Application of hydrogen and hydrogen-containing gases in internal combustion engines

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Abstract. The results of studies of the influence of hydrogen and hydrogen-containing gas additives on the parameters of various types of internal combustion engines are analyzed and summarized. It made possible to identify the features of the effect on the combustion of fuel during internal combustion engine operation at partial loads. The dependences of reducing the toxicity and fuel consumption of internal combustion engine on the amount of addition of hydrogen and a hydrogen-containing gas to the air-fuel mixture were obtained. It allowed to establish quantitative effects of free hydrogen, in particular, to quantify the region of small hydrogen additives and the conditions under which hydrogen exhibits the qualities of a chemically active component of the mixture.

1. Introduction

Due to the regular tightening of requirements for environmental friendliness of vehicles, as well as a limited amount of hydrocarbon fuel resources, it is necessary to search for new types of fuel, methods for their production and efficient use [1-3]. For piston internal combustion engines (ICE), hydrogen or a mixture of combustible gases with its high content are most promising. The advantages of using hydrogen as a fuel for internal combustion engines are well known. However, to date, its practical use is constrained by the high cost of producing hydrogen and the lack of infrastructure for its use. In this regard, it seems relevant to use pure hydrogen and/or hydrogen-containing gas as additives to the main hydrocarbon fuel.

In order to assess the prospects of this method at the Department of Energy Machines and Control Systems, Togliatti State University, work was carried out to establish patterns of reducing the toxicity and fuel consumption of internal combustion engines from the amount of hydrogen and hydrogen-containing gas added to the air-fuel mixture, as well as assessing the prospects for their use. Due to the complexity of the complex of issues to be investigated, many of which do not have an accuracy acceptable for practice, the experimental research method was applied by conducting tests in a motor box in the framework of the adopted methodology implemented by GOST 14846-81 (Automobile engines. Bench test methods) and GOST 41.083-2004 (Automobiles and engines. Emissions of harmful substances. Norms and methods of determination) [5].

Research included the following areas of work:

- assessment of the effect of additives of pure hydrogen to gasoline and natural gas;
- assessment of the effectiveness of the use of synthesis gas both as a primary fuel and as an additive to hydrocarbon fuel.
2. The effects of hydrogen additives in the air-fuel mixture

Assessment of the effect of the addition of pure hydrogen to gasoline according to the test results of various types of ICE (VAZ-21083, VAZ-2111, VAZ-1111, BA3-2114, KAMAZ-820.52 (53) -260) showed that a small amount of hydrogen additive in the range of 3- 6% by weight of the fuel reduces products of incomplete combustion, such as CH hydrocarbon, by expanding the combustion limits of carbon monoxide CO in the exhaust gases (see figure 1, where \( G_6 \) is the consumption of gasoline, CO and CH are the volume content of carbon monoxide and hydrocarbons, \( n \) is the frequency engine rotation, \( P_e \) - average effective pressure).

![Figure 1. Adjusting characteristic of the VAZ-2111 engine (\( n=2185 \, \text{min}^{-1}, \, P_e=0,2 \, \text{MPa} \)).](image)

With this value of hydrogen additives, a significant increase in the indicator efficiency of the engine \( \eta_i \) becomes noticeable, which in turn lowers the fuel consumption indicators (figure 2).

![Figure 2. Change in indicator efficiency of the VAZ-2111 engine depending on % hydrogen addition.](image)

It has been experimentally shown that the ability to work with values of the coefficient of excess air of the order of \( \alpha = 1.8 - 2.0 \) leads to a decrease in emissions of nitrogen oxides NOx, almost to the
trace. Figure 3 shows the characteristic dependences of the change in NOx content on the coefficient of excess air for the VAZ-2111 engine.

![Figure 3. Adjustment characteristic \((n = 1380 \text{ min}^{-1}, P_e = 0)\).](image)

An increase in the amount of hydrogen additives (more than 7-10% of the fuel mass) leads to a decrease in the intensity of CO and CH reduction. In this case, the dependence of the reduction of CO and CH obeys an almost linear law with a slight increase in engine efficiency.

Based on the research results, a calculation methodology has been developed for estimating the amount of hydrogen additives (by the ratio of gasoline-hydrogen) in a gasoline mixture. If necessary, to ensure stable combustion of the mixture at the depletion limit for various operating modes of the internal combustion engine, given the proposed dimensionless parameters:

\[
\beta = \frac{G_\beta + \kappa G_H}{G_{\beta 0}},
\]

(1)

where \(G_\beta\) - current gasoline consumption; \(k\) is the ratio of the lower calorific values of hydrogen and gasoline, \(G_{\beta 0}\) is the gas consumption during the operation of the internal combustion engine without hydrogen according to the adjustment characteristic at constant power and the optimum ignition timing and dependencies:

\[
\psi = \frac{G_H}{G_\beta + G_H}
\]

(2)

where \(G_H\) - hydrogen consumption; \(G_\beta\) - gas consumption detailed in [4].

Figure 4 shows the experimental dependences of \(\beta\) values obtained by processing the test results at various speed and load conditions of the engine, depending on the coefficient of \(\alpha\) excess air.

It is important to note that \(\beta\) parameter is \(\alpha\) function, and it does not depend on the engine operating mode. The study of the mixture composition range, where \(\alpha = 0.8\) - 1.5, shows that the scattering of points is affected by two main factors: the presence of a large amount of exhaust gas in the fuel assembly and charge turbulence. In this case, the regimes close to idling are grouped in the lower part of the dispersion band, and more stressful - in the upper one. The desired ratio of gasoline and hydrogen in the fuel composition (with the known dependencies \(\beta(\alpha)\) and \(\psi(\alpha)\) is determined by solving the system of equations (1) and (2).
3. The use of hydrogen-containing gases (gas synthesis)

The results of a study of the effect of hydrogen additives in fuel assemblies suggest that similar results can be obtained using hydrogen-containing gases, for example, synthesis gas. To this end, work was carried out to study the efficiency of using synthesis gas in an engine. A general view of the experimental setup is shown in figure 5.

Analysis of the test results of synthesis gas generators prototypes, which makes it possible to obtain from gasoline or natural gas a mixture of gases in the required quantities, which consists of 30-35% of hydrogen, 10-15% of carbon monoxide, 10-15% of carbon dioxide, includes 0-5% methane, as well as 40-50% nitrogen together with ICE, allows to draw the appropriate conclusions:

- the efficiency of the working process will be maximum at the optimum ratio of synthesis gas, which is determined by the heat supplied to the fuel during the operation of the internal combustion engine on a mixture of the main fuel and synthesis gas is higher than when the engine is running on pure synthesis gas;
The consumption of hydrocarbon fuel when the engine is operating on synthesis gas in some modes of operation of an internal combustion engine of the VAZ type tends to decrease;

- the use of synthesis gas allows the engine to operate with an excess air coefficient of up to 2.5 and significantly reduce emissions of nitrogen oxides NOx (to the traces);
- when using synthesis gas, emissions of products of incomplete combustion of CO and CH tend to decrease or remain at the initial level, however, in the case of using synthesis gas obtained by conversion of natural gas, an increase in CO emissions is observed, which requires a more detailed study.

The above advantages of using synthesis gas as a partially replacing fuel are confirmed by published data for both internal combustion engines using natural gas [6, 7] and gasoline [8].

The indisputable advantage of replacing part of the fuel with syngas additives compared to pure hydrogen additives in fuel assemblies is the possibility of inexpensive and effective synthesis gas production directly on board a car from regular hydrocarbon fuel. At the same time, the risks associated with the explosion of hydrogen are significantly reduced, and the dependence on the hydrogen supply infrastructure disappears.

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