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Integral Assessment of Influence Mechanism of Heavy Particle Generator on Hydrocarbon Composition of Vehicles Motor Fuel

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ABSTRACT

This article presents the results of engine and laboratory tests with fuel before and after treatment with a heavy particle generator. The results of the research have shown that in the course of conducted research the impact of heavy particle generator on fuel during engine tests leads to an increase in its detonation resistance and a reduction in fuel consumption (up to 15%), as well as significantly improves the environmental performance of the engine. The reduction in concentration of carbon monoxide (CO) from 0.09% to 0.03%, carbon dioxide - by 6% and nitrogen oxides - by 7%. The results of research of hydrocarbon composition of fuels by GC-MS method have shown that the impact of heavy particles generator have a favorable effect on the octane number of gasoline, as well as low-temperature properties of diesel fuel. The change of engine operation parameters after the impact of heavy particles generator is established. The change can occur as a result of complex influence on fuel and engine systems, and as a result of influence on a single factor, which is the root cause of the subsequent change of parameters.

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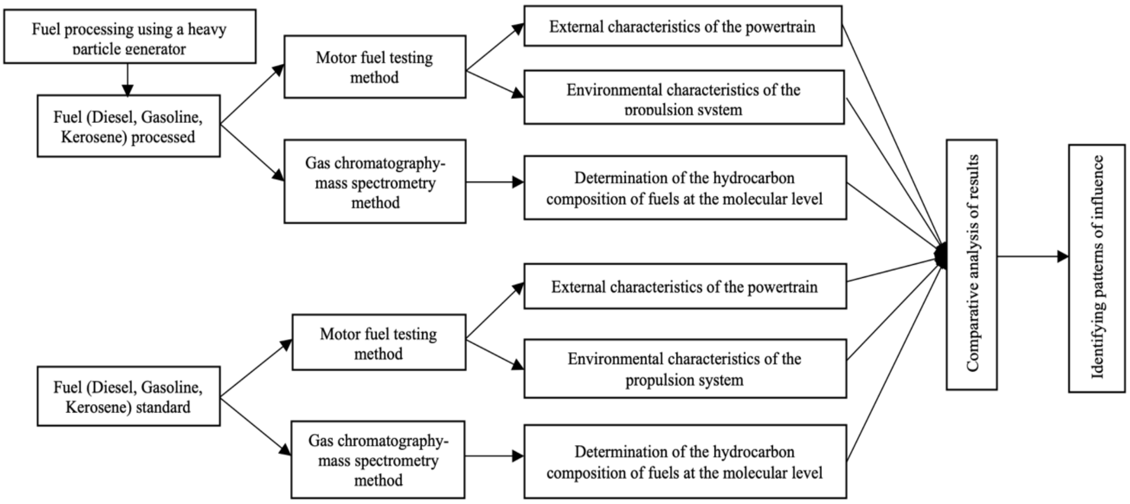
Graphical Abstract



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NOMENCLATURE

FREQ	Engine crankshaft speed sensor reading, rpm	O_2	O_2 content in exhaust gases, % vol.
JAIR	Mass air flow rate, kg/hour	NO_x	NO_x content in exhaust gases, % vol
JGBC	Amount of fuel injected into the engine cylinder for 1 cycle, mg/stroke	N	Integral criterion for assessing the level of fuel quality
JQT	Fuel consumption, kg/hour	α_Y	Complex quality indicator characterising fuel performance properties
THR	Throttle opening percentage, %	α_z	Single quality indicators obtained during testing of motor fuels
INJ	Injection duration, msec.	A_x	Weighting coefficient of i-th group quality indicator
TWAT	Coolant temperature, °C	B_y	Weighting coefficient of the i-th complex quality indicator in testing (motor, laboratory)
CO	CO content in exhaust gases, % vol.	C_z	Weighting coefficient of the i-th single quality indicator
CO_2	CO_2 content in exhaust gases, % vol.	D	Area of values of fuel quality indicators of this type regulated by the standards
HC	*CH* content in exhaust gases, % vol.	ψ_o	A certain range of values of fuel quality indicators of a given fuel type, regulated by standards
G	*AI-95 petrol according to GOST 32513*	D	summer diesel fuel DT-L-K-5 grade C according to GOST 32511
K	paraffin TS-1 according to GOST 10227	G_p	AI-95 petrol after treatment
D_p	summer diesel fuel DT-L-K-5 grade C after treatment	K_p	TS-1 paraffin after treatment

1. INTRODUCTION

The continuous increase of the country's transport fleet, increasing production level and the volume of mechanized mining work is accompanied by a continuous increase in the consumption of fuel and energy resources (1, 2). The problem of rational use of petroleum products can be solved only based on theoretical and experimental studies of complex processes of physical and chemical transformations of motor fuels, based on the theory of chemotology (3). The quality of motor fuels determines the operational and environmental characteristics of vehicles (4-6). The group chemical composition of motor fuels is the determining factor in the formation of their quality indicators and operational properties (7, 8). To search the individual hydrocarbon composition of light motor fuels (petrol, paraffin, diesel fuel), the method of gas chromatography-mass spectrometry (GC-MS) is quite effective. This method allows identifying up to 95-100 % of individual compounds (9-11).

When using fuel, a group of similar compounds in its composition behaves similarly and affects certain quality parameters (12, 13). For example, a high content of n-paraffins in diesel fuel negatively affects low-temperature properties, and their low content negatively affects the cetane number (cetane index). In petrol, n-paraffins negatively affect the octane number. Iso-paraffins and aromatic hydrocarbons have a positive effect (14-16).

Thus, the rational use of fuel by optimizing its composition while improving the design of vehicles is an urgent task and is of considerable theoretical and practical importance, and improving fuel quality is an important national task (17, 18).

The main objectives of theory and practice in the field of rational use of fuel in vehicles are: development of optimal requirements for fuel quality; introduction of new types of fuel into operation and establishment of conditions for their use; studying the processes of changes in the quality and composition of fuel when changing technologies for its production, including external influences of various natures, as well as establishing patterns connecting the quality of fuel with the efficiency and environmental friendliness of their work; development of accelerated methods for operational testing of fuel in technology; development of methods for monitoring fuel quality under operating conditions (19-21).

According to the results of earlier researches it was established that the impact of the heavy particle generator on motor fuel initiates the emergence of an energy-information field, which harmonizes the processes of fuel combustion with an increase in its efficiency, completeness of combustion and reduction of harmful emissions.

For profound understanding of the mechanism of heavy particle generator influence on motor fuel of vehicles it is necessary to develop special methods and means of assessment of physico-chemical, ecological and economic indicators to determine more precisely the mechanism of heavy particle generator influence on motor fuel of vehicles, on the basis of which it is possible to create fuels with improved operational properties. Fuel quality is assessed by a complex set of properties, which includes both operational properties of the fuel itself and properties determined on the basis of efficient operation of vehicles (22, 23).

In this regard, the present research is devoted to the development of standard and practical recommendations to improve the efficiency of vehicle operation by improving the operational performance of fuels, when applying the energy-information field, considering the obtained results of fundamental studies of the mechanism of impact.

2. MATERIALS AND METHODS

2. 1. Materials Three types of motor fuels were used as materials for the study:

G – AI-95 petrol according to GOST 32513;

D – summer diesel fuel DT-L-K-5 grade C according to GOST 32511;

K – paraffin TS-1 according to GOST 10227.

These types of motor fuels have been subjected to the energy-information field induced by a heavy particle generator:

G_p – AI-95 petrol after treatment;

D_p – summer diesel fuel DT-L-K-5 grade C after treatment;

K_p – TS-1 paraffin after treatment.

2. 2. Exposure to a Heavy Particle Generator The heavy particle generator is a centrifugal-vortex generator and forms a vortex flow of charged particles in a vertical direction during operation. The flow affects any devices in its field of action.

In this research, diesel fuel D was treated under the influence of a heavy particle generator. The treatment was carried out for 2 days of 6 hours each. Two third generation heavy particle generators were used for the treatment. One was installed under the diesel engine and the other under the fuel tank and generator. On the first day the D particles were saturated, on the second day the flow rate was measured using the diesel fuel poured into the tank.

2. 3. Motor Tests To improve the reliability of vehicle operation and to provide it with quality motor fuel, it is necessary to use a universal method of fuel quality control. This method is determined by its physical and chemical properties and based on the integral criterion for assessing the level of fuel quality, based on the application of weighted average indicator:

$$\mathrm{N} = A_x B_y C_z \iiint_D \alpha_{\mathrm{Y}} dzdydz = \psi_0 \iiint_D \alpha_z dxdydz\alpha \tag{1}$$

This dependence makes it possible to form an integrated approach to assessing the quality of fuel after exposure to HS, based on the use of a weighted average indicator, combining the physical properties of fuels according to the degree of influence on the operational properties of the vehicle, taking into account these indicators: αx, - group quality indicator characterizing the operational properties of the fuel α_y - a comprehensive quality indicator characterizing the performance properties of the fuel; α_z - single quality indicators obtained when testing fuels; A_x is the weight coefficient of the i-th group quality indicator; B_y - weight coefficient of the i-th complex quality indicator; C_z is the weight coefficient of the i-th individual quality indicator; ψo is the weight coefficient of certain quality indicators;

Integral evaluation of fuels performance properties was carried out on fuels treated with heavy particle generator during engine tests. Motor tests for diesel fuel D were carried out on a 240 kW diesel generator with a Toyota diesel engine. On this diesel engine, the flow rate, fuel consumption and fuel injection duration were recorded. These parameters were taken from the electronic control unit installed on the engine itself. Environmental parameters were recorded using a smoke meter, which recorded CO, CH, NO_x content in the exhaust gases. Experimental studies of gasoline were carried out in a specialized laboratory on a test bench equipped with a VAZ-2112 engine with a 5-speed manual transmission. Control of engine operating modes is carried out using a developed automated system for monitoring data on the technical condition of the internal combustion engine of a vehicle while simultaneously controlling the load device.

2. 4. GC-MS Method Determination of group and individual hydrocarbon composition of all three studied motor fuels before and after treatment with heavy particle generator was carried out on GCMS-QP2010 SE Shimadzu gas chromatography-mass spectrometer. Column parameters: HP-5MS - non-polar, length - 30 m, thickness - 0.25 mm, coating thickness - 0.25 mkm. The studied samples in the amount of 10 ml were dissolved in 1 ml CCl_4 to reduce the intensity of peaks to avoid premature failure of the detector. A micro syringe was used to take 1 ml of the sample dissolved in CCl_4 and injected into the column. Imaging parameters: evaporator temperature 280 °C, interface temperature 280 °C, column temperature 50 °C - 2 min; carrier gas - He; column gas velocity - 1 ml/min. Heating rate 10 °C/min up to 290 °C, holding isotherm 290 °C - 30 min.

Compounds were identified using the NIST MS 2011 mass spectra library with retention indices calculated for normal paraffins. Total ion current (TIC) and area normalized chromatograms were processed in the standard software package GSMS-solution (Shimadzu).

3. RESULTS AND DISCUSSION

According to the results of engine tests of diesel fuel D, the positive effect of heavy particle generator exposure was obtained with simultaneous increase of vehicle resource. The results obtained in the course of research and experimental operation of the generator consist in reduction of diesel engine fuel consumption within 13-15 %, increase of the inter-service period up to 50 % and reduction of diesel generator fuel consumption by 30 % under the condition of the same load before and during the measurements.

The results of the impact of the heavy particle generator on the fuel and environmental performance of vehicles are presented in Table 1.

Based on the data obtained, graphs showing the impact of the particulate generator on fuel and economic characteristics (Figure 1) and environmental indicators of vehicles (Figure 2) are plotted.

Figure 2 shows that when the fuel is affected by the generator, there is a reduction in hourly fuel consumption, injection duration and fuel consumption per stroke, which has a positive effect on its economic characteristics.

The graphs presented in Figure 3 clearly show that the concentration of harmful substances is reduced when the fuel of the particulate generator is exposed to particulate matter. That has a positive effect on its environmental characteristics.

To explain the changes occurring in engine test results, researches were carried out to investigate the hydrocarbon composition of different types of engine fuels before and after treatment with the heavy particle generator.

Table 2 summarizes the results of GC-MS analysis of all motor fuels under study.

Table 3 presents the relative content of aromatic compounds in petrol before and after treatment with the heavy particle generator.

Table 4 and Figure 3 show the distribution of n-paraffins in paraffin and diesel fuel.

From the results of GC-MS analysis, it can be concluded that heavy particle generator treatment has a more significant effect on the change in the composition of petrol and a less significant effect on the compositions of paraffin and diesel fuel (Table 2).

TABLE 1. Results of the effect of heavy particle generator exposure on the fuel and environmental performance of vehicles in engine tests D

Parameter	***D***	***D_p***	***D***	***D_p***	***D***	***D_p***	***D***	***D_p***	***D***	***D_p***
FREQ об/мин	1040	1040	1800	1840	2240	2200	2480	2520	2880	2800
JAIR кг/час	18,4	14,6	24,7	21,0	31,5	24,9	33,1	27,6	40,9	33,9
JGBC мг/ткт	150	123	115	98	116	95	110	94	113	98
JQT кг/час	1,7	1,4	2,2	1,9	2,8	2,2	2,9	2,5	3,5	2,9
THR %	0	3	2	5	3	5	4	6	5	7
INJ, мсек	3,4	2,85	2,69	2,41	2,81	2,34	2,73	2,41	2,81	2,42
TWAT,°C	90	90	95	91	101	91	99	99	99	95
CO, %	0,09	0,03	0,04	0,11	0	0,11	0	0,08	0	0,02
CO_2, %	13,8	13,1	14,2	13,8	13,4	13,5	13,5	13,7	13,5	13,8
HC, %	87	88	77	87	49	77	38	65	30	44
O_2, %	2,73	1,36	2,59	1,36	2,73	1,36	2,73	1,36	2,73	1,5
NO_x, %	1,13	1,06	1,12	1,06	1,14	1,06	1,13	1,06	1,13	1,07

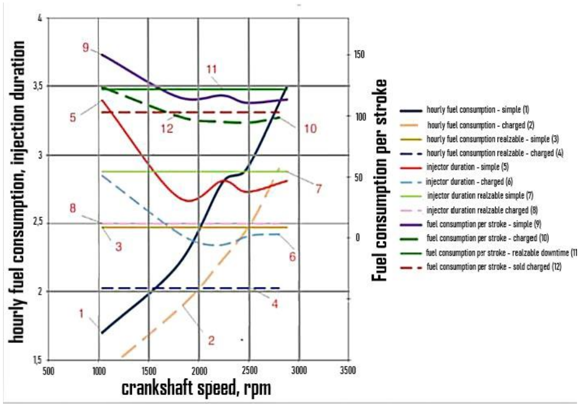

Figure 1. Fuel and economic characteristics of internal combustion engine using heavy particle generator

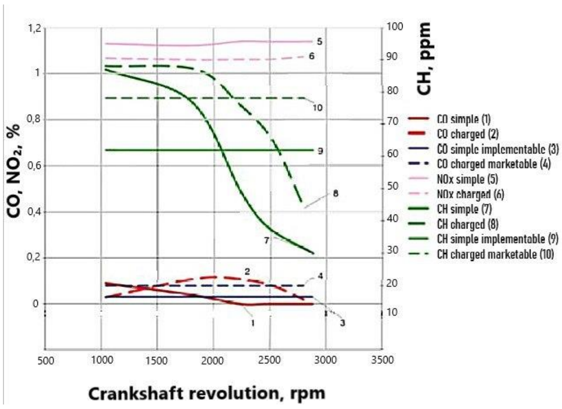

Figure 2. Environmental performance of vehicles when using a heavy particle generator

TABLE 2. Summary results of GC-MS analysis of motor fuels

Fuel	Group composition by GCMS, % wt.				
	n-Paraffins	**iso-paraffins**	**Naphthenes**	**Olefins**	**Arenas**
G	0	8,51	13,95	0	77,54
G_p	0	2,07	0,43	0	97,49
D	35,82	44,41	19,77	0	0
D_p	31,91	47,82	20,71	0	0
К	30,66	34,69	34,74	0	0
К$_p$	31,93	33,97	35,25	0	0

TABLE 3. Relative content of aromatic compounds in petrol

Fuel	Relative content of aromatics, % wt.				
	CH_3-Ar	**C_2H_5-Ar**	**C_3H_7-Ar**	**C_4H_9-Ar**	**C_5H_{11}-Ar**
G	13,22	45,31	34,34	7,13	0,60
G_p	38,35	28,72	31,87	1,06	0

TABLE 4. Distribution of n-paraffins in kerosene and diesel fuel

Name of n-alkanes	Number of carbon atoms	Content of n-paraffins, % MACC			
		D	**Dp**	**К**	**Кр**
Octane	8	0	0	0	1,19
Nonane	9	0	0	4,21	4,53
Decane	10	0	0,72	7,23	7,04
Undecane	11	3,48	2,88	8,38	7,95
Dodecane	12	5,36	4,09	6,62	7,05
Tridecane	13	5,8	5,34	3,27	3,18
Tetradecane	14	4,84	4,51	0,8	0,81
Pentadecane	15	4,31	3,89	0,15	0,18
Hexadecane	16	3,83	2,75	0	0
Heptadecane	17	2,92	2,36	0	0
Octadecane	18	2,29	1,82	0	0
Nonadecane	19	1,32	1,51	0	0
Eicosane	20	0,96	1,18	0	0
Heneicosane	21	0,24	0,42	0	0
Docosane	22	0,18	0,21	0	0
Tricosane	23	0,12	0,15	0	0
Tetracosane	24	0,17	0,08	0	0

In petrol after treatment with the heavy particle generator, naphthenes are practically absent and the content of iso-paraffins is noticeably reduced, but the share of aromatic hydrocarbons has increased significantly (by 20%) (Table 3).

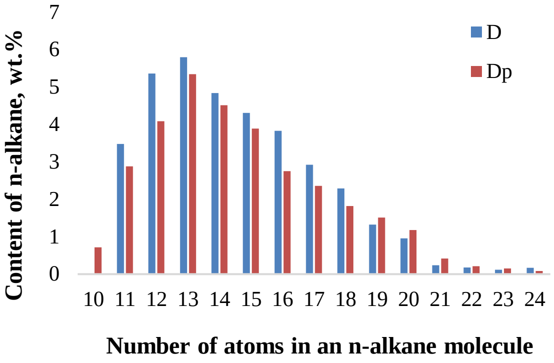

Figure 3 (a). Distribution of n-paraffins in diesel fuel

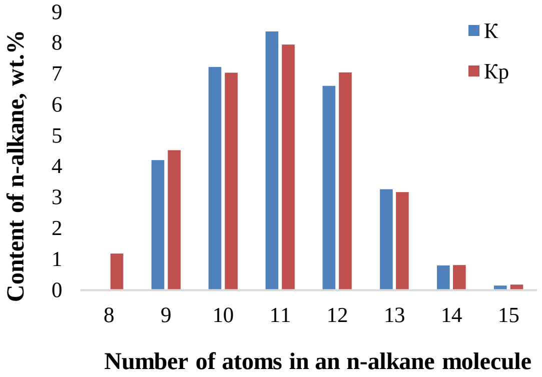

Figure 3 (b). Distribution of n-paraffins in paraffin

At the same time in the composition of the aromatic part of petrol after treatment with the heavy particle generator there were changes in the structure of alkyl substituents - a decrease in the share of alkylaromatic hydrocarbons with the number of carbon atoms from 2 to 5 in favour of an increase in methyl-substituted aromatic hydrocarbons (CH_3-Ar) (Table 3).

Probably, the effect of heavy particle generator on petrol is to initiate reactions of dealkylation of aromatic hydrocarbons, decyclisation of naphthenes to form iso-paraffins and evaporation of light n- and iso-paraffins. The effect of heavy particle generator influence on paraffin composition is to increase the content of low molecular weight (C_8H_{18}-$C_{10}H_{22}$) and decrease the content of high molecular weight n-paraffins ($C_{11}H_{24}$-$C_{15}H_{32}$). In diesel fuel the amount of n-paraffins decreases by 5 % and the amount of iso-paraffins increases by approximately the same amount.

4. CONCLUSION

From the data obtained from the results of engine tests, it can be concluded that under the influence of the heavy particle generator, the detonation resistance of fuel increases and its consumption decreases (up to 15 %), while its environmental characteristic increases significantly, specifically the number of harmful emissions decreases. Thus, the concentration of carbon monoxide CO during the experiment decreased threefold - from 0.09 to 0.03 %, carbon dioxide by 6 %, nitrogen oxide by 7 %. In addition, one of the advantages of using a heavy particle generator is its ability to switch from continuous treatment of the object to episodic treatment with simultaneous build-up of the effect of exposure. Based on the analysis of individual and group hydrocarbon composition of motor fuels, it can be assumed that the impact has a positive effect on the octane number of gasoline, as well as low-temperature properties of diesel fuel. The change of engine operation parameters after the impact of heavy particles generator is established, which can occur both because of complex influence on fuel and engine systems, and as a result of influence on a single factor, which is the root cause of the subsequent change of parameters.

Further research work is currently underway to research the influence of the vortex effect of the heavy particle generator on the fuel and environmental performance of internal combustion engines.

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Persian Abstract

چکیده

در این مقاله نتایج آزمایشات موتور و آزمایشگاه با سوخت قبل و بعد از درمان با مولد ذرات سنگین ارائه شده است. نتایج تحقیق نشان داده است که در جریان تحقیقات انجام شده تاثیر مولد ذرات سنگین بر سوخت در حین آزمایش موتور منجر به افزایش مقاومت آن در برابر انفجار و کاهش مصرف سوخت (تا ۱۵٪) و همچنین به میزان قابل توجهی می شود. عملکرد زیست محیطی موتور را بهبود می بخشد. کاهش غلظت مونوکسید کربن (CO)از ۰.۰۹٪ به ۰.۰۳٪، دی اکسید کربن - ٦٪ و اکسیدهای نیتروژن - ۷٪. نتایج تحقیق ترکیب هیدروکربنی سوخت ها به روش GC-MS نشان داده است که تاثیر مولد ذرات سنگین بر عدد اکتان بنزین و همچنین خواص دمای پایین سوخت دیزل اثر مطلوبی دارد. تغییر پارامترهای عملکرد موتور پس از ضربه مولد ذرات سنگین ایجاد می شود. این تغییر می تواند در نتیجه تأثیر پیچیده بر روی سیستم های سوخت و موتور و در نتیجه تأثیر بر یک عامل واحد رخ دهد که علت اصلی تغییر بعدی پارامترها است.