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USE OF PLASMA REFORMING OF FUEL FOR REDUCTION OF THE TOXICITY OF DIESEL ENGINES

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Problems in the use of plasma reforming of Diesel fuel for reduction of the toxicity of exhaust gases are considered. Results of experiments on the decomposition of Diesel fuel in nonequilibrium plasma of a spark discharge are given. It is shown that under these conditions the content of hydrogen in the obtained synthesis gas can reach 10% or more.

The widespread use of internal-combustion engines in different spheres of human activity has had serious ecological impacts, related mainly to pollution of the environment by toxic components of the exhaust gases (EG) of automotive engineering. In parallel with the known methods for reduction of the toxicity of exhaust gases (catalytic cleaning, electric-discharge plasma systems) [1], a method using a hydrogen-enriched gas mixture obtained by decomposition of a part of the Diesel fuel in the discharge [2] is promising.

A compact plasmatron that runs off an on-board power source can be used to convert a part of the fuel to a hydrogen-containing gas mixture for both direct injection to the combustion chamber and treatment of EG in the plasmachemical reactor or catalyst. The presence of hydrogen in the fuel mixture can lead to more complete burning of fuel at a smaller effective temperature and the corresponding decrease of soot and carbon and nitrogen oxides in EG. Plasma increases the partial oxidation reaction that converts hydrocarbons of the fuel to the hydrogen-enriched gas mixture (the oxygen/carbon ratio is unity, exothermal reaction):

$$C_nH_m + \frac{n}{2}(O_2 + 3.8N_2) = nCO + \frac{m}{2}H_2 + 1.9N_2 .$$

For Diesel fuel the reaction occurs with liberation of about 10–15% of the energy:

$$C_{14}H_{26} + 7O_2 \to 14CO + 13H_2 .$$

Figure 1 gives a basic diagram of the use of an on-board plasmatron-reformer of fuel with direct injection of a hydrogen-enriched synthesis gas to the engine. The effect of the operation according to this scheme is a reduction of the concentrations of NO_x, hydrocarbons, and soot particles, and improvement of the thermal efficiency of the engine.

We estimate the amount of hydrogen necessary for the case where partial replacement of the Diesel fuel by hydrogen does not considerably change the operating conditions of the engine but decreases the emission of toxic components. On the basis of experiments [3], we admit substitution of 10% of the Diesel fuel by hydrogen. Fuel consumption for a typical engine is ~100 g/min. Since the heat power of hydrogen is almost threefold higher than the heat power of the Diesel fuel, 3 g of hydrogen are enough to substitute 10 g of the Diesel fuel. In this case, the molar concentration of hydrogen will be more than 50%, which guarantees stable operation of the engine with very lean mixtures. The maximum pressure of combustion of these mixtures increases slightly.

Modern plasmatrons have a high efficiency (higher than 80%). A specific efficiency of a typical plasmatron is 1 g/h of conversion products at an electric power consumption of 1 W. The power consumption necessary for production of 3 g/min of hydrogen is ~200 W.

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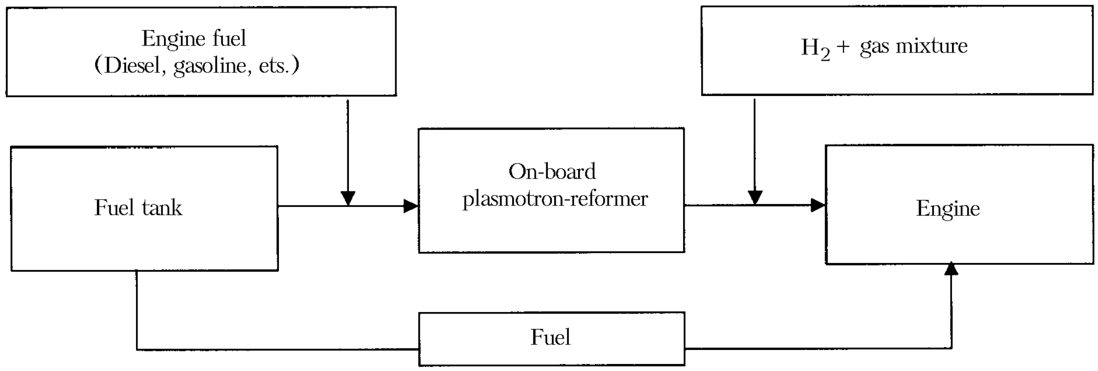

Fig. 1. Schematic diagram of the concept of an engine with low emission of toxic substances.

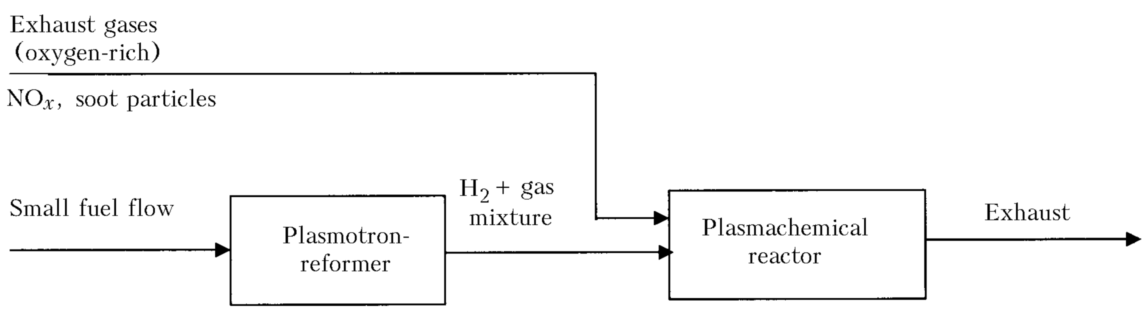

Fig. 2. Schematic diagram of the concept of the combined system for reduction of toxicity of exhaust gases: plasma reformer of fuel + plasmachemical reactor.

Introduction of hydrocarbon (ethylene, propane, methane) additives to the plasmachemical reactor (Fig. 2) under the conditions of pulse discharge sharply decreases the concentration of nitrogen oxides and the content of soot particles in exhaust gases [1]:

$$C + NO_2 \rightarrow CO_2 + \frac{1}{2} N_2 ,$$

$$C + OH \rightarrow CO + \frac{1}{2} H_2O ,$$

$$C + NO_2 \rightarrow CO + NO ,$$

$$HC + 5O_2 \rightarrow 2CO_2 + H_2O ,$$

$$HCHO + O_2 \rightarrow CO_2 + H_2O ,$$

$$CO + NO_x + OH \leftarrow \text{indirect} \rightarrow CO_2 + N_2 + H ,$$

$$H_2 + NO_x + ... \leftarrow \text{indirect} \rightarrow H_2 + N_2 + ...$$

The use of the on-board plasma reformer of the Diesel fuel for obtaining the synthesis gas with such products will make it possible to improve the efficiency of the plasmachemical system without the use of additional gases.

Experimental Study of the Decomposition of Diesel Fuel in Nonequilibrium Plasma of High-Voltage Spark Discharge. The plasmatron (Fig. 3) consists of an anode (made of steel, cone-shaped), cathode (spark plug), reactor, and chambers for gas-mixture cooling. The central electrode (cathode) is made on the basis of a standard Champion (RN9YC4) spark plug with a central copper electrode. The diameter of the electrodes is 6, 7, and 8 mm, and

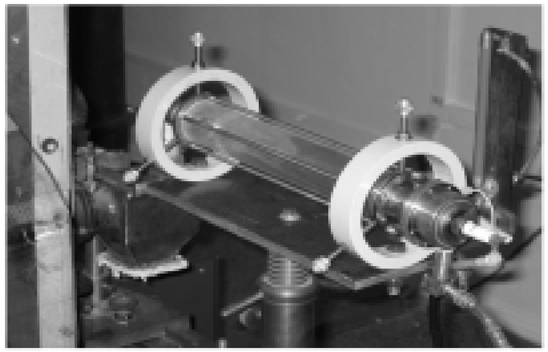

Fig. 3. Plasmotron with reactor

TABLE 1. Production of Nitrogen Oxides in the Plasmatron

Operating conditions of plasmatron	NO_2, ppm	NO, ppm	CO_2, %
Air	5	70	—
Fuel–air mixture	—	22	>2.0

TABLE 2. Concentration of the Products of Fuel Decomposition in the Gas Mixture

Mean discharge current, A	Concentration, %							
	H_2	CO_2	C_2H_6	C_2H_4	O_2	N_2	CO	CH_4
2	8.55	7.50	2.87	0.09	1.30	69.84	7.62	1.52
3	9.51	6.78	3.21	0.10	1.34	67.63	8.57	1.79
4	10.29	7.02	3.37	0.12	0.89	67.01	8.25	1.87

their length is 35 mm. The results of the test of production of nitrogen oxides in the air- and fuel–air-mixture-operated plasmatron are given in Table 1.

It is seen that in the products of decomposition of the fuel–air mixture in the plasmatron the content of NO_x is much smaller and the content of CO_2 is higher than in decomposition of air. This fact indirectly confirms the interaction of nitrogen oxides with the products of fuel decomposition ($H_2 + CO + N_2$), e.g., by the reaction $CO + NO_x \rightarrow CO_2 + N_2$.

Table 2 gives the results of decomposition of the fuel–air mixture in nonequilibrium plasma of high-voltage spark discharge at different mean discharge currents (air flow rate 0.5–1 liter/sec, fuel flow rate 0.15–0.5 ml/sec).

The concentration of hydrogen in the gas mixture reaches 10%, which allows one to count on the development of a highly efficient combined plasmachemical system for cleaning the exhaust gases of Diesel engines from toxic components.

Thus, the use of a plasma reformer of Diesel fuel for obtaining hydrogen- and hydrocarbon-rich synthesis gas makes it possible to realize, in combination with the plasmachemical reactor, a compact on-board system for reduction of the toxicity of the exhaust gases of Diesel engines.

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