Journal of Engineering Physics and Thermophysics, Vol. 72, No. 1, 1999

EFFECT OF THE PLAZMAZER PLASMA IGNITION SYSTEM ON THE FUEL COMBUSTION REGIMES IN COMBUSTION CHAMBERS OF ENGINES

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UDC 66.0:533.9+533.7

An economically efficient method of combatting toxic products of incomplete fuel combustion in engines and other movable and stationary power installations by means of pulsed automatic control of the ignition and combustion processes carried out by the PLAZMAZER system is proposed. A new concept of the occurrence of motor knock in internal combustion engines with external carburetion, the stiff operating mode of diesel engines, erosion of turbine blades, burn-out of combustion-chamber and exhaust-line elements, and jet engine compression stalling are presented.

Introduction. Modern engines are designed and built as applied to the classical ignition system with single ignition of the fuel load in combustion chambers, usually by an electric spark between the electrodes of the spark plugs [1]. In tending to achieve the maximum energy output, designers:

a) improve the combustion-chamber shape and material;

b) increase the compression ratio;

c) use fuel diffusers and ion-exchange filters in the supply line, working-mixture turbulizers, direct fuel injection with homogeneous and layered charges (das Einspirtzsystem) or direct injection of the fuel-air mixture (the Orbital Engine), individualization of the angle of advance of ignition (the SAAB Direct Ignition), turbosupercharging, and multichannel supply and exhaust systems that improve filling and emptying of the combustion chamber;

d) vary the number of cylinders as a function of the load, and vary the homogeneity of the fuel charge over the combustion-chamber volume;

e) use various fuel additives, including water, alcohols, ozone, hydrogen, and polycyclic aromatic hydrocarbons (PAH), in order to increase the octane rating of gasolines.

However, the conventional method of combustion of hydrocarbon and synthetic fuels does not ensure complete oxidation of carbon and hydrogen in the combustion chamber to yield carbon dioxide and water. The exhaust gases contain a wide range of highly toxic components [2].

It should be noted that incomplete fuel combustion is a forced measure included in the design due to instable operation of carburetor internal combustion engines at air excess coefficients exceeding unity. This problem induced invention of costly, low-efficiency, and short-lived catalytic neutralizers of exhaust gases, which, due to the additional gas-dynamic resistance in the exhaust line, increase fuel consumption by 20–25%, thus increasing the exhaust of toxic substances into the atmosphere, and are easily poisoned by oxygen, water, lead, manganese, mercury, and other compounds, including soot and analogs of warfare gases invariably present in exhaust gases.

In addition, PAH and azaarenes cannot be completely neutralized on platinum, rhodium, and palladium (with alumosilicate admixtures) catalyzers, and regeneration of neutralizers is not a less costly process than production of these expensive metals [3].

Belarusian State University, Minsk, Belarus. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 72, No. 1, pp. 105-116, January-February, 1999. Original article submitted July 10, 1997; revision submitted March 10, 1998.

In recent years, the attention of numerous scientists has turned to investigation of the microphysical and chemical processes taking place in spark and barrier discharges in the combustion chamber and outside it with various energy-liberation dynamics [4].

1. Hydrodynamics and Chemical Physics of Combustion. In Zel'dovich's opinion [5], investigation of the detonation wave itself cannot provide information on the chemical-reaction kinetics in the combustion chamber, unless its mechanism is revealed by some independent method. In investigating the explosion conditions in the combustion chamber, Semenov, the founder of the theory of chain reactions, derived the dynamic constant of the action on the process, which characterizes the ability of the reactants to transform in the course of the reaction into unstable chemical compounds that liberate the energy stored to provide a new act of transformation of the reactants [6, p. 28].

Earlier, the hypothesis of excitation of general-detonation noise by conversion of acetylenelike compounds (EGNCAC) was developed [7]. By now, extensive data directly or indirectly substantiating this the hypothesis are available [2; 6, p. 312; 8-12].

The modern hydrodynamic model of combustion (of not just hydrocarbon fuels) in the combustion chamber of an engine (e.g., internal combustion engine, jet engine, etc.) developed by Landau and Lifshits [13] on the basis of Zel'dovich's theory [5] makes it possible to describe, along with the detonation and deflagration regimes, condensation jumps (collapses) of pressure in the combustion chamber that are formally similar to detonation, deflagration, and other high- and low-frequency combustion waves. These collapses result from polycondensation of gases and vapors that are intermediates of the oxidative fuel pyrolysis, and it should be noted that the polycondensation process takes place at a very high rate within a very narrow zone that can be regarded as a discontinuity surface separating the original gas, vapor, or a mixture of both from "smoke" or "fog" that is a gas with suspended solid matter or condensed vapor (e.g., coke, soot, PAHs with their heterogeneous modifications, water, etc.) present in exhaust gases.

The condensation collapses (jumps) are an independent physicochemical phenomenon rather than a result of gas compression in conventional shock waves, where the effect of condensation due to an increase in the pressure is overcompensated by the effect of an increase in the temperature [13].

Manifestations of pressure collapses due to polycondensation, polymerization, copolymerization, etc., such as 1) reddish-green flames ejected from exhaust nozzles, 2) rumble, rattle, howl, knock, and other acoustic effects, 3) decrease of power and overheating of internal combustion engines, 4) ejection of black smoke (coke and soot) from the exhaust system, 5) sharp peaks and collapses in indicator diagrams, 6) vibration and disintegration of parts of the piston group of internal combustion engines, 7) erosion of turbine blades and the walls of the combustion chamber of jet engines, 8) chipping of pistons and burning-through of their bottoms in internal combustion engines, and 9) burning-through of gaskets and exhaust valves, are normally ascribed to detonation, and it should be noted that in the pressure diagram these periodic collapses are described as "ejections" or "peaks" of shock waves [14-17]. The above reasoning makes it possible to state that the "peaks" correspond to the pressure in the combustion chamber that would be observed in the absence of collapses.

Following Landau and Lifshits [13], we carry out an approximate calculation of the forbidden range of condensation jump (collapse) rates in the combustion chamber:

$$\sqrt{\left(c^2 + \frac{k^2-1}{2}q\right)} - \sqrt{\left(\frac{k^2-1}{2}q\right)} < v < \sqrt{\left(c^2 + \frac{k^2-1}{2}q\right)} + \sqrt{\left(\frac{k^2-1}{2}q\right)}\,. \qquad (1)$$

By substituting into (1) the parameter values $c^2 = k(k-1)C_VT = 1.4\ (1.4-1)\cdot 32\cdot 2500 \approx$ 40,000 $\mathrm{m^2/sec^2}$, $k = 1.4 \to k^2 \approx 2$, $T \equiv 2500$ K, $C_V = 32$ kJ/(kmole·deg) [1], $q \approx 3[C_2H_2]-[C_6H_6] \approx (3\cdot 227-40)\cdot 10^3 \approx 64\cdot 10^4$ kJ/mole [18], we obtain

$$\sqrt{\left(4\cdot 10^4 + \frac{2-1}{2}64\cdot 10^4\right)} - \sqrt{\left(\frac{2-1}{2}64\cdot 10^4\right)} < v < \sqrt{\left(4\cdot 10^4 + \frac{2-1}{2}64\cdot 10^4\right)} +$$

$$+\sqrt{\left(\frac{2-1}{2}64\cdot 10^4\right)}\ ;\quad 600-570 < v < 600+570 \quad \text{or} \quad 30 < v < 1170 \ \text{m/sec}.$$

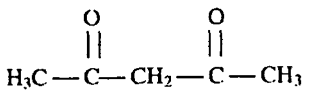
In the case where a high-molecular-weight polymer is formed, which is then converted into coke [10, 11], this range broadens due to an increase in the heat of conversion.

Zhorov shows in a table [18, p. 256] that the heat liberation upon addition of a monomer unit in oligomerization remains almost constant and equals approximately 70–100 kJ/kmole.

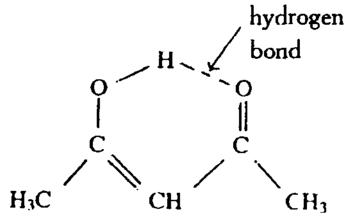
Coke formation at high temperatures is accompanied by release of diene hydrocarbons, which then cyclize into aromatic ones, and by reacting with the latter, acetylene and allene hydrocarbons increase the coking probability [18, p. 231]. Alkylation reactions are also exothermic, and their thermodynamic probability increases with the temperature [18, p. 242]; the heat liberation in alkylation of aromatic hydrocarbons by olefins is higher than in alkylation of paraffin hydrocarbons, the heat liberation and equilibrium constants for naphthalene alkylation are higher than for benzene alkylation, etc.

An increase in the pressure in the combustion chamber leads to an advanced increase in the equilibrium constant for formation of a high-molecular-weight polymer, for example: [18, p. 255], at 5 MPa ethylene conversion reaches 90% (the molar fractions of the dimer, trimer, and tetramer are 0.28, 0.14, and 0.48, respectively).

In the presence of oxygen, the rate of coke formation increases, and the dehydration rate decreases [19, p. 372]. In oxidative pyrolysis of hydrocarbons in the combustion chamber, acetylene being oxidized according to a reaction similar to Kucherov's reaction is capable of forming acetylacetone molecules, whose NMR spectrum serves as a reliable source of information on its structure [20]:



keto form (15%)



enol form (85%)

Resonance absorption of the keto and enol forms of acetylacetone is easily discernible by the following group signals: 218 and 120 Hz for CH_2 and CH_3, respectively, in the keto form, and 110 and 334 Hz for CH_3 and CH, respectively, in the enol form.

Due to electron delocalization in the enol form, acetylene dipoles are virtually captured electrically by each other and thus can form seed centers of polycondensation of acetylene and similar substances and their radicals (CN, C_2N_2, C_2, C_2H, C_3, etc.). Carbon granules are formed according to the following scheme [19, p. 233]:

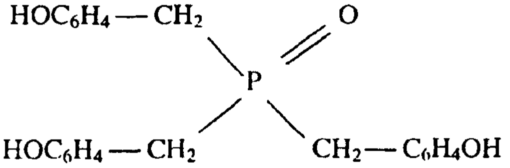
$$2C_2H_2 \rightarrow C_4H_3 + H\ ;\quad C_4H_3 \rightarrow C_4H_2 + H\ ;\quad C_4H_2 + H \rightarrow C_4H + H_2\ ;$$

$$C_4H \rightarrow C_4 + H\ ;\quad C_4 \rightarrow C_{sol} \ \text{etc.}$$

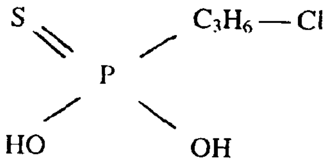
Upon interaction with benzene C_6H_6 the phenyl radical C_6H_5 yields the biphenyl radical $C_{12}H_{10}$ + H, upon interaction with biphenyl it yields triphenyl, etc.

Bicyclic radicals can also appear in the combustion chamber, which then transform into polycyclic structures. In parallel with these processes, cyanides, dicyanides, and other hetero compounds are formed due to burning of nitrogen at temperatures of the order of 2500 K, which participate, along with PAHs, polyacetylenes, and polyallenes, in coke formation [12, p. 169].

In our opinion, special attention should be paid to various fuel and motor-oil additives. Until recently [21], the following antisoot additives were added to tetraethyl lead-containing gasolines in addition to bromine (in the form of dibromopropane and bromoethane) and chlorine (in the form of chloro-alpha-naphthalene) to provide soot removal from combustion chambers of carburetor internal combustion engines:



tricresylphosphate

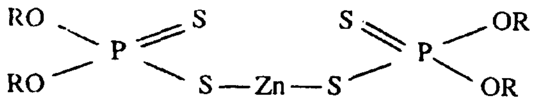


chloropropylthiophosphate

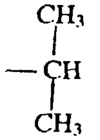
Presently, companies are secretive about information on even more exotic names and compositions of additives; however, their base remains unchanged – it is phosphorus.

It is well known that, despite all the advantages of wiper rings on pistons of internal combustion engines, oil still enters the combustion chamber, where it burns along with the additives, and combustion products necessarily enter the exhaust gases and the atmosphere. In two-cycle internal combustion engines, oil is added directly to the fuel to provide piston-group lubrication. Unfortunately, we failed to find information in the literature on the percent content of antisoot additives in gasolines, but in oils their content is 2.3–5%. This makes it possible to assume that 90–100 liters of oil admixtures alone is burned in the city of Minsk annually.

We will not present formulas for the obsolete LZ-309, Khloref-40, and AN-22k additives, and we provide only the formula for the modern DF-11 additive (available earlier as LANI-317):

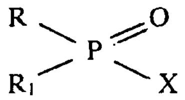


, where R is



etc.

As is evident from the structural formulas, all the types of additives are similar to general-toxicity and neuroparalytic warfare gases in composition [22]:



All these organometallic compounds are emitted in the immediate vicinity of the surface of human lungs ($\approx$ 100 m^2) and skin ($\approx$ 2 m^2).

Numerous attempts to replace tetraethyl lead by other antidetonators have still not met with any success. In 1975 (a volcanism maximum), all terrestrial volcanos exhausted about 8 kg of lead into the atmosphere, whereas automobiles exhausted 320,000 tons in the same year, i.e., 50 g per person. Lead is a cumulative substance and has no safe inhalation dose. Even at a dose of 0.00038–0.0014 mg per kilogram of body weight, functional disorders of nervous activity are observed in six months, and typical signs of poisoning are observed in eight years [23].

Let us return to the hydrodynamics of the processes taking place in the combustion chamber (of not just internal combustion engines). Again, following Landau and Lifshits [13], we calculate the propagation velocity of the condensation front relative to the immobile coke cloud in the combustion chamber in deflagration:

$$v_2 = \sqrt{\left(\frac{k_2 - 1}{2}\,[(k_2 + 1)\,q_1 + (k_1 + k_2)\,C_{v_1}\,T_1]\right)} - \frac{k_2 - 1}{k_2 + 1}\sqrt{\left(\frac{k_2 + 1}{2}\,[(k_2 - 1)\,q_1 + (k_2 - k_1)\,C_{v_1}\,T_1]\right)}\,. \qquad (2)$$

As a result, we arrive at

$$v_2 \approx \sqrt{\left(\frac{1.25 - 1}{2}\,[(1.25 + 1)\,78\,000 + (1.38 + 1.25)\,22\cdot 755]\right)} - \frac{1.25 - 1}{1.25 + 1}\times$$

$$\times \sqrt{\left(\frac{1.25+1}{2}\left[(1.25-1)\,78\,000+(1.25-1.38)\,22\cdot755\right]\right)} \approx$$

$$\approx 165.52 - 15.52 \approx 150 \quad \text{m/sec}.$$

Similar calculations for the velocity of the working mixture relative to condensation products $v_2 - v_1$ yield [13]

$$v_2 - v_1 = \sqrt{\left(\frac{2\,[(k_2-1)\,q_1 + (k_2-k_1)\,C_{v_1}\,T_1\,]}{k_2+1}\right)} \approx 124.15 \quad \text{m/sec}.$$

Hence, it is evident that under deflagration-combustion conditions, condensation-induced collapses and, consequently, a detonation-induced rarefaction wave, are *impossible*. However, a deflagration shock wave, when propagating ahead of the combustion front, is capable of inducing a detonation wave. This detonation should correspond to the Chapman–Jouguet point on the Hugoniot adiabat. Therefore, the velocity of the detonation wave relative to the combustion products left behind equals exactly the velocity of sound in the combustion chamber.

Similar conclusions can be drawn regarding the propagation of the rarefaction wave induced by acetylene oligomerization, formally described by the Hugoniot adiabat [13]:

$$c = \sqrt{\left(k\,\frac{RT}{\mu}\right)} = \sqrt{\left(1.38\,\frac{8314\cdot2500}{29}\right)} \approx 995 \quad \text{m/sec}. \tag{3}$$

As can be noted from an estimate by Eq. (1), under conditions of propagation of pressure collapses at the velocity of sound, these collapses are not feasible. Therefore, not acceleration but rather deceleration of combustion, for example, in the near-wall zone most distant from the spark plug or over the piston bottom in its motion in the cylinder at a velocity of 0–15 m/sec is the reason for general-detonation noise.

This, in our opinion, explains all the external manifestations of detonation described above. The gas fails to occupy the entire volume of the combustion chamber by transforming into coke, graphite, and soot, and the pressure drops, which results in loss in engine power. The latent heat of coking is released in this process, which results in overheating of the combustion-chamber walls, and unburned coke leaves the internal combustion engine (or other engine producing exhaust gases), damaging components of the exhaust system and the combustion chamber itself and adversely affecting the entire genetic pool of nature. The same phenomenon, in our opinion, is responsible for compressor stalling and vibration combustion in combustion chambers of jet engines.

In addition, soot, by combining with nitrogen and metals present in trace amounts in the fuel, forms abrasive particles [12, pp. 326-333] whose hardness exceeds that of the material of turbine blades and walls of combustion chambers of jet engines, etc.

2. PLAZMAZER and Condensation-Induced Combustion. One can eliminate condensation-induced pressure collapses and increase fuel combustion efficiency (especially during "quenching" of products of a plasmachemical reactor whose role is played by the combustion chamber of an internal combustion engine, under conditions of a sharp decrease in pressure and temperature of 4 MPa/sec and 10^6–10^7 K/sec, respectively) using the plasma ignition system developed by the authors [7, 24] and tested on more than 2000 automobiles with external carburetion. Tests of the PLAZMAZER system on diesel engines on a motor testing facility of the Minsk Automobile Plant have also yielded promising results.

The method of fuel combustion in (mostly internal combustion) engines implemented in our invention is based on automatic impulsive fixing of the electron energy distribution function in regions of quantum pumping of plasma reactors (e.g., combustion chambers) by optimizing the barrier-discharge frequency on the spark plugs.

Earlier, we developed and patented a device implementing the above method [24]. In addition to the above automotive tests, independent PLAZMAZER tests were carried out on testing facilities of the Automobile and Automotive Engine Scientific-Research Institute, the Moscow Lenin Komsomol Automobile Plant (Bacman and running-drums facility), the Ryazan High Military Engineering Automobile School (a ZD-2A device and a KI-4856

TABLE 1. Results of Measurements of Fuel Consumption and CO Concentration in Exhaust Gases in Comparative Tests

Ignition system type	Fuel consumption, liter/100 km					CO concentration, %
	1	2	3	4	average	
Conventional	8.8	8.6	8.4	8.4	8.55	2.00
PLAZMAZER	8.0	8.1	8.1	8.2	8.10	1.25
PLAZMAZER, without gasket	8.0	8.0	8.0	8.0	8.00	0.75

Note. 1-4, numbers of the measurements.

TABLE 2. Results of Measurements of the Effective Power of an Internal Combustion Engine in Comparative Tests at Different Speeds

Ignition system type	Effective power, kW, at the speed, km/h				
	60	80	100	120	140
Conventional	17	21	22	22	16
PLAZMAZER	18	21	26	28	27
PLAZMAZER, without gasket	118	28	30	34	35

facility developed at the State Scientific and Technological Institute for Repair and Maintenance of Truck and Tractor Fleets), VAZ (the Volga Automobile Plant), the Minsk Region Automobile Service Center "AvtoVAZtekhobsluzhivanie" (Elcon and Hoffmanndynatest-122), the Kamerton Production Association (Motortester), the Ministry of Automobile Transportation, and Auto-Wahl GmbH (Diagnoseottomotor).

The PLAZMAZER system provides: 1) a 10–20% reduction in fuel consumption, 2) a 8–15% increase in internal combustion engine power, and 3) a 50% decrease in the CO content in exhaust gases.

For its simplicity, reliability, and efficiency, the PLAZMAZER system was awarded the Bronze Medal at the 23d International Invention Exhibition held in Geneva in 1995.

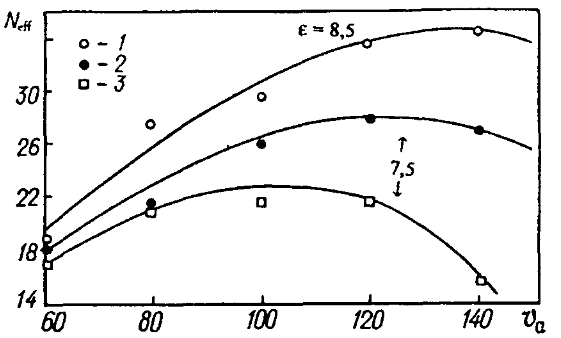
As has been shown by special investigations [1], the content of CO, CH, and NO in exhaust gases can be calculated rather exactly as a function of the coefficient α using the formulas

$$[\mathrm{CO}] = 61.3 - 114\alpha + 53\alpha^2; \quad [\mathrm{CH}] = 0.922 - 1.667\alpha + 0.776\alpha^2;$$

$$[\mathrm{NO}] = -3.64 + 7.88\alpha - 3.88\alpha^2.$$

At $\alpha = 1.13$, $[\mathrm{CO}] = 0.1557\%$, $[\mathrm{CH}] = 0.0179\%$, and $[\mathrm{NO}] = 0.31\%$. Measurements of the corresponding parameters carried out by the authors on June 7, 1996 on the Diagnoseottomotor facility for the idle run of an Opel Kadett-D automobile with 162,498 km total mileage at 880 rpm and at an oil temperature of 94°C and $\alpha = 1.13$ yielded the following results: $[\mathrm{CO}] = 0.12\%$, $[\mathrm{CH}] = 0.0135\%$, and $[\mathrm{NO}] = 0.25\%$, which illustrates the efficiency of the PLAZMAZER system.

As a result of comparative laboratory tests of the PLAZMAZER ignition system with a conventional (classical battery scheme) ignition system carried out on October 26, 1987 on a VAZ 21013 automobile with internal combustion engine serial No. 6803818 with removed gaskets (total mileage 47,000 km), an advantage of the ignition system proposed by the authors was revealed. Comparative tests of the ignition systems were carried out on a Dynatest-122 facility with running drums (Elcon-C200 gauge complex). After heating up the internal combustion engine (until the water temperature in the radiator reached 353 K), the initial setting of the ignition angle of advance was optimized with respect to the maximum effective power of the internal combustion engine accepted by the running drums of the facility. Measurements of the gasoline consumption (in liters per 100 km run) were carried



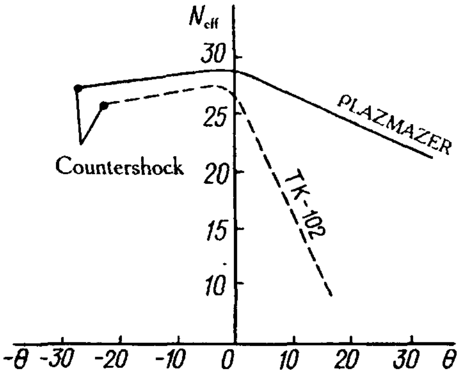


Fig. 1. Dependence of the effective power of an internal combustion engine on the automobile speed on the running drums of a Hoffmanndynatest-122 testing facility, for different degrees of compression and qualities of the ignition system: 1) PLAZMAZER without a deforcing gasket, 2) PLAZMAZER with a gasket, 3) classical battery-powered ignition system with a gasket.

Fig. 2. Dependence of the effective power of an internal combustion engine on the ignition angle of advance for the PLAZMAZER and TK-102 systems.

out four times at a speed of 80 km/h while maintaining an effective power of 6 kW. At the end of each series of measurements, the CO content in the exhaust gases was determined in an idle-running mode of 700 rpm. Results of measurements of the fuel consumption and the CO concentration are presented in Table 1 ($\varepsilon = 7.5$).

We also measured the effective power of the internal combustion engine transferred to the running drums within the range of speeds of 60–140 km/h (see Table 2).

Upon completing the tests, the deforcing gasket initially placed between the head unit and the cylinder unit of the internal combustion engine was removed, which provided its reheating back to the certified degree of compression (8.5). Then we repeated the measurements of the fuel consumption (with the same A76-brand gasoline as with the gasket installed; no motor knock was observed in this case), the power of the internal combustion engine, and the CO concentration with the plasma ignition system under the above conditions. Results of the measurements are presented in Tables 1 and 2 and Fig. 1.

Based on the results of the tests, the following conclusions can be drawn: the CO content in the exhaust gases decreased by 37.5% and 62.5% for the engine with the gasket installed and removed, respectively, the fuel consumption decreased by 5.3% and 6.4%, and the internal combustion engine power increased by 27.3% and 59.1%. A negative result revealed by the tests was the "incandescent" ignition after turning the engine off, i.e., the engine with the ignition turned off operated similarly to a diesel engine with compression-induced ignition. The reason for this remained unclear. We assumed that the combustion chamber of the internal combustion engine contained soot due to the prolonged operation with the gasket, which initiated fuel-load ignition after turning the ignition off.

Numerous field experiments confirmed the results of the laboratory tests described in part by the authors.

We should point out a characteristic feature of the tests carried out on a KI-4856 facility developed at the State Scientific and Technological Institute for Repair and Maintenance of Truck and Tractor Fleets. In measuring the power characteristics of the internal combustion engine as a function of the ignition angle of advance, a sharp drop in the engine power was observed with late ignition of the working mixtures in the combustion chamber with the conventional (TK-102 and others) ignition systems used, whereas only a gradual decrease in the engine power was observed with the PLAZMAZER system, under the same conditions. In our opinion, this phenomenon substantiates the efficiency of the multispark PLAZMAZER system, which self-adjusts to the combustion process (based on feedback via the spark-plug electrodes and the ignition coil) (see Fig. 2).

It should also be noted that in all tests, when the PLAZMAZER system was used, the temperature of the exhaust gases was 100–120 K lower compared to the conventional ignition systems. This makes it possible to reduce

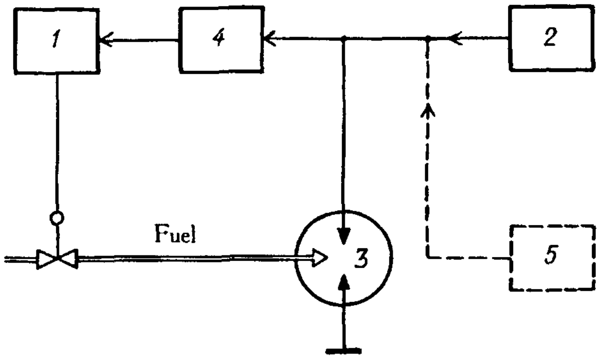


Fig. 3. Schematic of the device for fuel combustion.

in the future the cost of the exhaust system of not only automobiles but also all power installations equipped with the PLAZMAZER. It should be pointed out that, despite the considerable decrease in the temperature of the exhaust gases, we observed self-cleaning of both the spark-plug electrodes and the combustion chamber and the exhaust system already after 15-min operation of the PLAZMAZER.

It is well known that spark-plug electrodes during their operation become covered with a strong thin soot layer close in composition to ceramics. Therefore, the discharge between the electrodes can be regarded as a barrier discharge [25]. Spark-plug electrodes with reversed polarity of the voltage supplied play the role of a probe for measuring the electron energy distribution function with an accuracy sufficient for carrying out an on-line analysis of the quality of the oxidative fuel pyrolysis in the combustion chamber. This made it possible to introduce feedback into the spark-forming circuit that makes it possible to change the frequency of the high-voltage pulse generator in accordance with the quality of the oxidative pyrolysis occurring in the combustion chamber [26].

Various parameters of the spark discharges can be used to control the working-mixture composition unit: the on-off time ratio, frequency, duration, rise and fall-off fronts, decay decrement, magnitude of the breakdown voltage, etc. However, in our opinion, the amplitudes of the spark discharges are optimum.

The invention described in [26] is related to power engineering and thus can be used in systems for fuel combustion control, e.g., in engines, in particular, internal combustion engines. The method is implemented by monitoring the completeness of fuel combustion in the combustion chamber and, based on the results, changing the content ratio of the oxidant, e.g., air, and the fuel in the working mixture to achieve better combustion efficiency. Upon complete fuel combustion, the electrical resistance of the spark gap increases sharply as a result of recombination of ions and ion-radicals of the reagents, which is accompanied by the appearance of finishing spark discharges of increased amplitude. The absence of discharges of this type characterizes incomplete fuel combustion due to over-enrichment of the combustible mixture. In this case the combustible mixture is depleted, and upon the appearance of at least one finishing pulse of increased amplitude the mixture is enriched again.

The device for fuel combustion operating according to the above method (see Fig. 3) consists of combustible-mixture composition control unit 1, ignition system 2, e.g., the PLAZMAZER, connected to a spark discharger 3 with electrodes, unit for analyzing the parameters of the spark discharges 4, whose output is connected to combustible-mixture composition control unit 1 and whose input is connected to one of the electrodes of spark discharger 3, which, in order to provide a higher efficiency of preparation of the working mixture for combustion, is additionally connected to a corona-discharge voltage supply 5.

The device operates as follows. The ignition system ignites the working mixture by means of a series of spark discharges between discharger electrodes. The unit for analyzing the parameters of the spark discharges produces signals for control of the combustible-mixture composition control unit. Initially, the control unit is programmed to provide continuous mixture enrichment at a rate of, e.g., 0.001 of the stoichiometric composition of the mixture per 1000 working cycles of each cylinder of the internal combustion engine, provided that at least one finishing pulse with an increased amplitude is present in the pulse packet. When no such finishing pulse is observed, the combustible mixture is depleted by, e.g., 0.01 of the stoichiometric composition per working cycle of each cylinder of the internal combustion engine.

Thus, the internal combustion engine will operate mostly on a depleted mixture in an economical mode. The corona-discharge voltage is supplied to the spark-discharger electrodes immediately after turning the ignition system on and is not turned off during the operation of the internal combustion engine.

The method proposed makes it possible to improve the fuel combustion efficiency and prevents the appearance of warfare gases in the composition of the exhaust gases by means of thorough oxidation of them. This approach was not obvious prior to investigations carried out using a known discharge mode [24]. However, it is easily implemented and is not restricted to application in internal combustion engines. In particular, we suppose that the PLAZMAZER system can be used to eliminate large quantities of warfare gases.

Under conditions of a barrier discharge occurring at a controlled frequency of the main energy pulses of 2–10 kHz, the conditions of heat transfer in the working and combustible mixtures are improved in the combustion chamber due to the radiative heat conduction. We managed to detect the electromagnetic field within the wavelength range of 0.1 nm to 1000 m using: a) x-ray films, b) radio receivers, c) commercial radiometers, and d) the naked eye (in the visible range) with a dose rate of $10^{11}-10^{12}$ eV/(cm^3·sec).

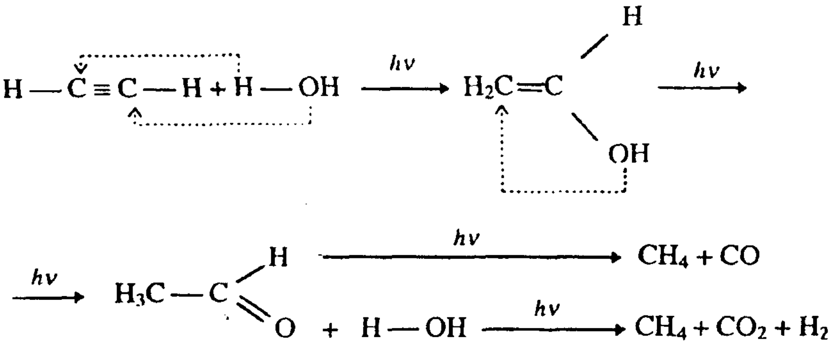
High-energy pumping of the reaction zone of the chemical maser in the combustion chamber and periodic dumping of the stimulated emission make it possible to eliminate not only condensation-induced pressure collapses but also shock deflagration waves and, therefore, detonation waves, thus increasing the octane rating of the gasoline (nondeforced internal combustion engines continued to operate on A-72 and A-76 gasoline instead of AI-93 and AI-98 without detonation knocks). All this and the increase in the power of the internal combustion engine are explained, in our opinion, by the fact that pulsed radiolysis and photolysis activate old channels of ion-molecular reactions [27] and open up new ones in near-wall zones, at the piston bottom, and in the entire combustion-chamber volume [28].

Termination of the barrier discharge due to the danger of jumping of sparks into the combustion chamber with the unprepared combustible mixture substantially reduces the possibilities of applications of the PLAZMAZER for elimination of coke nucleation and formation of superphosphate for fertilization, water and carbon dioxide for photosynthesis, and free nitrogen instead of lacrimators (such as sarin, soman, amyton, tabun, diisopropyl fluorophosphate, ethyl sarin, GF, yperites, hydrocyanic acid, cyanogen bromide, phosgene, bromopicrine, CS, CN, CR, CH, and ther paralyzing, general-toxicity, and psychotropic agents [22]). We are going to overcome this disadvantage by a method similar to that used in the SAAB Direct Ignition [26], and in this case the modification of the PLAZMAZER designed for gas-turbine and diesel engines should be used.

Pulse-rate control in relation to the electron energy distribution function, in our opinion, is the most promising approach, and already at the present time it makes it possible to substantially eliminate the inherent disadvantages of the most up-to-date internal combustion engine by Ralph Sarich (Orbital Engine Co.), in particular, burning-through of piston bottoms, without affecting its indisputable advantages. Engines with molecular mixing (the Vasil'ev–Sviridov S-process [29]) that provide 100% mixing of the fuel with air or another oxidant can also be equipped with the PLAZMAZER system, since good mixing is only one step toward high-efficiency fuel combustion. In addition, the PLAZMAZER makes it possible to avoid ethylation of gasoline and synthetic fuels, which not only leads to pollution of the environment with lead but also destroys the ozone shield of our planet as a result of emission of methyl bromide into the terrestrial atmosphere in a quantity of about 300,000 tons per annum only by carburetor automobiles, which exceeds by a factor of more than three the quantity of Freons emitted in the same period. The hypothesis of destruction of the ozone layer by vibrating water crystals from high clouds and inversion jet traces by no means removes the effect of anthropogenic methyl bromide – the number one toxic agent for O_3 according to the Montreal Protocol.

The PLAZMAZER makes it possible to carry out individual diagnostics of the quality of operation of the cylinders of an internal combustion engine using any oscilloscope-based testing unit, since the pulse-packet shape is uniquely related to the fuel combustion efficiency via the number of vibrationally excited particles of combustion products N_v and, therefore, via the electron energy distribution function in combustion chambers of engines and other power installations.

Energy-optimized barrier discharge prevents accumulation of acetylene in the combustion chamber at the low concentrational limit of explosion by, for example, activating C_2H_2 and H_2O for a reaction similar to Kucherov's reaction [7]:



with subsequent slow oxidation of methane and hydrogen or CO.

This and similar new photochemical reaction channels [27, 28, 30] exclude, in our opinion, the reason for the appearance of condensation-induced collapses [13] (jumps according to Landau's terminology) and open up possibilities of use of less toxic low-octane fuel components. In addition, injection of electrons into a chemically active plasma initiates recombination of H, CH, CH_2, and CH_3 radicals and the ions H^+, CH^+, etc., while at the same time negatively charging O_2, which impedes the coking process [19, pp. 230-240]. It has been shown [31, p. 100] that the C_2H_2 polymerization rate is approximately two and a half times higher than the benzene polymerization rate. This fact is explained by an analysis of the results presented in Tables 1 and 2 of [10].

Due to inclusion of CH, N, O, and CO in the coke composition at an air excess coefficient $\alpha = 0.86-0.94$ in carburetor-type internal combustion engines, the efficiency of carbon-particle disintegration decreases somewhat [31, pp. 109-168]. Therefore, based on economy considerations, one should maintain $\alpha = 1.1-1.3$.

The appearance of compression stalling and the damage to turbine blades by abrasive particles, as has been stated above, may be a result of condensation-induced pressure collapses.

CONCLUSIONS

1. We presented results of investigations by different authors that substantiate the EGNCAC hypothesis of excitation of general-detonation noise by conversion of acetylenelike compounds in combustion chambers of engines operating on hydrocarbon fuels.
2. The hypothesis of a condensation regime of fuel combustion that leads to condensation-induced pressure collapses (Landau's condensation jumps), a formal description of which is presented in Zel'dovich's detonation theory and is developed by Landau and Lifshits, is presented.
3. The assumption of the onset of the condensation combustion mode as a result of decelerated frontal combustion of fuel in combustion chambers of engines is made.
4. The notion that compressor stalling in jet engines, vibrational combustion, and damage to combustion chambers are consequences of condensation-induced pressure collapses is presented.
5. An efficient method for eliminating the above adverse phenomena using the PLAZMAZER system for plasma-based control of combustion is developed.
6. A method for elimination of warfare gases, including ones formed in incomplete combustion of fuel in engines, by means of the PLAZMAZER technology is proposed.
7. Results of investigations of the PLAZMAZER system in certain modes of operation of the internal combustion engine that substantiate its efficiency and potentialities are presented.
8. The hypothesis of decomposition of stratosphere ozone by bromine and chlorine contained in the ethyl liquid added to gasoline to increase its octane rating is put forward.

Fruitful discussions of the results of the work with A. M. Starik are acknowledged.

NOTATION

c, velocity of sound in the combustion chamber, m/sec; k, adiabatic exponent; T, temperature, K (by completion of combustion, $T \approx 2500$ K); q, heat of acetylene-to-benzene conversion (polycondensation), kJ/kmole; v, velocity, m/sec; v_2, propagation velocity of the condensation front in the combustion chamber, m/sec; v_1, velocity of expansion of the combustible mixture in the combustion chamber, m/sec; X, halogens (Cl, Br, F), acyloxy, dialkylamino, ethylmercapto, CN, or nitrophenoxy group; C_{sol}, solid phase of carbon (coke); R, acryl or alkoxy group; R_1, alkoxy, alkyl, mercapto, or amino group; R, gas constant, $R = 8314$ J/(mole·deg); k_1, adiabatic exponent of the working mixture after compression, $k_1 \approx 1.38$; C_v, specific heat of the combustible mixture, $C_v \approx 32$ kJ/(kmole·deg); C_{v_1}, specific heat of the working mixture after compression, $C_{v_1} \approx 22$ kJ/(kmole·deg); T_1, temperature of the working mixture after compression, $T_1 \approx 755$ K; k_2, adiabatic exponent of the combustion products, $k_2 \approx 1.25$; q_1, lower heat of combustion of the fuel, $q_1 \approx 78{,}000$ kJ/kmole; μ, molecular weight, $\mu = 29$; α, coefficient of air excess in the working mixture; ε, degree of compression of the mixture in the cylinders of the internal combustion engine; rpm, number of revolutions of the crankshaft of the internal combustion engine per minute; N_{eff}, effective power of the internal combustion engine, kW; N_v, mean number of vibrationally excited particles of combustion products; h, Planck's constant; ν, frequency, Hz; v_a, speed of the automobile on the running drums, km/h; θ, ignition angle of advance, deg.

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