Effect of adding hydrogen to a primary fuel on enjine operating modes

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Abstract*. Hydrogen has a good environmental performance, high energy characteristics, high burning rate and low ignition temperature. In case of using hydrogen as a primary fuel in an internal combustion engine, there is a drop in power and detonation combustion at high load modes, so hydrogen is best used in a composition with the primary fuel.*
In the mode of partial load, the hydrogen content in the fuel mixture decreases, and it should decrease as the load increases, and in the mode of full load, its amount is minimal, which will allow us to maintain the power characteristics, otherwise the power will decline.
The main thing is to know in which mode what should be the ratio of hydrogen and the primary fuel, which ensures the normal flow of the operation process, which will result in primary fuel economy and reducing the toxicity of exhaust gases.
Based on the studies conducted, we can conclude that it is preferable for the engine to work with a high content of hydrogen in the fuel mixture at no load and at light loads, its concentration should decrease as the load increases.
KEY WORDS: *INTERNAL COMBUSTION ENGINE; HYDROGEN ADDITIVE; FUEL SUPPLY SYSTEM; POWER, ECOLOGY.*

1. Introduction

Undesirable anthropogenic changes in the ecosystem occur during the operation of motor transport. If we take into account the fact that the level of environmental pollution is quite high and environmental threats are growing, attention should be paid to the use of such fuels, whose economic and environmental efficiency will prove to be high. The need to switch to alternative fuels is also confirmed by the fact that oil stocks are irreplaceable and their current amount is expected for several decades. From an environmental perspective, hydrogen is an ideal fuel. It burns in pure oxygen and releases water. Hydrogen is ьщыедн obtained from hydrocarbons, where up to 85% is carbon, the main part of the amount of heat is released as a result of burning. Hydrogen has good environmental performance characteristics, high energy performance, high burning speed and low ignition temperature.

In the 1970s, the world experienced an energy crisis, which strengthened interest in hydrogen fuel, which has a high energy capacity of 120-103 kJ/kg, which is 2.8 times more than the energy capacity of diesel fuel, although hydrogen fuel requires 2.3 times more oxygen.

To use hydrogen as a fuel in gasoline and diesel engines, it is necessary to make changes in the design of the fuel supply system. During external mixing, cylinder filling deteriorates and power drops due to low hydrogen density. During internal mixing, the energy capacity of the charge can be increased or maintained at the existing diesel fuel level. From this it is assumed that the use of hydrogen is more favorable in diesels. For self-ignition of the mixture of hydrogen and air in the cylinder, it is necessary to increase the temperature at the end of compression, which would be achieved by pressure charging or by heating the charge during the filling process.

2.Preconditions and means for resolving the problem

In case of using hydrogen as a primary fuel in an internal combustion engine, there is a drop in power and detonation combustion at high load modes, so hydrogen is best used in a composition with the primary fuel. The main thing is to know in which mode what should be the ratio of hydrogen and the primary fuel, which ensures the normal flow of the operation process, which will result in primary fuel economy and reducing the toxicity of exhaust gases. Based on experimental data, a team of researchers [1] has developed a method that allows us to determine in each specific case the ratio of hydrogen and gasoline in the mixture, which ensures good operational characteristics.

The methodology is based on determining the amount of thermal energy released during the combustion process and allows theoretically calculating the optimal ratio of gasoline and hydrogen in the mixture for each specific mode.

In general, the amount of hydrogen to be added to the primary fuel is calculated by the formula [3]:

$$G_{H_2} = \frac{r \cdot G_D}{1 + r \cdot \frac{Hu_{H_2}}{Hu_D}}$$

where $r = \frac{GH_2}{G_D}$, G_{H2} and G_D are the quantities of hydrogen and diesel fuel, respectively, while H_{UH2} and H_{UD} are the heat capacities of hydrogen and diesel fuel, respectively.

As is known, idle and warm-up modes are characterized by unfavorable conditions for the combustion of the fuel mixture (cold engine, etc.), due to which there is an incomplete combustion of the mixture and an increase of toxic components in the exhaust gases. Therefore, to ensure relatively complete combustion, an active additive (hydrogen) can be used in a certain dose, which will lead to the emergence of additional active centers, and due to its physico-chemical properties, the engine operation moves to the stoichiometric and lean mixture zone, and the combustion process becomes more complete. Therefore, it is desirable to make the engine work with a high content of hydrogen in the fuel mixture during idle and warm-up modes.

In the mode of partial load, the hydrogen content in the fuel mixture decreases, and it should decrease as the load increases, and in the mode of full load, its amount is minimal, which will allow us to maintain the power characteristics, otherwise the power will decline. The paper [2] presents the results of a static engine test, which showed that the addition of hydrogen to the primary fuel at idle and warm-up modes resulted in a reduction of CO and CH, while NO and CO_2 remained unchanged. The results of the static test of the engine were checked and confirmed during the dynamic test, which proves the effectiveness of using hydrogen as an additive, ensuring the sustainable operation of the engine and expanding the limits of fuel mixture leaning.

The main source of the formation of hydrocarbons is the incomplete combustion of the mixture. In particular, when touching the cold walls of the combustion chamber, the flame is extinguished, such zones contribute to the release of CH. Another source of CH formation is oil entering the cylinder due to incomplete cleaning of oil from the walls by the oil rings and also due to oil leakage in the gaps between the valve stem and the guide. An increase in the concentration of hydrogen in the fuel mixture contributes to the reduction of CH due to the appearance of additional “active” centers by improving the combustion process, which can be clearly seen in Figure 1. When the concentration of hydrogen in the fuel mixture is >70%, then the amount of hydrocarbons decreases to zero.

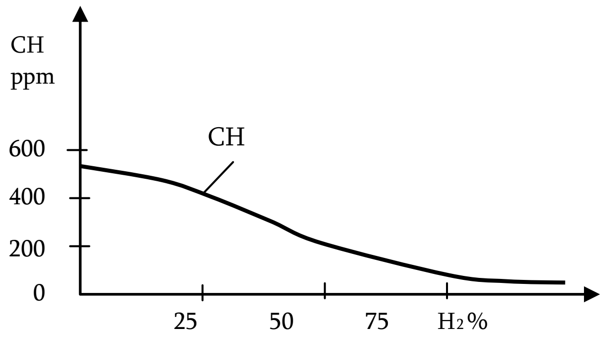

Fig. 1. *Change of hydrocarbons depending on the concentration of hydrogen in the fuel mixture*

Figure 2 illustrates how the amount of hydrocarbons in the fuel mixture changes depending on the temperature at different concentrations of hydrogen.

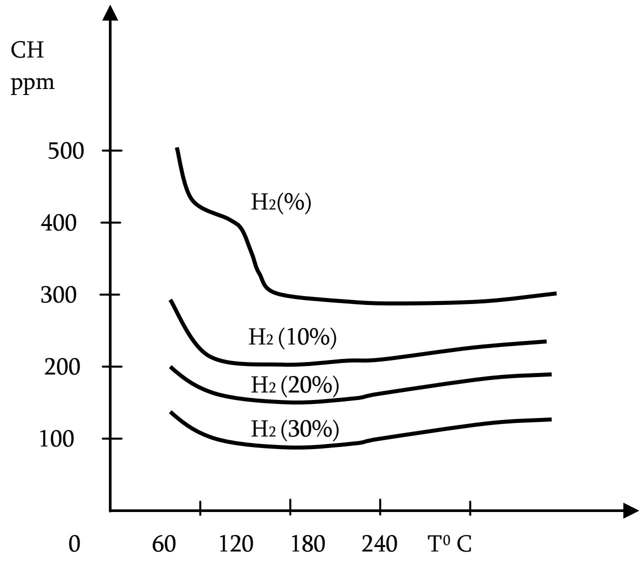

Fig. 2. *The change of hydrocarbons in the fuel mixture at different concentrations of hydrogen depending on the temperature*

As for nitric oxide (NO), its formation is determined by the temperature regime of combustion of the mixture. The higher the combustion temperature (T_{max}), the higher the formation of NO, that is, NO=f(T_{max}). Σ

NOx emission can be reduced by leanening the working mixture, when a>1.8 NO_x decreases to zero. Supplying water with ≈8 times more mass of hydrogen during the filling cycle reduces the emission of nitric oxides by ≈8 times. The following formula can be used to determine the amount of nitric oxides in the exhaust gases [3]:

$$G_{NO_x} = A \cdot \varphi_z \sqrt{\frac{(\alpha_\Sigma - 1)\tau\left(G_T + G_{H_2}\right)}{\eta_V \cdot i \cdot V_R \cdot n^3}} \cdot e^{-E/RT_z}$$

where α_Σ- is a total excess air factor;

φ_z- the time from the start of the combustion process to P_z depending on the crankshaft rotation angle;

T_Z- maximum combustion temperature, K;

G_T- diesel fuel consumption, kgph

G_{H2}- hydrogen consumption, kgph

n- rotational rate, rpm

V_R- cubic capacity, liter

τ- cyclicity

A-coefficient, A=8.61*109

i- number of cylinders

η_V- fill factor

Figure 3 illustrates the change in the nitric oxide concentration depending on the excess air factor.

Hydrogen used as an additive to the primary fuel also helps to reduce the concentration of carbon dioxide, what can be clearly seen in Figure 3, where the change in the CO concentration depending on the excess air factor.

Carbon monoxide is a product of incomplete combustion, which is a toxic substance and has a negative impact on the environment. To reduce it, a number of measures should be taken, including the addition of hydrogen to the fuel mixture in a certain dose, which moves the engine operation into the stoichiometric and lean mixture zone and the combustion process becomes more complete, and as a result, CO is reduced.

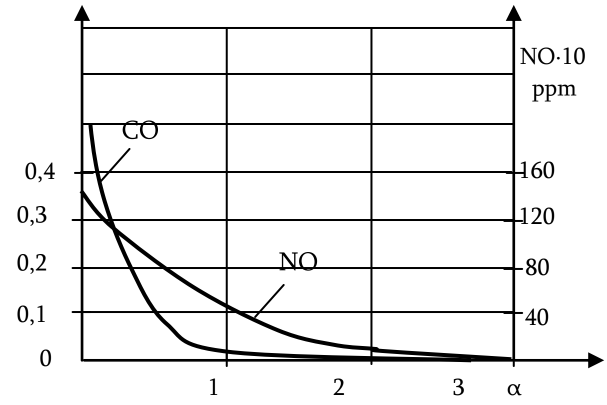

Fig.3. *Change in the nitric oxide and carbon dioxide concentrations depending on the excess air factor*

In the near future, adding hydrogen to the fuel mixture in the limits of 20% may become optimal for hybrid vehicles.

3. Conclusion

Based on the studies conducted, we can conclude that it is preferable for the engine to work with a high content of hydrogen in the fuel mixture at no load and at light loads, its concentration should decrease as the load increases. The use of hydrogen as an additive allows us to increase the engine's efficiency, the maximum value of which when working on hydrogen is much higher than when the engine is working on gasoline

4. References

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