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# EXPERIMENTAL RESEARCHES OF THE MACHINE-TRACTOR FLEET WITH THE YAMZ-238 GASDIESEL ENGINE

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## Abstract

A description is given of a device for reducing the toxicity of exhaust gases of diesel engines used in agriculture. The indicators are given, with the help of which it is possible to conduct a technical assessment of the efficiency of diesel exhaust gas cleaning. The installation scheme of the combined device for reducing the toxicity of exhaust gases of diesel engines on the YaMZ-238 engine during testing is described, and the research methodology is also presented. The main results obtained during testing of the developed toxicity reduction device installed on the ULTZ-700 tractor with the YaMZ-238 engine, which most fully reflect the efficiency of purification of harmful emissions, are presented. The dependency graphs characterizing the cleaning efficiency are constructed, and the obtained empirical formulas are also given. The technique of technical and economic evaluation of exhaust gas neutralizers, which is applicable to the developed device for reducing toxicity, is presented. As a result, the main conclusions of the study are formulated.

***Keywords*** : gas diesel, agriculture, compressed natural gas, machine-tractor fleet, exhaust toxicity, profitability.

## Introduction

In recent decades, there has been a tendency to expand the field of application of compressed natural gas as a motor fuel, both in Russia and around the world. In Russia, a machine and tractor fleet with an operating life of more than 10 years in the environmental class, as a rule, corresponds to Euro 0: such agricultural machines have emissions of 5-10 times more than equipment with an ecological class of Euro 3 and higher (Al-Maidi *et al.*, 2019). Thus, the park of tractors and combines of the country's agriculture causes environmental damage: exhaust emissions, uneconomical use of natural resources of oil origin, as well as material resources. Therefore, large-scale work is underway to convert the machine-tractor fleet to alternative fuels, and mainly to gas ones. . Carbon monoxide pollution is a global concern (Hassoon, 2019). Among all currently existing gas fuels, compressed natural gas is preferred, which has several advantages over liquefied gas. The use of CNG as a motor fuel on agricultural machinery, the bulk of which runs on diesel engines, is possible in two ways: conversion (that is, transfer to gas with a spark ignition and changing the compression ratio) and gas diesel (which uses the ignition dose of diesel fuel )

Due to the fact that the conversion of a diesel engine requires global and laborious work on the modernization of the elements of the connecting rod and piston group and cylinder head, engines working on the gas-diesel cycle are more widely used (Al-Maidi *et al.*, 2017; Lomovskikh *et al.*, 2017). Therefore, their research and improvement, aimed at improving environmental friendliness and efficiency, is of global importance. the tillage is the largest consumable energy of the tractor (Almaliki, 2018).

## Materials and Methods

Experimental studies were carried out using private and general methods for testing diesel engines and GOSTs, using modern instruments and equipment. The results were processed using the methods of statistical data processing.

To conduct experimental research on the basis of the Military Training and Scientific Center "Air Force Academy named after Professor N.E. Zhukovsky and Yu.A. Gagarin, Voronezh, used the load test bench Gazmotor-Komplekt, Rybinsk, shown in Figure 1.

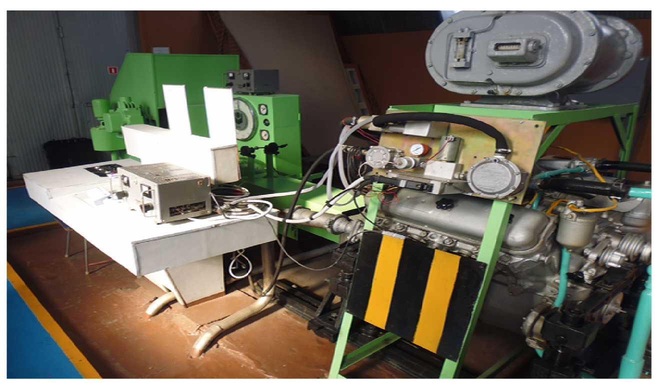

**Fig. 1 :** Load test bench with the YaMZ-238 engine operating on the gas-diesel cycle

The aim of the research is to verify the mathematical model of the heat transfer process in the fuel lines of both gas and liquid fuels flowing in gas-diesel engines used in agriculture, to substantiate the parameters of the fuel-supply system of a gas-diesel engine and to determine the dependences of the system performance. When conducting bench research, engine operation parameters were set under load.

To measure the smoke of an exhaust gas from a diesel engine, an Infracar 1 smoke meter is used that complies with GOST R 41.24-2003 and GOST R 52160-2003. Smoke was measured according to the methodology for determining the content of soot particles in the exhaust gases of diesel engines (Table 1).

**Table 1 :** The results of the measurement of smoke

| Power N, kW | Air temperature, T, K | Atmospheric pressure, P, Pa | $C(C)$, g/м$^3$ |
|---|---|---|---|
| 15 | 293 | 102410 | 0,0066 |
| 30 | 293 | 101745 | 0,0085 |
| 45 | 291 | 101900 | 0,0107 |
| 60 | 292 | 101950 | 0,0131 |
| 75 | 292 | 102100 | 0,0156 |
| 90 | 293 | 102200 | 0,0184 |
| 105 | 293 | 102320 | 0,0216 |
| 120 | 294 | 102350 | 0,0248 |
| 135 | 294 | 102400 | 0,0281 |
| 150 | 295 | 102400 | 0,0310 |

The exhaust pipe was installed in the exhaust pipe of the exhaust gas of the YaMZ-238 engine at the stand. Measurement was carried out at ten power modes of the engine, after it was warmed up to operating temperature. During the study, measurements were taken of ambient temperature and atmospheric pressure.

To measure the concentrations of the main toxic components of the exhaust gas of a diesel and gas-diesel engine, measuring equipment was used that complies with GOST 13320-81. The measurement results are presented in table 2.

**Table 2 :** The results of measuring the concentration of toxic components

| Power N, kW | Exhaust gas concentration | | | | Air temperature, T, K | Atmospheric pressure, P, Pa |
|---|---|---|---|---|---|---|
| | CH, g/м$^3$ | $CO_2$, g/м$^3$ | $NO_x$, g/м$^3$ | $O_2$, % | | |
| 15 | 0,006 | 0,092 | 0,121 | 18,2 | 293 | 102410 |
| 30 | 0,007 | 0,104 | 0,133 | 18,1 | 291 | 101745 |
| 45 | 0,008 | 0,129 | 0,152 | 17,8 | 292 | 101900 |
| 60 | 0,009 | 0,146 | 0,174 | 17,5 | 292 | 101950 |
| 75 | 0,012 | 0,165 | 0,196 | 17,1 | 293 | 102100 |
| 90 | 0,016 | 0,187 | 0,221 | 16,8 | 293 | 102200 |
| 105 | 0,021 | 0,212 | 0,246 | 16,4 | 294 | 102320 |
| 120 | 0,026 | 0,238 | 0,271 | 15,8 | 294 | 102350 |
| 135 | 0,032 | 0,270 | 0,298 | 15,2 | 295 | 102400 |
| 150 | 0,038 | 0,303 | 0,352 | 14,7 | 295 | 102400 |

To measure hourly fuel consumption, a flow meter was used. After mounting the flowmeter in a diesel fuel supply system, it was mounted on a gas fuel supply line. Measurements were carried out at ten power modes of the engine, after it was warmed up to operating temperature. During the study, measurements were taken of the ambient temperature and atmospheric pressure (Table 3).

The difference between the gas inlet to the thermostat and its outlet was determined by a liquid manometer, which was installed, respectively, at the inlet and outlet of the thermostat. The results of measuring the change in fuel pressure, both gas and liquid, performed in ten operating modes (Table 4).

**Table 3 :** the results of the measurement of fuel consumption

| Power N, kW | Air temperature, T, K | Atmospheric pressure, P, Pa | Fuel consumption, GT, kg / h |
|---|---|---|---|
| 15 | 293 | 102410 | 10,2 |
| 30 | 293 | 101745 | 11,6 |
| 45 | 291 | 101900 | 12,5 |
| 60 | 292 | 101950 | 14,9 |
| 75 | 292 | 102100 | 16,7 |
| 90 | 293 | 102200 | 18,4 |
| 105 | 293 | 102320 | 21,6 |
| 120 | 294 | 102350 | 26,5 |
| 135 | 294 | 102400 | 30,2 |
| 150 | 295 | 102400 | 36,8 |

**Table 4 :** The results of measuring the pressure drop in the thermostat

| Power N, kW | Air temperature, T, K | Atmospheric pressure, P, Pa | Pressure drop, Δp, Pa |
|---|---|---|---|
| 15 | 293 | 102410 | $23{,}6\cdot10^3$ |
| 30 | 293 | 101745 | $26{,}5\cdot10^3$ |
| 45 | 291 | 101900 | $28{,}5\cdot10^3$ |
| 60 | 292 | 101950 | $36{,}6\cdot10^3$ |
| 75 | 292 | 102100 | $43{,}4\cdot10^3$ |
| 90 | 293 | 102200 | $54{,}7\cdot10^3$ |
| 105 | 293 | 102320 | $69{,}5\cdot10^3$ |
| 120 | 294 | 102350 | $80{,}6\cdot10^3$ |
| 135 | 294 | 102400 | $94{,}7\cdot10^3$ |
| 150 | 295 | 102400 | $106{,}6\cdot10^3$ |

To measure the temperature of the gas at the inlet and outlet of the temperature regulator, an ITP-2 device was used. The measurement results are shown in table 5. The device works with a thermoelectric converter (thermocouple) according to GOST R.

**Table 5 :** Temperature Measurement Results

| Power N, kW | Air temperature, T, K | Atmospheric pressure, P, Pa | Temperature, TOG, ° C |
|---|---|---|---|
| 15 | 293 | 102410 | 250,2 |
| 30 | 293 | 101745 | 308,6 |
| 45 | 291 | 101900 | 375,1 |
| 60 | 292 | 101950 | 421,7 |
| 75 | 292 | 102100 | 485,3 |
| 90 | 293 | 102200 | 532,3 |
| 105 | 293 | 102320 | 583,9 |
| 120 | 294 | 102350 | 632,6 |
| 135 | 294 | 102400 | 663,1 |
| 150 | 295 | 102400 | 698,6 |

During operational tests at the enterprises of the Tambov region: CJSC Agro firma Svoboda, LLC Agro Mash Tambov daily and periodically inspected the technical condition of the temperature regulator and gas fuel supply system. Daily:

- checked the integrity of the structural elements;
- reliability of fasteners;
- tightness of the system.

The values of the measured concentrations of toxic components are reduced to an oxygen concentration of 15% according to GOST R 52408-2005:

$$C_{i(O_2=15\%)} = C_{i(O_2=x\%)} \cdot \frac{20{,}8-15{,}0}{20{,}8-x}$$

where

$x$ - the measured oxygen concentration in the exhaust gas during the operation of the internal combustion engine in a controlled mode,%;

$C_{i(O_2=x\%)}$ - the measured concentration of the harmful substance in the exhaust gas during the operation of the internal combustion engine in a controlled mode, million$^{-1}$;

20,8 - srednestatichesky oxygen content in air,%.

The translation of the concentration of toxic components from parts per million is carried out according to the formula:

$$C_i\left(г/м^3\right) = C_i\,(ppm)\cdot\frac{M_i}{V}\cdot 1000$$

The translation of the concentration of toxic components into a specific indicator is carried out according to the formula:

$$q_i = C_i\left(г/м^3\right)\cdot\frac{G_{ОГ}^{ср}}{\rho\cdot N_{ср}}$$

where $G_{ОГ}^{ср}$ - the average exhaust gas consumption, kg / h;

$\rho$ - density of exhaust gases, kg / m$^3$;

$N_{ср}$ - average engine power, kW.

The pressure at the inlet and outlet of the BUSH, the exhaust gas flow, the exhaust gas temperature, and also the mass of the grid are brought to normal atmospheric conditions:

$$X_i^{пр} = F\cdot X_i$$

Where

$F$ - coefficient taking into account atmospheric conditions, according to formula 3.1;

$X_i$ - the measured parameter at the input and output of the BUST during the i-th test.

Finding the mean values and errors is carried out according to the generally accepted method (Al-Maidi *et al.*, 2017). The average value is calculated by the formula:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

where

$x_i$ - the measured parameter in the i-th test;

n - number of tests.

The variance estimate is determined by the formula:

$$\sigma^2 = s_n^2 = \frac{\sum(x_i - \bar{x})^2}{(n-1)}$$

The standard error is determined by the formula:

$$s_x = \frac{s_n}{\sqrt{n}}$$

The confidence interval module is determined by the formula:

$$\Delta x = s_x \cdot t$$

Where

t - the student coefficient.

The true value of the measured parameter is written in the form:

$$X = \bar{x} \pm \Delta x$$

Systematic errors are taken into account by determining and indicating the marginal errors of the instruments.

Relative errors of measuring instruments used in the study:

- ОГ p – 1,5%;
- $G_T$ - 0,3%;
- $T_{ОГ}$ - 0,5%;
- when measuring smoke, soot concentration C - 0.5%;
- when measuring (O2), (NOx), (CO) and (CH) - 0.5%.
- $m_c$ - 0.5%.

To process the experimental data, software products MatCAD, Microsoft Excel were used.

## Results and Discussion

In the Tambov State Technical University (TSTU) at the Department of Mechanics and Engineering Graphics, a fuel supply system was developed for engines operating on a gas-diesel cycle (Al-Maidi *et al.*, 2018).

The study of the dependences of the change in the fuel performance of the YaMZ-238 gas diesel engine with the experimental fuel supply system when changing its load conditions allows us to assess the impact on diesel performance (traction, fuel efficiency, etc.)

(Al-Maidi *et al.*, 2018; Knyazev *et al.*, 1996; Chernetsov and Kapustin, 2010).

Figures 2, 3 and 4 show the dependences of fuel consumption, exhaust gas pressure and exhaust gas temperature on the internal combustion engine power used (Chernetsov and Kapustin, 2010; Chernetsov *et al.*, 2012).

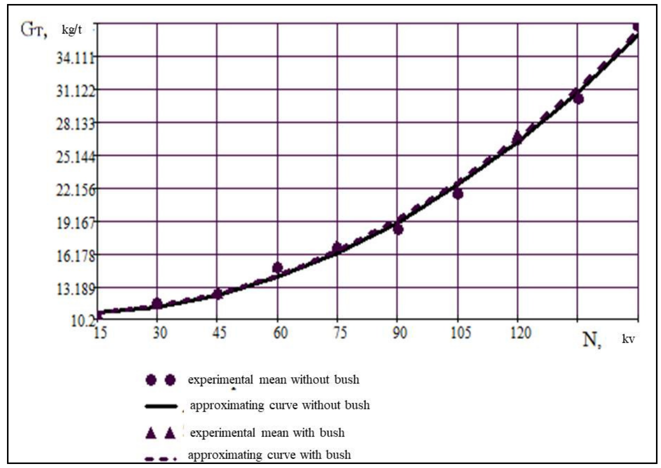


**Fig. 2 :** Dependence of fuel consumption on the used engine power

As a result of data processing, regression equations were obtained:

- No BUSH $G_T(N) = 10{,}952 - 0{,}027 \cdot x + 1{,}291 \cdot 10^{-3} \cdot x^2$
- with BUSH $G_T^{КУСТ}(N) = 10{,}845 - 0{,}021 \cdot x + 1{,}271 \cdot 10^{-3} \cdot x^2$

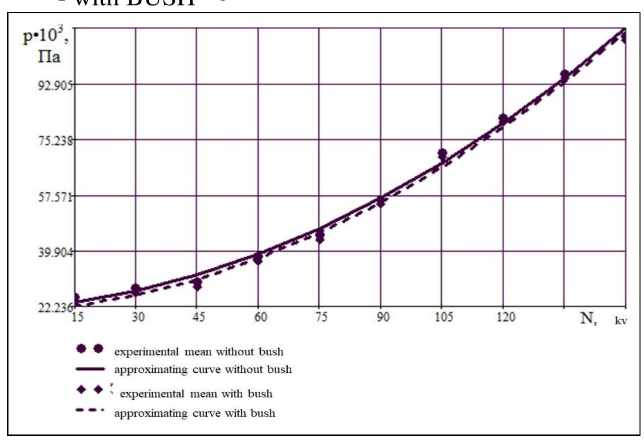


**Fig. 3 :** Dependence of the exhaust gas pressure on the internal combustion engine power used

The regression equations for the dependence of the exhaust gas pressure on the internal combustion engine power used are:

- No BUSH $p_{ОГ}(N) = 21720 + 79{,}747 \cdot x + 3{,}418 \cdot x^2$
- with BUSH $p_{ОГ}^{КУСТ}(N) = 20290 + 78{,}293 \cdot x + 3{,}431 \cdot x^2$

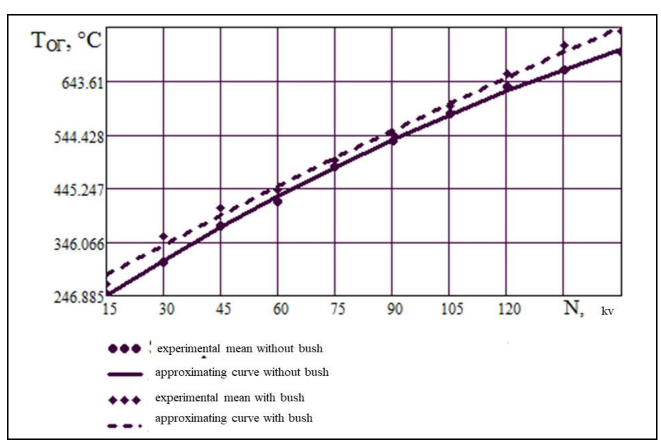


**Fig. 4 :** Dependence of the exhaust gas temperature on the internal combustion engine power used

The regression equations have the form:

- No BUSH $T_{ОГ}(N)=178{,}975+4{,}643\cdot x-7{,}722\cdot 10^{-3}\cdot x^2$

- with BUSH $T_{ОГ}^{КУСТ}(N)=225{,}883+3{,}91\cdot x-3{,}094\cdot 10^{-3}\cdot x^2$

At low loads, the power does not decrease to a level that corresponds to the temperature of the current fuel consumption, but is periodically set to a value sufficient to accumulate thermal energy in a thermo-accumulator (Al-Maidi *et al.*, 2019; Chernetsov and Kapustin 2010; Chernetsov *et al.*, 2012).

Figures 5-8 show the obtained dependences of toxic components on the power of the internal combustion engine when working on the gas-diesel cycle.

After processing the experimental data, the regression equations are obtained:

- No BUSH $C_{CO}(N)=0{,}079+7{,}986\cdot 10^{-4}\cdot x+4{,}529\cdot 10^{-6}\cdot x^2$

- with BUSH $C_{CO}^{КУСТ}(N)=0{,}083+1{,}209\cdot 10^{-4}\cdot x+1{,}246\cdot 10^{-6}\cdot x^2$

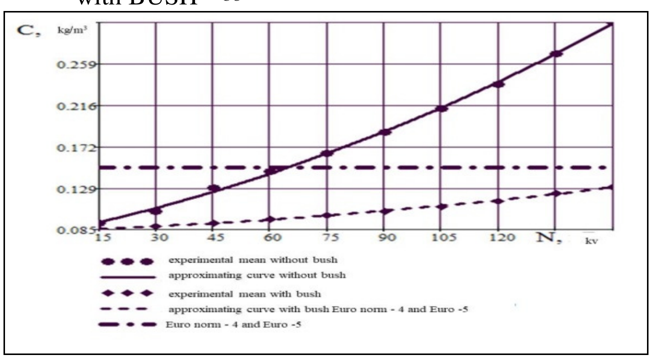


**Fig. 5 :** Dependence of the concentration of CO in the exhaust gas on the used engine power

An analysis of the change in the concentration of carbon monoxide (CO) (Figure 5) shows that with increasing power, the concentration of CO increases from 0.092 g/m$^3$ to 0.303 g/m$^3$ due to incomplete combustion of the fuel and a decrease in the duration of the process. The concentration of carbon oxides at the KUST outlet is lower by 15-57% than at the inlet, especially at high engine loads and at high exhaust gas temperatures, which contributes to better combustion of carbon oxides.

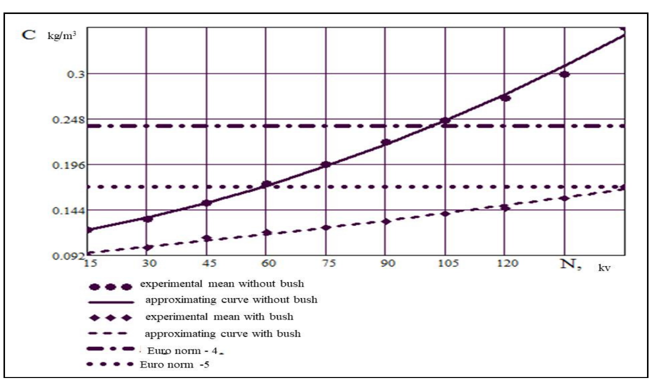


**Fig. 6 :** Dependence of the concentration of $NO_x$ in the exhaust gas on the used engine power. The regression equations have the form:

- No BUSH $C_{NO_x}(N)=0{,}11+6{,}75\cdot 10^{-4}\cdot x+5{,}875\cdot 10^{-6}\cdot x^2$

- with BUSH $C_{NO_x}^{КУСТ}(N)=0{,}088+4{,}307\cdot 10^{-4}\cdot x+6{,}566\cdot 10^{-7}\cdot x^2$

An analysis of the change in the concentration of nitrogen oxides (Figure 6) shows that with an increase in the load on the internal combustion engine, their concentration increases almost linearly and has the greatest value at maximum load, and at high load conditions, the concentration of NOx increases more sharply. This is due to the fact that with an increase in the power of the internal combustion engine and a decrease in the coefficient of excess air, fuel underburning occurs, which contributes to the formation of nitrogen oxides (Zvonov *et al.*, 2001; Zvonov, 1998). From figure 6 it follows that the BUSH of the exhaust gas works more efficiently with loads of more than 40%.

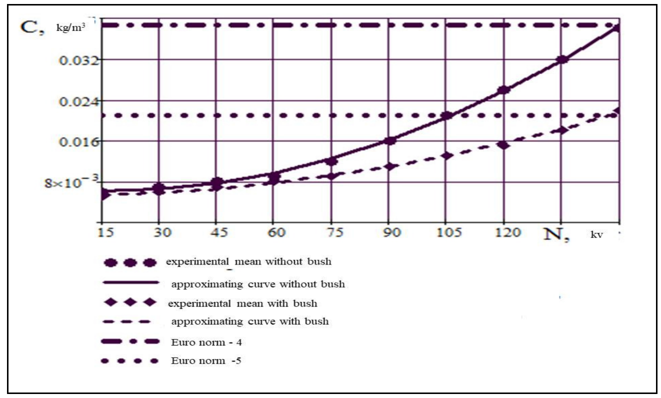


**Fig. 7 :** Dependence of the concentration of hydrocarbons in the exhaust gas on the used engine power

The regression equations have the form:

- without BUSH $C_{CH}(N)=6{,}567\cdot 10^{-3}-5{,}485\cdot 10^{-5}\cdot x+1{,}785\cdot 10^{-6}\cdot x^2$

- with BUSH $C_{CH}^{КУСТ}(N)=5{,}35\cdot 10^{-3}-6{,}212\cdot 10^{-6}\cdot x+7{,}576\cdot 10^{-7}\cdot x^2$

Figure 7 shows that the concentration of hydrocarbons in the exhaust gas with increasing engine load increases from 0.006 g/m$^3$ to 0.038 g/m$^3$, that is, CH emissions at maximum power are six times greater than at minimum load.

This nature of the dependence is explained by an increase in fuel consumption, and, accordingly, an increase in the amount of hydrocarbons released during the combustion of fuel in the combustion chamber (Al-Maidi *et al.*, 2018; Jang and Lee, 2005).

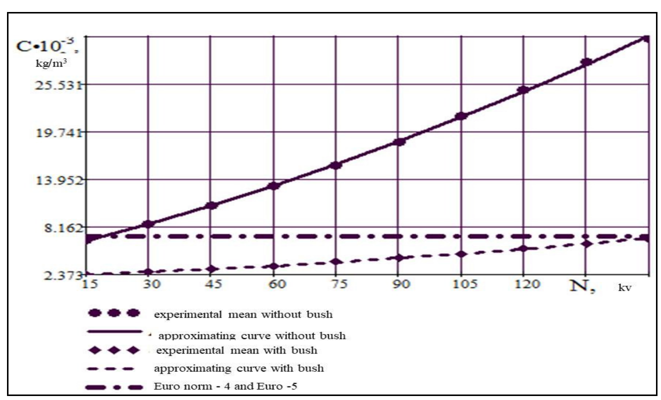


**Fig. 8** : Dependence of the soot concentration in the exhaust gas on the power of the internal combustion engine

The equations of soot concentration from the ICE load have the form:

- without BUSH $C_C(N)=4{,}587\cdot 10^{3}+1{,}196\cdot 10^{4}\cdot x+3{,}906\cdot 10^{7}\cdot x^2$

- with BUSH $C_C^{КУСТ}(N)=2{,}1\cdot 10^{3}+1{,}677\cdot 10^{5}\cdot x+9{,}428\cdot 10^{8}\cdot x^2$

An analysis of the dependence (Figure 8) shows that as the load on the internal combustion engine increases, the soot concentration in the exhaust gas increases almost linearly. This is due to the incomplete burning of fuel in the combustion chamber. Soot concentration increases from 0.007 to 0.031 g/m$^3$ (4.5 times) without BUSH and from 0.002 to 0.007 (3.5 times) with BUSH. At the output of the BUSH, depending on the increase in load, the soot concentration changes in a smaller range, since in the high temperature zone the soot burns better.

Table 6 presents a comparison of the content of toxic substances in the exhaust gas of the YaMZ-238 engine obtained during research with the standards (On requirements for emissions of harmful, 2005).

**Table 6 :** Comparison of the content of toxic components in the exhaust gas of diesel engine with standard

| **Toxic component** | **Regulations** | | | **ICE YaMZ-238** | |
|---|---|---|---|---|---|
| | **Euro III** | **Euro IV** | **Euro V** | **Without Bush** | **With Bush** |
| CO, g / kW · h | 2,10 | 1,50 | 1,50 | 3,71 | 1,48 |
| CH, g / kW · h | 0,66 | 0,46 | 0,26 | 0,46 | 0,25 |
| $NO_x$, g / kW · h | 5,00 | 3,50 | 2,00 | 4,31 | 1,94 |
| C, g / kW · h | 0,127 | 0,08 | 0,08 | 0,38 | 0,076 |

Analyzing table 6, we can say that the use of an exhaust gas neutralizer allows fulfilling the Euro-V standards for all toxic components (On amendments to clause 13 of the technical regulation, 2012). The average degree of purification of exhaust gases from harmful substances is: for CO - 60%, for CH - 45%, for NOx - 55% and for soot - 80%.

During the operational tests, the high performance and reliability of the fuel supply system design in operating conditions was shown. During the test cycle, which amounted to 700 hours, the efficiency was high for more than half of the operating time, which is confirmed by the relevant test certificates.

Figure **9** shows the change in specific indicators of the performance of the BUST in operating conditions, depending on the operating time.

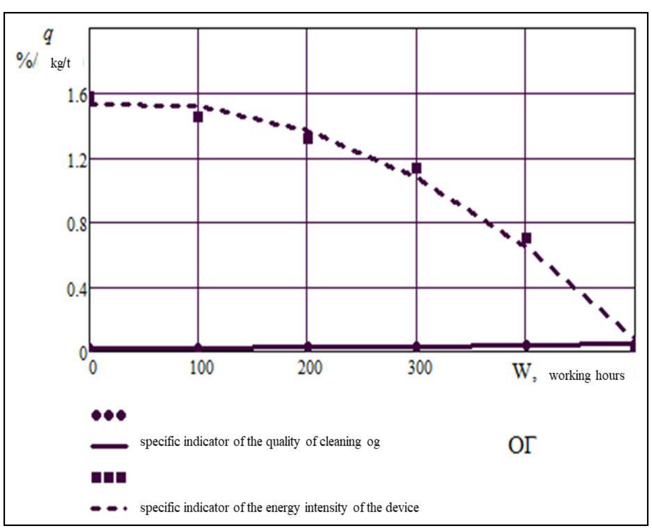


**Fig. 9 :** Dependence of specific indicators of the performance of the KUST on the operating time of the internal combustion engine

The regression equation for a specific indicator of the quality of exhaust gas purification has the form:

$$q_{\Delta G}(W) = 1{,}531 + 5{,}677 \cdot 10^{-4} \cdot x - 6{,}955 \cdot 10^{-6} \cdot x^2$$

The regression equation for the specific energy intensity indicator has the form:

$$q_{\Delta p}(W) = 0{,}023 - 2{,}186 \cdot 10^{-5} \cdot x + 1{,}5 \cdot 10^{-7} \cdot x^2$$

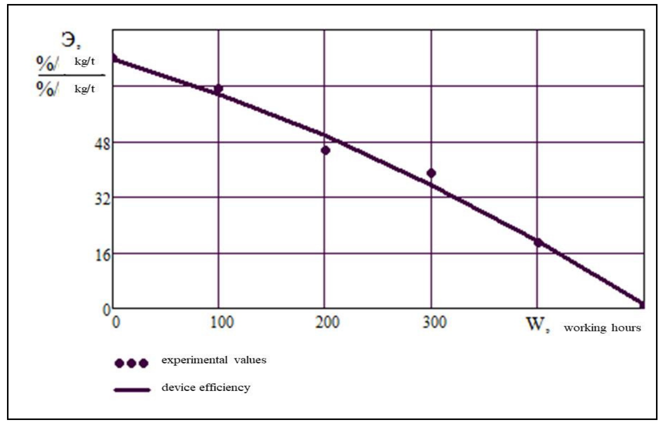


**Fig. 10 :** The dependence of the performance of the KUST on the operating time of the internal combustion engine

The equation of the regression of the effectiveness of the KUSTA has the form:

$$Э_{КУСТ}(W) = 71{,}713 - 0{,}09 \cdot x - 1{,}025 \cdot 10^{-4} \cdot x^2$$

Thus, experimental studies of changes in the concentrations of toxic components have shown that the developed fuel supply system for gas-diesel engines can reduce the amount of exhaust gases and reduce fuel consumption by 2.5%.

### Feasibility Study of the device

The feasibility study of the fuel supply system of gas diesel engines used on agricultural machines allows us to establish the economic effect of the adopted structural and technological solutions, as well as to conclude the feasibility of using the fuel supply system.

The calculation was carried out in the following sequence: the costs of acquiring and installing a compressed natural gas fuel supply system were determined; determined the amount of savings under the item of expenses "Fuel"; the annual economic effect of using a gas-diesel fuel supply system for a specific fleet of agricultural vehicles was determined; set payback period.

The introduction of a gas diesel system into operation leads to the costs of its production and further maintenance, which are determined by the formula:

$$З_{НОГ} = З_П + З_Э, \quad ...(1)$$

where

$З_П$ - annual production costs, rubles;

$З_Э$ - annual operating costs, rubles.

$$З_П = З_П^{уд} \cdot D_p \cdot n, \quad ...(2)$$

$$З_П = 2200 \cdot 12 = 26400$$

The annual cost of operating the fuel supply system is determined by the formula [7, 37, 55, 56]:

$$З_Э = З_Э^{уд} \cdot \frac{G_{ОГ}^{н}}{\rho} \cdot \Delta p \cdot T_н \cdot n, \quad ...(3)$$

where $З_Э^{уд}$ - the specific annual cost of operating one exhaust gas purification device, rub / kWh. When calculating the unit costs are taken according to [7, 37], taking into account the consumer price index as of 01.01.2019, it means $З_Э^{уд} = 133{,}5$ rub/(kW · h);

$\rho_{ОГ}$ - density of exhaust gases, kg/m³. In kg/m³ calculations (table E1);

$\Delta p$ - pressure loss in the exhaust gas purification device, kPa;

$T_н$ - daily operating time of a unit of equipment;

For the experimental system according to the formula (3):

$$З_Э = 133{,}5 \cdot \frac{812{,}4}{0{,}7 \cdot 3600} \cdot 1{,}5 \cdot 10 \cdot 12 = 7747 \text{ rub.}$$

$$З = 26400 + 7747 = 34147 \text{ rub.}$$

Thus, the installation of a fuel supply system for a gas diesel will require additional costs. This is due to the acquisition of system elements, as well as their installation, in addition to the additional costs of maintaining the system.

The gas-diesel fuel supply system allows to reduce hourly fuel consumption by 2%, respectively, and fuel costs will be reduced by the same amount.

Fuel consumption by agricultural machinery for a certain period can be determined by the formula:

$$G_W = G_T \cdot W \cdot n, \quad ...(4)$$

Fuel costs will be determined by the formula:

$$З_T = G_W \cdot Ц_T, \quad ...(5)$$

where $Ц_T$ - the price of diesel fuel, rubles / kg. In the calculation we accept

$Ц_Т = 32{,}5$ rubles / kg, since 1 liter of diesel fuel costs 46 rubles, and gas - 15 rubles / kg.

If we substitute (4) in expressions (5), then the costs under the item "Fuel" will be:

$$З_Т = 34{,}7 \cdot 500 \cdot 12 \cdot 15 + 4{,}2 \cdot 500 \cdot 12 \cdot 32{,}5 = 3942000 \text{ rub.}$$

For a gas diesel fuel costs will be:

$$З_Т = 34 \cdot 500 \cdot 12 \cdot 15 + 4{,}2 \cdot 500 \cdot 12 \cdot 32{,}5 = 3879000 \text{ rub.}$$

The change in costs will be:

$$\Delta З_Т = 3942000 - 3879000 = 63000 \text{ rub.}$$

The annual economic effect for diesel engines equipped with block converters used on automotive vehicles will be determined by the formula:

$$Э_г = \Delta З_T - \Delta З, \quad ...(6)$$

Then the annual economic effect of the installation and operation of the gas-diesel installation will be equal to:

$$Э_Г = 63000 - 34147 = 28853 \text{ rub.}$$

The payback period for measures to modernize the fuel supply system will be calculated by the formula:

$$T_{ок} = \frac{\Delta З_П}{\Delta З_Т}$$

where $\Delta З_П$ - the change in the cost of production of the exhaust gas catalyst with optimal geometric parameters, rub.

$$Т_{ок} = \frac{34147}{63000} = 0{,}54 \text{ year.}$$

Thus, we can conclude that the use of a gas-diesel fuel-supply system with optimal parameters, compared with the industrial one, allows reducing diesel fuel consumption by an average of 2%, which leads to savings under the item "Fuel".

## Conclusions

- Experimental tests of the fuel supply system confirmed the results of theoretical studies for gas-diesel engines mounted on agricultural machinery. The problem of preserving the power characteristics of a gas-diesel engine at the level of the diesel prototype YaMZ-238: Me = 880N · m at 1300 m$^{-1}$.
  The calculated maximum pressures and cycle temperature in a gas-diesel engine do not exceed their values in a diesel engine and are $P_{max}$ = 10.7 MPa, $T_{max}$ = 1864 K.
- Provided indicators of toxicity of exhaust gases that meet Euro-2 standards without a catalytic converter, and with its use, a toxicity characteristic that meets Euro-6 standards is achieved.
- The reduction in fuel costs during the operation of automotive vehicles equipped with a gas fuel supply system amounted to 63,000 rubles, while the annual economic effect amounted to 28,853 rubles. Subject to full additional costs. The payback period of the measures taken to equip and modernize the gas-diesel fuel supply system with optimized parameters was 0.54 years.
- The annual economic effect of installing a fuel supply system per unit of equipment shows that the use of the system on gas diesel engines is economically feasible.

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