Improving efficiency of use of gas fuels in automobile

E G Safarov, E A Zakharov, V A Alimov and E A Fedyanov
Volgograd Technical State University, 28, Lenina Street, Volgograd, 400005, Russia
E-mail: emin.safarov@mail.ru

Abstract. The paper discusses ways to increase the efficiency of using propane-butane compositions on board a car. The main reasons for the decrease in power during the transition from gasoline to propane-butane are given and the ways to solve them by changing the conditions of supply to the engine intake, as well as the use of thermochemical recovery of exhaust heat, are analyzed.

1. Introduction
The increase in the number of cars running on gas fuels has been steadily increasing in recent years. This is mainly due to the lower cost of these fuels compared with gasoline and diesel fuel.

The conversion of a spark-ignited automobile engine designed to run on gasoline to gas fuel improves its environmental performance, but at the same time leads to some reduction in power. Taking into account the fact that the concept of a dual-fuel engine is being implemented most often, the essence of which is that the existing gasoline engine is additionally equipped with gas-balloon equipment, the problem of increasing the power of gas-powered automobile engines takes on particular importance.

When converting a gasoline engine to power with a liquefied petroleum gas (propane-butane), the reduction in power, as claimed by many researchers, is 5-7% [1]. At the same time, in many works, this reduction in power is explained by the lower heat of combustion of mixtures of propane-butane with air as compared with air-gas mixtures.

2. Materials and methods
Our calculations show that this difference in the heat of combustion is not the main cause of power reduction. Thus, the heat of combustion of a stoichiometric mixture of air and propane-butane, in which the first component by mass is 55%, is 2.76 MJ/kg (when calculating the heat of combustion of propane and butane, taken according to reference data 46.4 and 45.66 MJ/kg, respectively [2]). Taking the heat of combustion of gasoline 44 MJ/kg [3], we find that the heat of combustion of the stoichiometric air-gas mixture is 2.714 MJ/kg. Thus, the heat of combustion of a gasoline-air mixture may even be somewhat less than the heat of combustion of a mixture of propane-butane and air.

Depending on the hydrocarbon composition, the heat of combustion of gasolines varies, as follows from published data, in the range from 43 to 48 MJ/kg. The heat of combustion of propane-butane mixtures, in which the standard specifies the content of propane, is not a strictly defined value. Based on the foregoing, we can assume that the heat of combustion of gasoline-air and propane-butane-air mixtures are about the same.

The main reasons for the decrease in power during the transition from gasoline to propane-butane are associated with the conditions for the supply of these types of fuel and the formation of air-fuel mixtures. Only due to the different density of air-stoichiometric mixtures of these two types of fuel with
air, the mass of propane-butane-air mixture in the cylinder is, ceteris paribus, 2.3% less than the air-gas mixture. Heating the intake air, which contributes to the evaporation of gasoline, adversely affects the filling of the cylinders with the propane-butane-air mixture.

3. Differences between gas-cylinder equipment

The role played by the conditions for the supply of propane-butane to the engine intake well illustrates the results of the comparative tests of cars with gas-cylinder equipment of the 1st and 4th generations carried out at VSTU [4]. The equipment of the 1st generation was installed on the carburetor engine of GAZ-24 Volga. Propane-butane entered the unbranched portion of the heated manifold. The equipment of the 4th generation with distributed gas supply was tested on a Hyundai Sonata car, equipped with a distributed gasoline injection system as standard. The resulting characteristics of the test are shown in figure 1 and 2.

![Figure 1](image1.jpg)

**Figure 1.** Characteristics of the engine car GAZ-24 "Volga": 1 – work on gasoline; 2 – work on LPG.

![Figure 2](image2.jpg)

**Figure 2.** Characteristics of the engine of the car Hyundai Sonata: 1 – work on gasoline; 2 – work on LPG.

As you can see, the reduction in engine power of the Volga GAZ-24 when it is transferred to propane-butane power supply reaches 24%, while in the Hyundai Sonata engine it does not exceed 10%.
The next stage in the development of systems for powering engines operating on liquefied hydrocarbon gas should be the transition to distributed fuel injection in the liquid phase with the subsequent rapid transition to the gas phase directly in front of the intake valves. Tests of engines with this type of gas-balloon equipment [5] indicate that the propane-butane effective power is higher than when working on gasoline.

Figure 3 shows the data from [5] - superimposed on each other indicator diagrams of a four-cylinder S4PH engine with a displacement of 1.6 dm³, taken during its operation on gasoline and on propane-butane. It is seen that the rate of combustion of propane-butane is higher and the indicator work cycles more. At the same time, this work emphasizes that in this variant of fuel supply, emissions of nitrogen oxides, carbon oxides and unburned hydrocarbons when operating on propane-butane exceed the emissions of the same toxic components when the engine is running on gasoline.

Analyzing the nature of the combustion process according to the indicator diagrams in fig. 3, it can be assumed that by selecting adjustments (primarily adjustments to the ignition timing) it will be possible to ensure almost the same engine power on propane-butane and gasoline without deteriorating its environmental performance.

Figure 3. Indicator diagrams of engine operation on gasoline and liquefied petroleum gas at different throttle opening.

4. The study of thermochemical recovery of the heat of exhaust gases
Another promising direction for improving the performance of engines operating on propane-butane compositions is the use of thermochemical recovery of the heat of exhaust gases. Directly on board the car, due to the engine exhaust heat, a portion of the propane-butane entering the engine is converted in the catalytic converter to synthesis gas containing free hydrogen. Synthesis gas is supplied to the main propane-butane-air mixture at the inlet to the engine. Having high chemical activity, free hydrogen accelerates the combustion process and increases its fullness.

Our theoretical (with the help of mathematical modeling) and experimental (under the conditions of a constant volume combustion chamber and engine VAZ 11194) studies confirm that synthesis gas additives significantly reduce the duration of propane-butane combustion and thereby increase the engine efficiency. The promoting effect of synthesis gas additives is illustrated in fig. 4 indicator diagrams of the engine operating on propane-butane, as well as propane-butane with the addition of 3% and 10% by weight of synthesis gas, respectively. The indexing was carried out using Kistler candle sensors. In experiments, synthesis gas was prepared artificially by mixing hydrogen and carbon dioxide gases. The mass content of hydrogen in the synthesis gas was 11.5%.
Figure 4. Experimentally obtained indicator diagram of the operation of the engine VAZ 11194.

5. Conclusion
The increase in the maximum cycle pressure observed in the indicator diagrams and the displacement of the point where this pressure is reached towards TDC indicates that with addition of synthesis gas to the propane-butane-air mixture, it is necessary to change the ignition timing adjustments to smaller values. This will ensure increased cycles without a significant increase in the content of nitrogen oxides in the exhaust gases.

In our opinion, the integrated use of propane-butane gas engines for automobile engines, gas-cylinder equipment with distributed injection of liquid propane-butane and thermochemical heat recovery will provide these engines with higher effective power with better environmental performance than gasoline.

References
[1] Panov Y V 2007 Installation and operation of gas equipment vehicles (Publishing Center Academy)
[2] Bakunin V N, Breschenko E M, Dubovkin N F, Favorsky O N 2009 Gas fuels and their components. Properties, production, application, ecology: a reference book (Publishing House MEI)
[3] Khovakh M S Automobile engines 1977 (Mashinostroenie) 1977
[4] Zakharov E A, Levin Y V, Potapov P V, Moiseev Y G, Statirsky R K, Lykov D V 2016 Reducing the consumption of liquefied hydrocarbon gas of an internal combustion engine with spark ignition due to gas equipment settings Energy and Resource Saving: Industry and Transport 5 (17) 44–47
[5] Mustaffa N, Fawzi M, Osman S A ,Tukiman M M Experimental analysis of LPG injection by the engine Proc. IOP Conf. Series 469 1–12