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RESEARCH OF HEAT GENERATION INDICATORS OF GAS ENGINES

Otari N. DIDMANIDZE[1], Alexander S. AFANASYEV[2], Ramil T. KHAKIMOV[3]
[1] *Russian State Agrarian University K.A.Timiryazev, Moscow, Russia*
[2] *Saint-Petersburg Mining University, Saint-Petersburg, Russia*
[3] *Saint-Petersburg State Agrarian University, Saint-Petersburg, Russia*

A comprehensive strategy for reviving the production of mining industry equipment and ensuring its competitiveness includes the wide use of gas engines for various purposes. Experimental studies of the working cycle of a gas engine are one of the main tasks in determining the heat generation characteristics. To this end, indicator charts were recorded in various modes, which were subjected to analysis in order to determine the key parameters characterizing intra-cylinder processes. According to the experimental program, the maximum cycle pressure, the rate of pressure build-up, the heat generation characteristic, the first heat generation phase, the duration of the second combustion phase, and the effect of the ignition advance angle for the ignition period were determined.

The results of an experimental study of the influence of gas engine working process with allowance for the change in the ignition advance angle for the ignition period are described and the parameters of the maximum cycle pressure, the rate of pressure build-up, and the heat generation characteristics are determined. In the processing of data, integral charts are constructed, the working cycle parameters are calculated, and the dynamics of the engine heat generation is determined.

Key words: gas engine, heat generation, combustion, excess air coefficient, indicator charts, full load curve, effective coefficient of performance, temperature, intra-cylinder processes, throttling, gas-air mixture

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Introduction. In the mining industry they use a significant number of different machines and mechanisms that work on heat engines [9]. The use of gas-fueled engines makes it possible to increase their reliability, significantly save material resources and improve environmental parameters. The results of the heat generation resulting from working processes of transport engines operating on different types of fuel (natural gas, diesel fuel and gasoline) affect the main technical, economic and environmental indicators, which is reflected in [1-8, 11, 14]. One of the main tasks of experimental research was to determine the heat generation characteristics of gas engines (GE). In order to do this, the indicator charts were recorded in various working modes, which were further analyzed to determine the key parameters characterizing intra-cylinder processes.

Methods of research. The experimental results of the studies show that changes in the engine adjustment and power conditions characteristics are too complex to describe and unpredictably affect the heat generation of the gas engine. It is experimentally difficult to determine the influence of one of the existing factors, such as the rate of flame front spread, the initial fuel supply temperature, the heat capacity of the combustion products, etc., on the heat generation process. As a rule, some of these factors act simultaneously and in some cases, have the opposite direction. In experiments, the share of fuel heat supplied at the engine inlet together with gas, the crankshaft rotational speed (CS), the compression ratio and the gas injection advance angle were changed simultaneously. The effect of individual engine adjustment factors (excess air coefficient, air and gas temperature, volume of fresh incoming charge, etc.) on the carburation allowed to develop a set of regulatory measures that improved the fuel-economic and environmental performance of the gas engine.

Research of heat generation index of gas engines. First of all, the timing of the gas-air mixture combustion was determined. It should be noted that the method of indicator charts imposing with different fixed advance angles of the gas-air mixture injection was chosen to determine the start of combustion [12, 13, 15].

According to the tasks set, the experimental studies were carried out in several stages [10, 16, 17].

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1. Determination of the GE parameters at different fixed advance angles. In the course of experimental studies [18, 20], data were obtained for various fixed advance angles when the engine 8GCh12/12 was running in the gas operating mode.

2. Determination of GE parameters at fixed advance angles and different gas injection options. To assess the effect of fuel injection, the advance angles were set before reaching the top dead center (TDC), at which a series of operation data was obtained at the rated power mode. In addition, the full load curves of GE were calculated to assess the influence of power control methods [19, 21]. During the processing of the experiment data, integral characteristics, working cycle parameters and gas engines heat generation dynamics were obtained.

Discussion of the results. The installation scheme provides the possibility of separate regulation of air G_a and gas G_g, flow rates, which makes it possible to estimate the effect of the excess air coefficient on the engine characteristics and to choose rational gas-air mixture compositions in the modes of the full load curve [22, 24].

With an open engine throttle U_{et}, almost linear increase in air flow with an increase in the rotational speed is observed (Fig.1). The ratio of gas flow to air flow decreases with decreasing rotational speed. So, when working with a full load curve, lower frequencies correspond to lower power (the mixture is depleted).

When the engine throttle is closed, the overall trend remains, but the slope of the curves decreases, since the effect of throttling on the engine inlet is more noticeable at a high speed of rotation.

The flow rate of the gas consumption reflects the operation of the gas

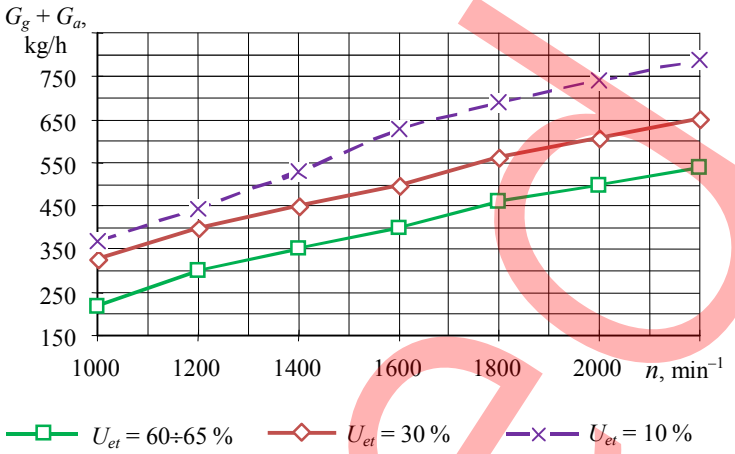


Fig.1. Air and gas flow rate for operation with a full load curve with a different throttle position and a constant fixed advance angle 12° of the crankshaft rotation (CSR)

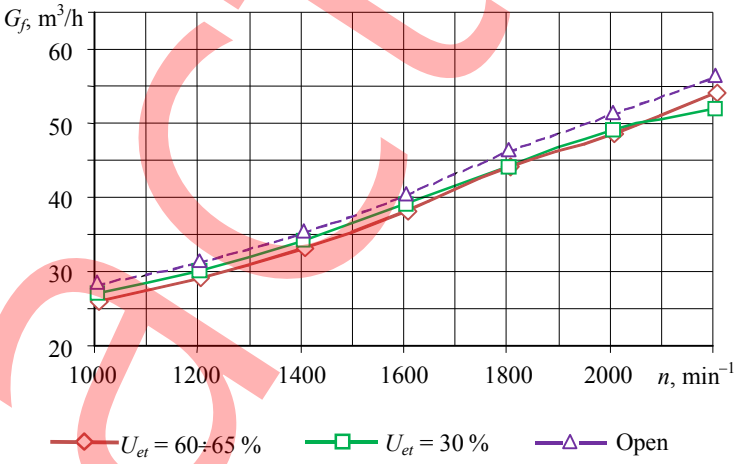


Fig.2. Gas fuel consumption G_f when working with full load curve and different positions of engine throttle U_{et} and constant fixed advance angle φ_{aa} = 12° CSR

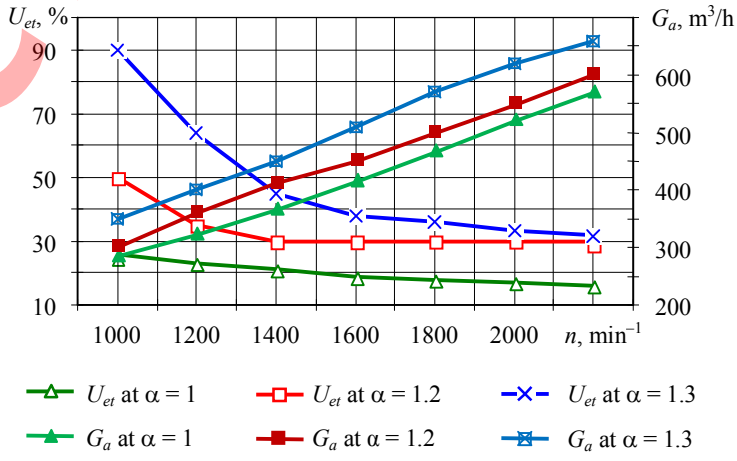


Fig.3. Air flow G_a at different excess air coefficients α of gas-air mixture and different positions of engine throttle U_{et} and constant fixed advance angle φ_{aa} = 12° CSR

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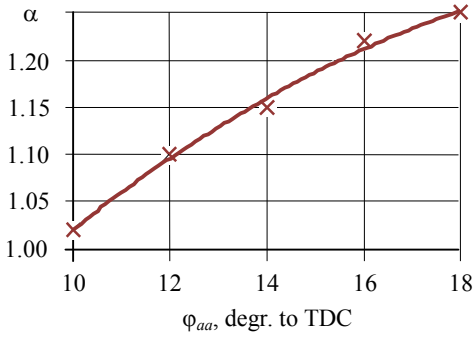


Fig.4. Changes of excess air coefficients α at different advance angles φ_{aa} of gas engine 8GCh12/12 and constant crankshaft $n = 2200$ min^{-1}

measuring device against the rotational speed of the crankshaft (CS) when operating with a full load curve with different positions of the gas-air damper.

At a given speed of rotation, with a constant effective coefficient of performance, the heat flow supplied with the gas charge must be constant [25]. The curves given in (Fig.2) indicate a difference in gas flow rates at the same values of the rotational speed, therefore, the effective coefficient of performance must also differ.

The excess air coefficient is one of the key parameters determining the combustion conditions in engines with positive ignition. In such engines, an increase in the excess air coefficient reduces the rate of flame front spread, contributing to the delaying of the combustion process with a corresponding decline of effective coefficient of performance [24]. The dependence of the excess air coefficient in the gas-air mixture on the speed of rotation when operating with a full load curve is shown in Fig.3.

The obvious result is an increase in the excess air coefficient with a decrease in the rotational speed. At minimum speeds and loads, the excess air coefficient is $\alpha = 1.3 \div 1.35$, that is it approaches the flammability limit of the gas-air mixture. With the help of throttling at the engine inlet it is possible to reduce the excess air coefficient (α), which has a positive effect on the values of efficiency coefficient of performance [17].

It should be noted that under the experimental conditions, there is a relationship between the efficiency coefficient of performance and the excess air coefficient: the increase in excess air coefficient reduces the efficiency coefficient of performance, while the gas flow that affects the excess air in the opposite direction increases.

The decrease in excess air at small advance angles observed in Fig.4 is explained by the fact that with practically constant air flow, the gas flow necessary to preserve the required power increases. When assessing the causes of the effect of various factors on the engine efficiency coefficient of performance this set of factors should be taken into account.

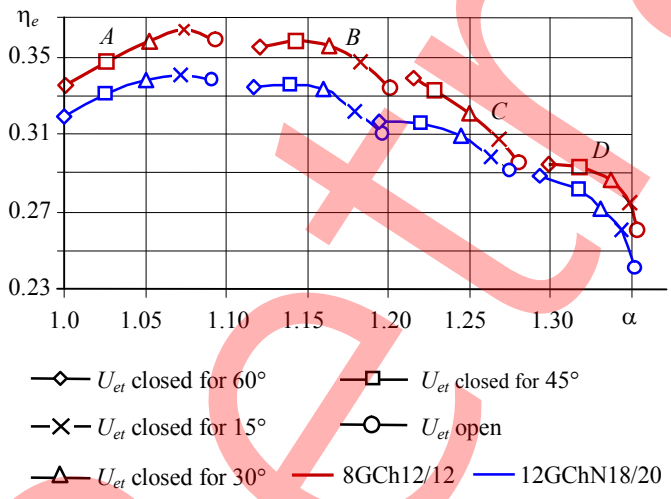


Fig.5. Dependency of efficient coefficient of performance from excess air coefficient with different positions of gas-air damper under conditions of gas engines working with full load curve and constant fixed advance angles

8GCh12/12: $\varphi_{aa} = 12°$ CSR, $A = 2200$ min^{-1}, $B = 1800$ min^{-1}, $C = 1500$ min^{-1}, 57 kW, $D = 1200$ min^{-1};
12GChN18/20: $\varphi_{aa} = 21 \div 22°$ CSR, $A = 1500$ min^{-1}, $B = 1300$ min^{-1}, $C = 1150$ min^{-1}, 57 kW, $D = 1000$ min^{-1} [17];
A, B, C, D – crankshaft rotation speed

The effective coefficient of performance η_e is determined by the process flow and mechanical losses. Other things being equal, the flow of the working process in the piston engine depends mainly on the composition of the gas-air mixture, therefore the values of the efficiency coefficient of performance when working with a full load curve are plotted as a function of the excess air coefficient (Fig.5).

The general tendency to decrease the efficiency coefficient of performance as the transition to a low speed of rotation is determined by the relative increase in mechanical losses, since the dependence of the loss torque on the rotational speed is linear, and the effective moment is quadratic. Therefore, one can judge here the influence of the composition of a mixture on the efficiency coefficient of performance only on points corre-

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sponding to constant values of the rotational speed [10, 26].

Comparison of the curves in Fig.5 allows us to conclude that the maximum effective coefficient of performance at different sections of the speed characteristic corresponds to different positions of the gas-air damper. Thus, for small values of the speed, the maximum efficiency coefficient of performance corresponds to the closed position of the damper, as soon as it approaches the rated power mode, the maximum efficiency coefficient of performance is shifted to the open position of the damper. The obvious reason is a decrease in the rate of flame front spread with a large excess of air. According to this, it can be concluded that there is a need for mixed qualitative and quantitative regulation to ensure the most efficient efficiency coefficient of performance over the entire range of engine rotational frequency [23].

Figures 6 and 7 show the gas fuel mass flow rate, the ratio of the amount of heat supplied; while the abscissa is the actual injection start angles determined by the indicator diagrams [10]. Dependencies show that the marine engine 12GChN18/20 has hour fuel consumption, which is 4-5 times greater than that of the engine 8GCh12/12

When the fixed advance angle is reduced by 8.5 degrees the consumption of gas fuel increases by approximately 40 %; this growth is explained by the drop in the effective coefficient of performance with a decrease in the actual fixed advance angle (Fig.8).

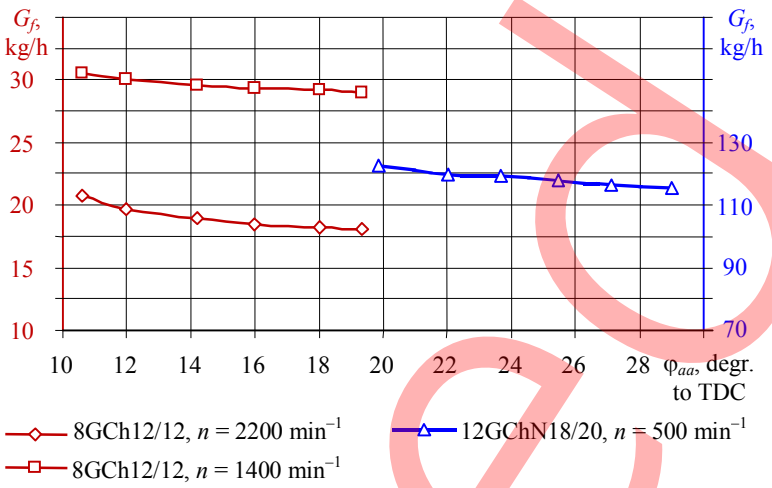


Fig.6. Gas fuel consumption G_f at average and nominal working modes of gas engine with different advance angles φ_{aa}, excess air coefficient α = 1.25 and position of engine throttle U_{et} = 25 %

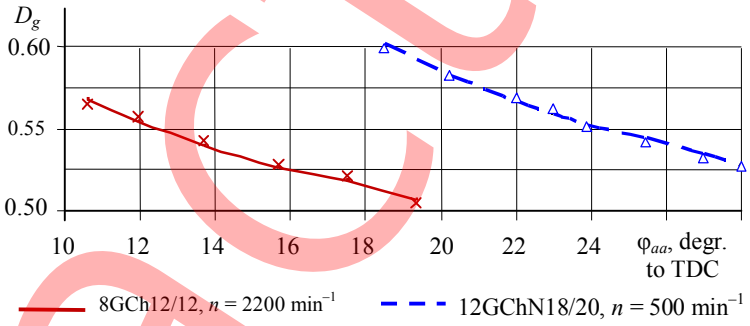


Fig.7. Heat charge D_g, injected with gas fuel, with different advance angles and constant crankshaft rotation frequency values

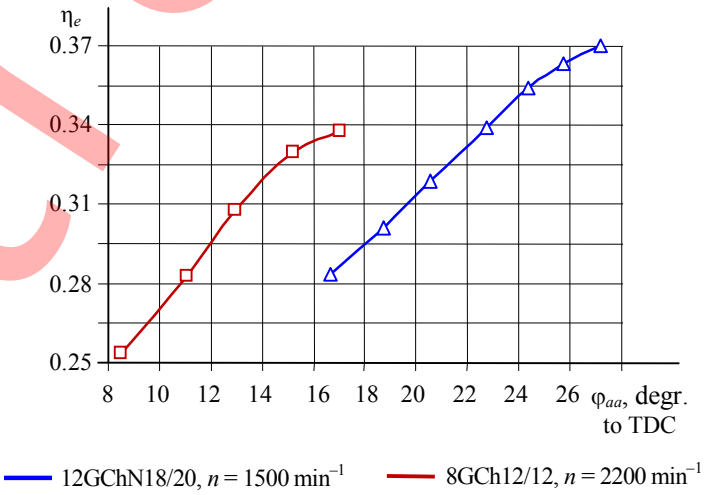


Fig.8. Efficient coefficient of performance depending on advance angle with constant crankshaft rotation

On the basis of the above data, it can be argued that modes of smaller fixed advance angles are preferable, since the average effective pressure is achieved at lower gas flow rates. The growth of the effective coefficient of performance with increasing fixed advance angle for the gas mode is in good agreement with the theoretical assumptions. When comparing the effective coefficient of performance for the gas mode, attention is drawn to the fact that work on the gas working cycle with

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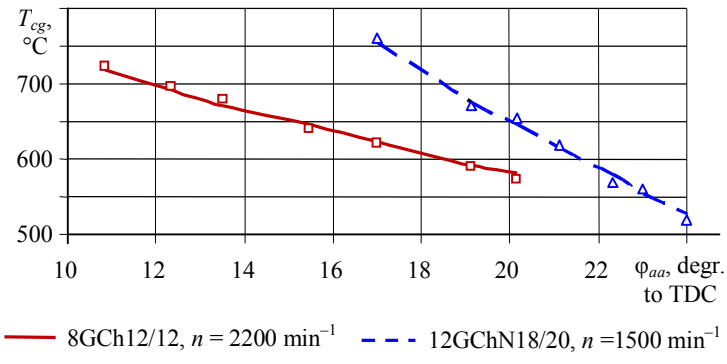


Fig.9. Combustion gas temperature in relation to advance angle with constant crankshaft rotation

fixed advance angle is less than 19 degrees before TDC leads to a decrease in efficiency coefficient of performance. The different nature of the effect of the fixed advance angle on the efficiency coefficient of performance is explained by different combustion mechanisms in the gas engine [13, 15, 16].

The temperature of the exhaust gases of the gas engine at large fixed advance angles decreases. With a decrease in the actual fixed advance angles, the temperature in the gas engine rises more rapidly (Fig.9). This is in complete agreement with the corresponding data on the excess air coefficient.

Conclusions. Analysis of the mining industry development processes and the results of experimental research allow us to draw the following conclusions.

1. Structural reorganization in mineral-raw and fuel-energy industries testifies to the increasing use of gas engines.

2. The transfer of the diesel engine to the gas working process provides the possibility of maintaining the power of the main engine without impairing the economy and significantly increasing the loads on the parts of the crank and rod mechanism.

3. The main factors influencing the course of the working process are the use of mixed regulation of the gas-air mixture, the use of an additional information-measuring channel of the electronic control system of the diesel engine, the fixed advance angle, and the change in the excess air coefficient. The latter factor plays a decisive role in changing the engine characteristics when working on the full load curve.

4. The data obtained in the study of the throttling effect of the gas-air mixture on the effective coefficient of performance, allow one to conclude that mixed regulation is preferable.

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***Authors*: Otari N. Didmanidze,** *Doctor of Engineering Sciences*, *Professor*, *Corresponding Member of the RAS*, *did-manidze@rgau-msha.ru* (*Russian State Agrarian University K.A.Timiryazev*, *Moscow*, *Russia*), **Alexander S.Afanasyev**, *Candidate of Military Sciences*, *Professor*, *a.s.afanasev@mail.ru* (*Saint-Petersburg Mining University*, *Saint-Petersburg*, *Russia*), **Ramil T. Khakimov**, *Candidate of Engineering Sciences*, *Associate Professor*, *haki7@mail.ru* (*Saint-Petersburg State Agrarian University*, *Saint-Petersburg*, *Russia*).
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