalytic torch-ignition is more effective. Emission of CO is typical for an engine with the Otto cycle, feed with lean mixture. Emission of NOx is lower for the spark ignition, in the range of $\lambda < 1.5$.

Influence the kind of fuel on the performance of the engine was investigated for unleaded petrol ON 95. In the both fuels only contains of toluene and MTBE are different. In Figs. 3c,d are compared specific fuel consumption g_e and emission of CO, HC and NOx as a function of excess air coefficient λ for the Ni catalyst and ON 95 unleaded petrol. The result of the investigation showed that for this fuel the limits of knock combustion are shift in the direction of a lean mixtures. Now the stable operation of the engine are in the ranges: $1.45 < \lambda < 1.5$ for the pure catalytic ignition, $1.45 < \lambda < 1.65$ for the spark-catalytic ignition and $1.5 < \lambda < 1.55$ the spark ignition. It can be notice that for the unleaded petrol ON 95 the specific fuel consumption g_e of the engine for all of the methods of ignition, under consideration, are much lower for the same excess air coefficient. The lowest specific fuel consumption g_e = 245 g/kWh was obtained for conditions n = 2500 r.p.m and $\lambda \leq 1.43$.

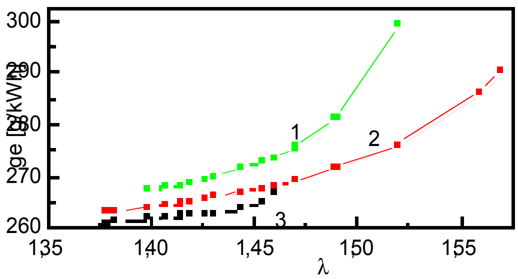

Fig. 3a.

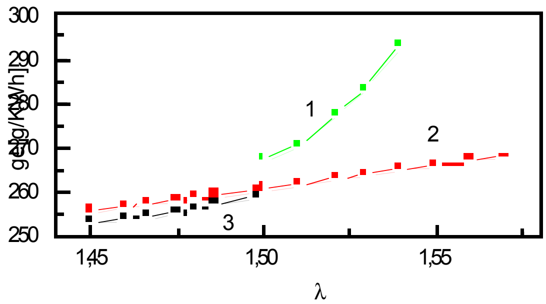

Fig. 3c.

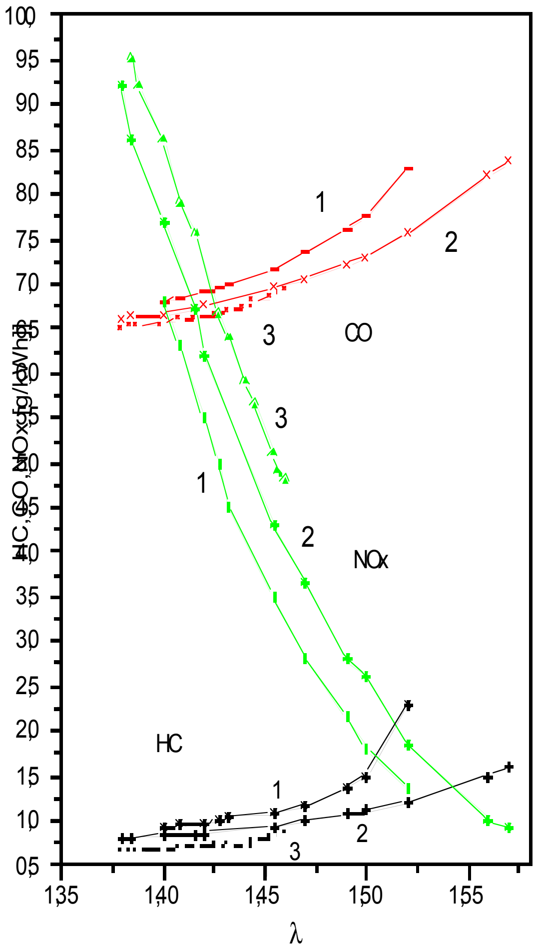

Fig. 3b.

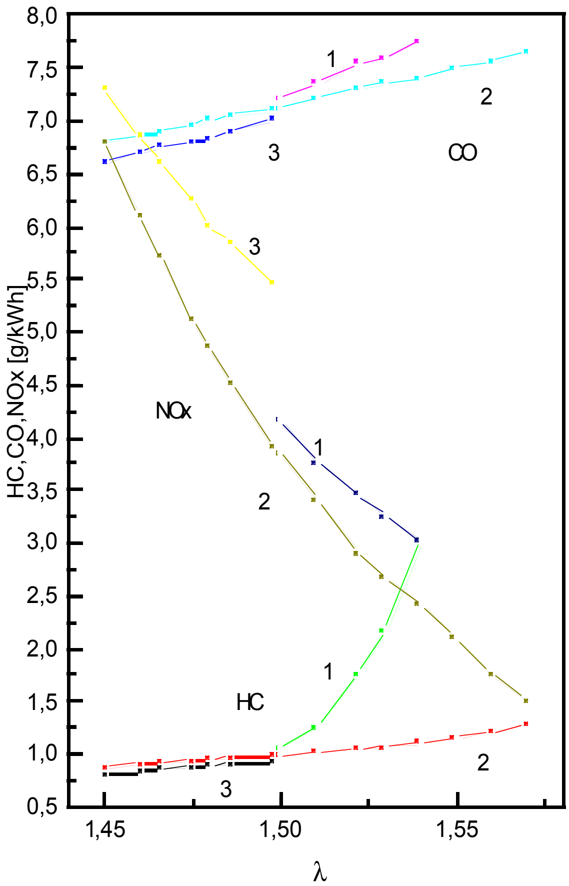

Fig. 3d.

Fig.3a,b,c,d Comparison of the specific fuel consumption and of the emission of CO, HC and NOx versus air excess coefficient for three methods of creation of the torch-ignition: 1- spark ignition, 2- spark-catalyst ignition, 3- pure catalyst ignition. Condition of the experiment: fig. 3a,b for Ni catalyst and unleaded petrol ON 98, fig. 3c,d for Ni catalyst and unleaded petrol ON 95; n=3000 rpm.

The emissions of HC for the engine with the pure catalytic ignition and with the spark-catalytic ignition (Fig.3d) are practically the same value (0.8-0.9) as for the unleaded petrol ON 98 for the same excess air coefficient.. The emissions of CO for the engine with the pure catalytic ignition and with the spark-catalytic ignition are a few percent lower then for the unleaded petrol ON 98 for the same excess air coefficient. The emission of NOx for the engine with the pure catalytic ignition and with the spark-catalytic ignition (Fig.3d) are considerably higher (~ 40 %) then for the unleaded petrol ON 98 for the same excess air coefficient. Influence the kind of catalyst on the performance of the engine was investigated for Pt catalyst and the unleaded petrol ON 98. The result of the investigation showed that for this catalyst the limits of knock combustion are shift in the direction of a lean mixtures. The range of the stable operation of the engine with the pure catalytic ignition are contain in the range of air excess coefficient $1.45 < \lambda < 1.5$. The range of the stable operation of the engine with the spark-catalytic ignition are the widest $1.45 < \lambda < 1.65$. For the engine with the spark ignition the range of the stable operation is $1.5 < \lambda < 1.55$.

The reduction of the fuel in air-fuel mixture decreases the temperature of the exhaust gases t_e, particularly in case of the pure catalyst ignition (Fig.4). As the result of this the temperature of the catalyst and the mixture more quickly attains the level of catalytic burn out ($Tc < T_{HI}$). Therefore the range of the stable operation of the engine is narrower. In the solution of the combustion system selected in this study it was impossible to control the temperature of the catalyst.

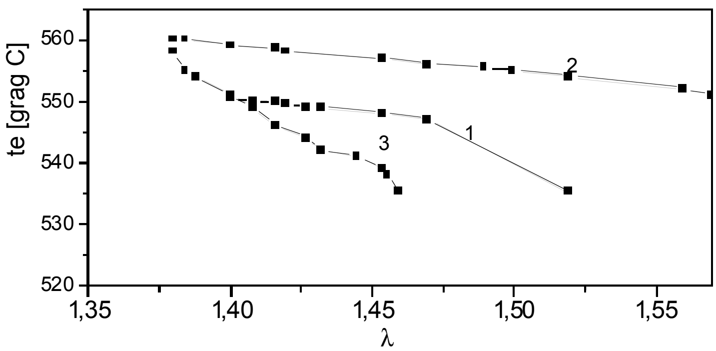

Fig.4 Comparison of variations of the temperature of the exhaust gases versus air excess coefficient for three methods of creation of the torch-ignition. Conditions of the experiment as for Fig. 3a,b.

Acknowledgment

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