The algorithm for determining the effect on the dynamic characteristics of the fuel composition on the properties of the working process of the gas-diesel engine

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Abstract. The article deals with the method of determining the optimal composition of the components of the combined fuel taking into account the heat-dynamic tension in the operation of the diesel engine on a mixture of diesel fuel and natural gas, i.e. the gas-diesel cycle. The calculation was based on the method developed by A. V. Grinevetsky and M. N. Mezingom, taking into account the specific conditions of the diesel engine on a mixture of natural gas and diesel fuel. The peculiarity of the mathematical model is that the optimal composition of the fuel components is initially unknown and is indicated as an array. The search for the optimal ratio of fuel components will take into account the heat and Dynamo tension. The resulting model can be used in the study of the diesel engine on other alternative fuels. Thus, it is possible to significantly improve the quality of the fuel combustion process, thereby increasing the engine power and ensuring the environmental safety of exhaust gases.

1. Introduction

In recent years, problems have arisen associated with the need to take into account the elastic properties of in recent decades, one of the most pressing problems in the world for the leading suppliers and consumers of motor vehicles has become: firstly, a marked reduction in natural oil reserves and an increase in the cost of liquid fuels, which requires a significant reduction in fuel consumption [1]; secondly, the constant tightening of environmental requirements due to global pollution of the planet and the "greenhouse" effect of reducing emissions of harmful substances into the atmosphere [2]. Thus, the aggravation of the global energy crisis has intensified the search for new solutions in the last years of the twentieth century [3-6]. Every year, the use of natural gas as a motor fuel for various types of power plants is constantly expanding. Natural gas as an alternative fuel is now the most promising due to the fact [3] that has several advantages over other types of fuel, in terms of complexity, investment and consumer value, more economical than coal and fuel oil. In addition, the relative ease of use of gas is of great importance [4]: there is no need for pre-treatment and supply devices, which are necessary when using solid and liquid fuels, gas supply is easily regulated, any gases are easily mixed with air and with each other. At the moment, progress in the development of internal combustion engines has been achieved in competition with other types of power plants [5].
Key indicators [2, 7], which gave them advantages over other types of engines: fuel efficiency and compliance with international environmental requirements; low specific energy consumption; large volume (mass) energy intensity, as well as reserves for further development and improvement of a design. Therefore, it is these ecological and economic indicators of piston ice that allow us to consider them in the near future as the main type of energy sources for vehicles.

At present, that is, at the beginning of the twenty-first century [7-9], there is an additional need to consider the use of alternative fuels.

2. Formulation of the problem

Diesel power plants are usually powered by compressed gas, although the use of liquefied gas for them significantly reduces fuel costs (relatively compressed gas) [7, 9]. It can be predicted that due to the huge reserves of natural gas on earth and taking into account its advantages, it can be concluded that in the short term in the development of energy, the priority will be given to natural gas, which may eventually take the place of oil fuel.

The use of natural gas will allow: first, to reduce the tension of the fuel supply of energy facilities; secondly, to provide savings due to the lower cost of gas; thirdly, to improve the performance of the ice, almost completely eliminates the condensation of fuel in the intake pipeline and the engine cylinders, so that there is no flushing of the oil film from the walls of the cylinders and pistons. In addition, a more complete combustion of the gas reduces the formation of carbon on the piston bottoms and the surfaces of the combustion chamber, reduces wear of the cylinder group and increases durability, reduces the need for lubricating oils. Fourth, to improve the sanitary and hygienic conditions of industrial centers, since the operation of engines on gaseous fuel reduces the amount of carbon monoxide and toxic components in the exhaust gases, there is no soot. A more complete combustion of gases is explained by a better mixture formation and a more perfect combustion process. And, finally, fifthly, to increase the economic performance of the engine Park due to reduced wear, as according to studies, the overhaul period of engines increases by almost 1.5 ... 2 times.

3. Theory

Into the composition of gaseous fuels include combustible and non-combustible gases. Physicochemical and thermal characteristics of the gas fuel are due to the difference in the composition of the combustible components and the presence in the gas of non-combustible gaseous components (ballasts) and harmful impurities. The combustible components of gaseous fuels include, first of all, methane [1] - a colorless non-toxic gas without smell and taste, which includes 75% carbon and 25% hydrogen; 1 Nm³ it has a mass of 0.717 kg. At atmospheric pressure and a temperature of 111 °K methane is liquefied and its volume is reduced about 600 times. Liquefied methane is a promising fuel for many sectors of the economy. The use and transportation of liquefied natural gas in some cases gives a great economic effect, can significantly reduce the cost of metal for the construction of gas pipelines and thus helps to solve the problems associated with the reservation of gas supply in certain areas of the country and the creation of reserves of raw materials for the chemical industry.

Due to the methane content of 25% hydrogen (by mass), there is a large difference between the higher and lower calorific value. The highest combustion heat of methane is 39820 kJ/m³, 9510 kcal/m³ or 212860 kcal/mol; the lowest is 35880 kJ/m³, 8570 kcal/m³ and 191820 kcal/mol, respectively. Methane content in natural gases reaches 98%, so its properties almost completely determine the properties of natural gases.

Combustion of methane in the air proceeds according to the equation

\[ CH_4 + 2O_2 + 7.52N_2 = CO_2 + 2H_2O + 7.52N_2. \]  

(1)

As a result of combustion, 10.52 Nm³ combustion products are formed (1). Methane has a relatively low reactivity. This is because breaking four bonds in a methane molecule requires a lot of energy. In addition to methane, combustible gases may contain ethane \( C_2H_6 \), propane \( C_3H_8 \), butane \( C_4H_{10} \).

Hydrocarbons of the methane series have the General formula \( C_nH_{2n+2} \).
The main estimated parameters of gaseous fuels are: elemental composition, calorific value, octane number, specific volume, Flammability, moisture content, degree of purification from contaminants. By the elementary composition it is possible to judge the quality of the gas, to determine the calorific value and the amount of air necessary for its combustion, the calorific value of the working mixture and a number of other parameters. Natural gas mainly consists of methane with admixture of other hydrocarbons and inert gases. The elementary structure depends on its field. The calorific value of the gas depends on its state, so it usually refers to the normal cubic meter Nm³, i.e. taken at a temperature of 0°C and a pressure of 760 mm hg. art. (100 kPa). The lower heat of combustion of natural gases depends on the gas field. Average value of combustion of liquefied natural gas - 48500 kJ/kg (for diesel fuel, this value is 42800 kJ/kg). The heat of combustion of 1m³ of natural gas is equivalent to 1.0 ... 1.12 liters of gasoline.

The octane number characterizes the anti-knock properties of the gas and serves as a criterion for determining the permissible degree of compression of the engine. The gaseous fuel having relatively simple structures of the molecules have a higher octane number than liquid fuel, which lie in the range of 85 to 125. Moisture content. The moisture contained in the gas worsens the combustion process of the mixture in the cylinder, causes corrosion of the metal surfaces in the engine, sometimes causes failure of the spark plugs in electric ignition. Gas drying from moisture vapor is carried out mainly by its conversion in refrigerators of various types and scrubbers. The efficiency of the gas engine largely depends on the Flammability of the fuel mixture, which is filled with the engine cylinders. This determines the type of ignition used when using fuel in the cylinder. However, due to the fact that gases are light fuels with a high self-ignition temperature, they require ignition from an external source in the engine. The Flammability of the gas mixture is influenced by the temperature, pressure and swirls of the gas-air mixture at the inlet to the cylinder. At the moment, there are three ways of ignition of the gas-air mixture: spark ignition by a spark plug, spark pre-chamber-flare ignition and by injection into the cylinder of the ignition dose of liquid fuel. All combustible gases contain impurities that cause wear and corrosion of engine parts. Among the impurities polluting the gas are mechanical impurities, hydrogen sulfide and other sulfur compounds. Gas purification from mechanical impurities is carried out in wet and dry cleaners of various types. In comparison with oil fuels, natural gas is considered to be the fuel with the best environmental characteristics. By volume, however, low energy intensity. Therefore, in Autonomous power plants it is used pre-liquefied or compressed. Liquefied gas is stored in containers at a pressure of 0.2...1.8 MPa and a temperature of 112...115°C, and compressed - in cylinders at a pressure of 20...40 MPa.

4. Results of experiments
When choosing schemes for conversion of diesel engines to gaseous fuels, it is necessary to take into account the specific nature of the diesel engines. The conversion of diesel engines to natural gas is carried out by converting them into pure gas engines with internal and external mixing and spark ignition, or by converting them into engines operating on a gas-liquid cycle. Along with certain positive results, such as the most complete use of the physical and chemical properties of the gas, a relatively high unit power, a decrease in the excess air ratio, etc.,-has significant drawbacks. In this case, to avoid detonation, the compression ratio of the base engine is reduced to 8...9 units. In this case, the head of the unit, or pistons or both are structurally changed: the engine is equipped with special gas supply and mixture formation systems, and the serial fuel equipment is replaced by a set for electric ignition. In this regard, the operation of such an engine on liquid fuel is excluded. Although this method is quite simple, but because of these shortcomings it can not be considered the best.

The gas-diesel process, with injection of liquid ignition fuel, allows to keep high degree of compression and to use the serial fuel equipment. Therefore, such an engine can be operated on one diesel fuel, effectively burn relatively poor gas-air mixtures due to the presence of a powerful source of ignition, a ignition fuel torch.
Thus, taking into account the above-mentioned advantages, and taking into account the specific nature of the power plants in road transport, the most preferred way to transfer diesel engines to gaseous fuel is the gas-liquid cycle.

5. Discussion of results

As shown by the experience of the gas-diesel process, the best performance is obtained by using diesel engines with undivided combustion chambers and direct injection of liquid fuel. Much worse results are obtained when using diesel engines with separated combustion chambers. This is due to the deterioration of the conditions of the processes of mixing and self-ignition of the ignition dose of diesel fuel, the presence of hot spots in the combustion chamber, etc.

The gas-diesel process, with injection of liquid ignition fuel, allows to keep high degree of compression and to use the serial fuel equipment. Therefore, such an engine can be operated on one diesel fuel, effectively burn relatively poor gas-air mixtures due to the presence of a powerful source of ignition, a ignition fuel torch.

Thus, the most preferable is the transfer of the gas-liquid process of the diesel engine to gaseous fuel.

The basis of the thermal calculation was based on the technique developed by A. V. Grinevetsky and M. N. Mesing [10], taking into account the specific operating conditions of the diesel engine on a mixture of natural gas and diesel fuel. The peculiarity of the mathematical model is that the optimal composition of the fuel components is initially unknown and is indicated as an array. The search for the optimal ratio of fuel components will take into account the heat and Dynamo tension. The mathematical model is created with the help of software [4, 11].

The content of diesel fuel in the mixture with natural gas expressed in terms of the lower calorific value of the fuel was given by an array of 10...100% in increments of 1%. Since, practice shows [12-14] that at the content of diesel fuel in a mixture with natural gas less than 10% does not give a stable self-ignition of the working mixture

\[ Q_g = 1 - f(x), \]
\[ f(x) = Q_d, \]
\[ Q_d = 0,1,0,11...1 \]

Next, you need to carry out an array of values through the thermal calculation. Difficulties arise in the selection of the maximum temperature on the compression stroke. It is necessary that the 90 input values of the maximum temperature array coincide with the 90 values of the output maximum temperature at the compression stroke. Below is a formula with which you can solve this problem.

\[ t_z(Q_d) = \left( T_{z_{max}} + \frac{T_{z_{max}} - T_{z_{min}}}{9} \right) - \left( T_{z_{max}} - T_{z_{min}} \right) \times Q_d, \text{where} - Q_d = 0,1,0,11...1. \]

Thus, it can be seen that the arrays of incoming and outgoing values of the maximum temperatures at the compression stroke coincide with the change in the composition of the components of the mixture of diesel fuel and natural gas (Figure 1). The graph has two y-axes and one x-axis. The content of diesel fuel in the mixture varies from 10 to 100%.

Now it is possible to determine an array of values of maximum combustion pressures on the compression stroke, which will determine the optimal ratio of the components of the combined fuel taking into account the heat-dynamic stress state when working on a mixture of diesel fuel and natural gas.

If you combine two functions \( T_z(Q_d) \) and \( P_z(Q_d) \) on two Y axes, relative to the X - Qd axis, they will intersect at a certain point. If this point is projected on the X axis, it is possible to determine the value of the optimal ratio of the composition of the components of the combined fuel, taking into account the heat, and the Dynamo intensity when the diesel engine is running on a mixture of diesel fuel and natural gas at the maximum combustion pressure (Figure 2 and 3).

\[ \lambda(Q_d) = \lambda(Q_g, Q_d) \]

As you can see their graphs (Figure 4), for this calculation, the optimal ratio of the fuel mixture is 55% diesel and natural gas 45%.
6. Conclusions and conclusion

In conclusion, it can be noted that the optimal ratio of the composition of the components of the combined fuel, taking into account the heat-dynamic characteristics of the engine on a mixture of diesel fuel and natural gas.

![Figure 1](image1.png)

**Figure 1.** Graph of the dependence of the input and output values of the maximum temperature at the compression stroke when changing the composition of the components of the mixture of diesel fuel and natural gas.

![Figure 2](image2.png)

**Figure 2.** Diagram of the dependence of the maximum combustion pressures on the compression stroke taking into account the heat-stressed state when working on a mixture of diesel fuel and natural gas.

![Figure 3](image3.png)

**Figure 3.** Diagram of the dependence of the maximum combustion pressures on the compression stroke taking into account the dynamic stress state when working on a mixture of diesel fuel and natural gas.

![Figure 4](image4.png)

**Figure 4.** Graphs of the optimal ratio of the fuel mixture composition.

The obtained model can be used to study the operation of a diesel engine on other alternative fuels [15, 16].

Thus, the primary task is not to find an alternative, more environmentally and economically advantageous fuel, but is that in the formation of a chemical reaction of combustion of the fuel-air mixture, the combustion of the fuel is accompanied by an oxidizer.

Consequently, it is possible to significantly improve the quality of the fuel combustion process, thereby increasing the engine power and ensuring the environmental safety of exhaust gases [6, 7].
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