Analysis of the effect of detergent additives on fuel on the performance of a diesel engine

A Yu Shabanov, Yu V Galyshev, A B Zaitsev and A A Sidorov

Higher School of Power Engineering, Peter the Great Saint-Petersburg Polytechnic University, Polytechnicheskaya St., 29, St.Petersburg, 195251, Russia

E-mail: turbo_motor@mail.ru

Abstract. In work questions of influence of composition of basic diesel fuel on overall performance of the washing additives on the basis of results of motor tests are considered. The received results show need of individual selection of concentration of additive depending on composition of basic fuel. The analysis of results allowed to draw a conclusion on existence of an optimum ratio of concentration of additive and composition of basic fuel at which receiving the maximum effect of input of additive at preservation of the acceptable prime cost of the final product of fuel is possible. This conclusion is supported by the results of comparative stand tests of diesel engine firing fuels that significantly differ in basic physicochemical parameters. The tests have been conducted on laboratory test stand equipped with hydraulic dynamometer coupled with full-sized diesel engine type KAMAZ-740.10. Such arrangement enabled operation at any point within allowed zone of engine load/speed map.
Keywords: The diesel engine, basic diesel fuel, the washing additive, kinematic viscosity, toxicity, smoke of the fulfilled gases.

1. Introduction

State-of-the-art fuels for modern high-powered high-speed diesel engines, particularly those featuring direct fuel injection and turbocharging, must, inter alia, have anti-sludge properties and high cleaning capacity [1-4].This goal may be achieved by improvement in base fuel quality and use of dedicated detergent additives [5-7].

This paper discusses the results of investigation into detergent additive performance as a function of its concentration and base fuel composition.

This investigation was targeted at:

- determination of correlation between fuel composition and engine combustion efficiency, toxic emission and exhaust opacity;
- determination of optimum detergent additive concentration in terms of engine fuel efficiency and environment performance, depending on base fuel type

2. Materials and Methods

A series of experiments were conducted to study correlation between fuel composition and detergent additive concentration, on the one hand, and engine performance, on the other hand.

The tests have been conducted on laboratory test stand equipped with hydraulic dynamometer coupled with full-sized diesel engine type KAMAZ-740.10. Such arrangement enabled operation at any point within allowed zone of engine load/speed map.

Test procedure included preliminary partial engine disassembly, photofixation of initial contamination level, weighing of inlet & outlet valves and injector atomizers with analytical balance so as to register initial level of deposit. Weighting accuracy was within 0,001 g. After reassembly and short-term running-in, a number of engine initial parameters were measured, including power, fuel consumption, exhaust opacity, noxious emission content and exhaust gas temperature. All the measurements were carried out on engine loaded according to 2 different load curves. Where upon the engine ran for 20 hours at specified loads firing fuel under test.

On completion of the test cycle engine parameters at the same load points have been measured once more. Then partial engine disassembly followed by visual examination and weighing of selected parts was repeated, which enabled evaluation of changes in sedimentation level of their critical surfaces.

Three types of winter diesel fuel from different producers have been selected for testing. The results of testing of each base fuel type are presented in table 1.

Table 1. Principal physicochemical properties of selected base fuel types.

№	**Parameter/Characteristic**	**Diesel fuel sample**		
		№1	№2	№3
1	Cetane number, units	57.1	54.5	51.5
2	Fractional composition:			
	is rectified at temperature 250˚C, vol.%	35	28	45
	is rectified at temperature 350˚C, vol.%	95	91	99
	95% vol. is rectified at temperature, ˚C	350	358	298
3	Flash point – Pensky-Martens closed cup method, ˚C	60	55	52
4	Kinematic viscosity, mm^2/s	2.94	2.18	1.45
5	Mass fraction of polycyclic aromatic hydrocarbons, %	1,0	1,6	0,6
6	Cold filter plugging point, ˚C	-31	-41	-41
7	Mass fraction of sulfur, mg/kg	3.1	4.9	2.9
8	Density at 15 ˚C	818	812	804

3. Results

The analysis of the test results witnesses to compliance of all the three types of base fuels have obvious spread in some principal fuel characteristics. Thus, spread in cetane number, a main parameter characterizing fuel combustibility, was as high as 5.6. Furthermore, there is large spread in fractional composition that characterizes fuel volatility. Thus, temperature at which 95% fuel evaporates, varies from 298° to 358°, i.e. its variation practically amounts to 17%. Vaporization temperature largely determines fuel volatility and its scaling tendency. Flash point of selected fuels varies from 52° to 60°C, i.e. by 13%. Most prominent is spread in kinematic viscosity, being practically twofold. All the above parameters affect mixture formation and fuel combustion. This was demonstrated by the results of the first test cycle, which included comparative engine stand tests with each of three selected base fuel types.

The diagrams figure 1 and figure 2 present fuel consumption and exhaust gas opacity curves vs. engine torque at constant engine speed 1500 RPM for all the three tested fuel types.

The difference in fuel consumption on the average was about 2.2%, while in low load area it amounted to 8…9% (figure 1).

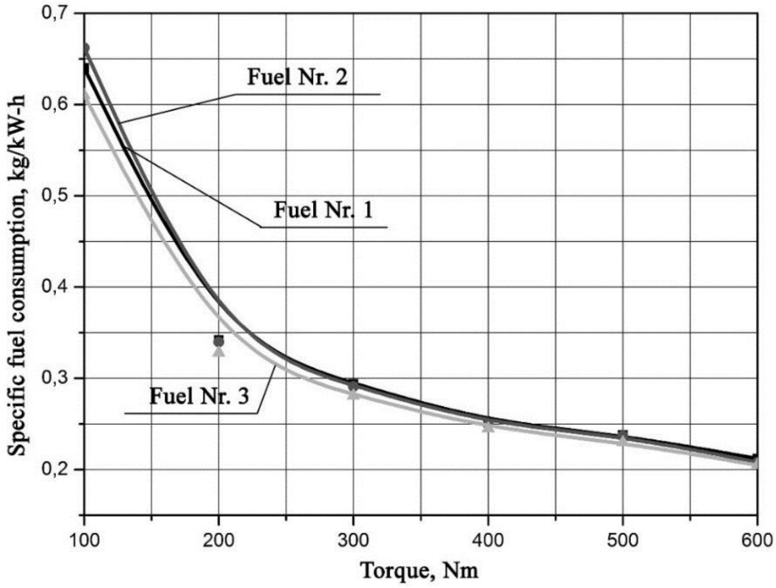

Figure 1. Specific fuel consumption vs. engine load depending on fuel type.

Greater difference may be seen in exhaust gas opacity (up to 20…25% in maximum load zone) and up to 12…15% on the average (figure 2). Supposedly, the main reason for such variation is difference in fuel hydrocarbon-type composition, which entails as big difference in fuel combustibility and volatility.

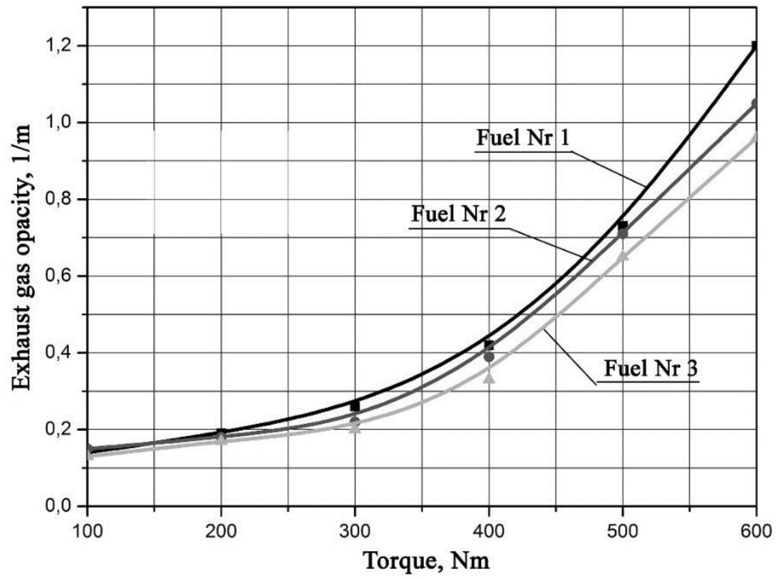

Figure 2. Exhaust gas opacity vs. engine load depending on fuel type.

It should be noted that the engine under test features mechanical fuel injection system, and is optimized for low cetane number fuels. This accounts for the best performance of base fuel Nr. 3 (in terms of fuel consumption and exhaust gas opacity), whose cetane number is the least among tested fuels. Moreover, this fuel is the best in terms of volatility as well, as follows from its fractional composition.

Also, the results of representative part weighing show definite correlation between fuel composition and its scaling tendency (table 2).Respective difference in averaged masses of deposit on valves and injectors is quite perceptible, though relatively small.

Table 2. Increment in representative part mass for the test cycle period.

Increment in averaged deposit mass for the test cycle period (mg / percent in relation to initial values)				
Nr.	Parts	Diesel fuel sample Nr.1	Nr.2	Nr.3
1	Injector atomizers	+1 mg/ +2.6%	+2 mg/ +5.8%	0 mg/0.0%
2	Inlet valves	+10 mg/+ 3.6%	+12 mg/ +4.3%	+8 mg/ +2.9%
3	Outlet valves	+7 mg/ +4.3%	+9 mg/ +5.6%	+6 mg / +3.8%

Particularly noteworthy is distinct similarity of dependences of fuel economy and fuel scaling tendency on its composition. Fuel sample Nr. 3 that showed maximum combustion efficiency, demonstrated less scaling tendency as well.

The second part of this work included experimental investigation of correlation between detergent additive concentration, on the one hand, and engine fuel efficiency, emission performance, and level of deposits on combustion chamber surfaces, on the other hand.

In these tests a multi-component additive was used, originally developed as a part of premium commercial grade fuels, with a view to improve fuel detergency and combustibility. Additive mass concentration recommended by manufacturer equals 100 ppm, regardless of base fuel sort and composition. Confirmation of the above recommendation was one of the goals of this investigation.

This test cycle, like the previous one, was carried out according to the test procedure described earlier. Base fuel types used in these tests were modified with the above-mentioned multi-component additive of varying concentration (50, 100, 150, 200 ppm).

The results of these tests demonstrated undoubted effectiveness of the multi-component additive. It should be noted, however, that its performance depends considerably on base fuel composition and additive concentration. Shown in figure 3 and figure 4 are functional dependences of fuel saving and decrease in exhaust gas opacity (averaged across all the measurement points) on multi-component additive concentration. In each case a respective value measured at the final test stage for each fuel type with no additive was taken as a comparison base.

It may be noted that for each fuel type there is optimum concentration of the additive, at which its effectiveness reaches maximum.

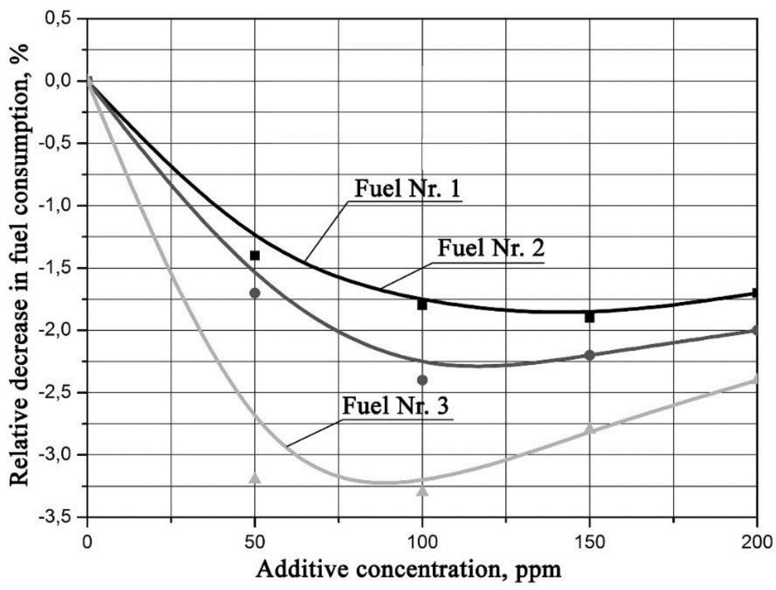

Figure 3. Dependence of fuel saving (averaged for the test cycle) on additive concentration, with various base diesel fuels.

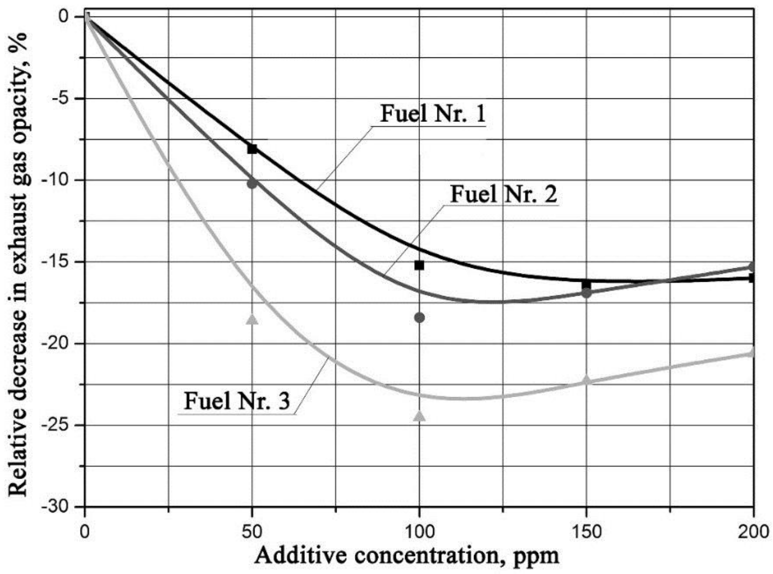

Figure 4. Dependence of decrease in exhaust gas opacity (averaged for the test cycle) on additive concentration, with various base diesel fuels.

The latter reveals itself in the biggest decrease in fuel consumption and exhaust gas opacity. Thus, for base fuel Nr. 1 such optimum point lies in the range 140...150 ppm, for base fuel Nr. 2 – in the range 110...120 ppm, for base fuel Nr. 3 it drops down to 75 ppm. The same is largely true for exhaust gas opacity trend. Use of the additive in optimum concentration results in decrease in fuel consumption by 1.8...3.5%, in exhaust gas opacity – by 17...22% as compared with respective base fuel. The best results were shown with base fuel Nr. 3.

Both weighing and visual inspection of selected parts confirmed effectiveness of the additive in terms of detergency (table 3) and existence of optimum concentration, at which the cleaning capacity reaches its maximum (figure 5).

Table 3. Decrement in representative part mass for the period of test cycle for fuel modified with optimum amount of the multi-component additive.

Increment in averaged deposit mass for the test cycle period (mg / percent in relation to initial values)				
Nr.	Parts	Diesel fuel sample Nr.1	Nr.2	Nr.3
1	Injector atomizers	-6 mg/ -17.5%	-6 mg/-18.4%	-9 mg/ -26.2%
2	Inlet valves	-12 mg /-5.2%	-15 mg /-5.8 %	-18 mg/-6.9%
3	Outlet valves	-8 mg /-5.0%	-10 mg/-6.3%	-12 mg /-7.4%

A number of authors noted the existence of optimum concentration of additive containing combustion intensifier [8-10].Such effect is in a way similar to influence of cetane number on combustion process. In both cases the reason for the existence of an optimum lies in reaching certain balance between compression and expansion work of engine thermodynamic cycle as combustion rate changes [11-12].

Obviously, fuel activation with combustion intensifier as a part of the multi-component additive modifies ignition lag period, and, therefore, balance of kinetic and diffusion phases of combustion process [13-16].

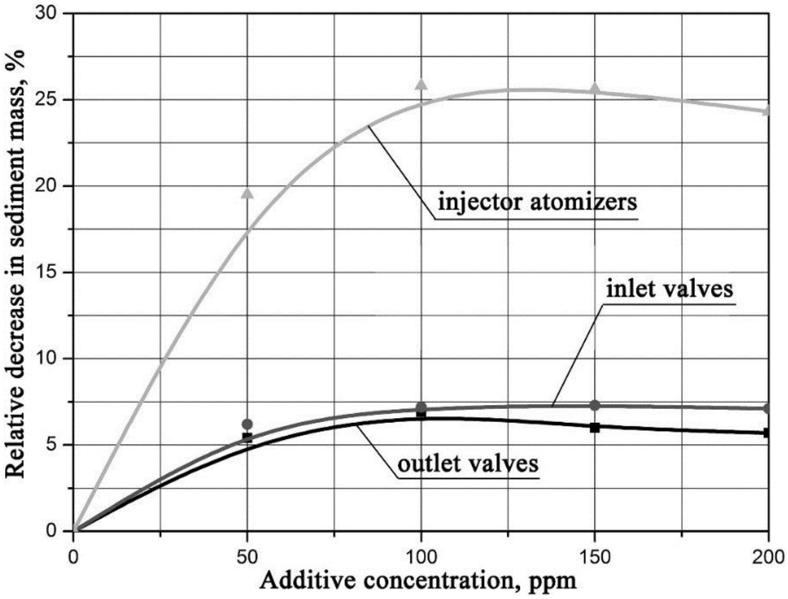

Figure 5. Correlation between cleaning effect (relative decrease in mass of sediments on representative part surfaces) and concentration of the additive for base fuel Nr.3.

Fortunately, both optimum additive concentrations – based on combustion efficiency and minimum deposit – closely agree, which makes it possible to considerably simplify time-consuming and costly multifactorial experiments.

4. Conclusion

The following conclusions may be derived from this investigation:

Nomenclature of base diesel fuels commercially available in Russian Federation is characterized by wide range of principal physicochemical parameters, such as cetane number, fractional composition, kinematic viscosity, flash point and density, considered acceptable. These are parameters that strongly influence mixture formation and fuel combustion processes, and therefore, engine power, fuel efficiency, exhaust gas toxicity and opacity.This conclusion is supported by the results of comparative stand tests of diesel engine firing fuels that significantly differ in basic physicochemical parameters.Mean spread in fuel consumption averaged for the test cycle amounts to 2.2%. Similar spread in exhaust gas opacity is still more pronounced – up to 12…15%.

Testing of diesel fuels modified with multi-component additive revealed that effectiveness of the additive generally depends on is concentration. Optimum additive concentration widely varies (75…160 ppm), depending on base fuel composition. Total effect of the additive usage is noticeable, amounting to 3.5% in terms of fuel economy and to 22% in terms of exhaust opacity reduction. Besides, the additive considerably lowers sedimentation on exposed surfaces of combustion chamber, inlet and outlet valves. Thus modification of base fuel with the multi-component additive appreciably improves its performance.

References

[1] Danilov A M 2014 Additives as a Solution to Chemmotological Problems *Chemistry and Technology of Fuels and Oils* **50(5)** 406–10

[2] Grażyna Żak, Leszek Ziemiański, Zbigniew Stępień and Michał Wojtasik 2014 Engine testing of novel diesel fuel detergent–dispersant additives *Fuel* **122(15)** 12-20

[3] Alexanyan K, Stokolos O, Solodova E, Zaytceva Y, Salmanov S Y, Yarullin N, Naletova A and Mikhailov E 2018 Istoriya razvitiya i primeneniya antiokislitel`ny`x prisadok dlya topliv i masel [The history of development and applying of antioxidant additives for fuel and oil] *Izvestiya vysshikh uchebnykh zavedenii Khimiya khimicheskaya tekhnologiya* **61(9-10)** 120-5 [In Russian]

[4] Borzaev B Kh, Karpov S A and Kapustin V M. 2007 Mnogofunkcional`ny`e dobavki k avtomobil`ny`m benzinam [Multifunctional additives for automotive gasolines] *Khimiya i tekhnologiya topliva i masel* **43(2)** 108-13 [In Russian]

[5] Danilov A M 2001 Prisadki k toplivam. Razrabotka i primenenie v 1996—2000 gg. [Fuel Additives: Evolution and Use in 1996-2000] *Khimiya i tekhnologiya topliva i masel* **6** 43-50 [In Russian]

[6] Shilpi Agarwal, Vijay K. Chhibber and Ajay K. Bhatnagar 2013 Tribological behavior of diesel fuels and the effect of anti-wear additives *Fuel* **106** 21-9

[7] Shabanov A, Zaitsev A and Mokhnatkin E 2008 Svyaz' gruppovogo sostava topliva i motornyx i e'kologicheskix pokazatelej benzinovogo dvigatelya [Correlation between fuel composition and petrol engine mechanical & environmental performance] *Trudy V Mezhdunarodnoj nauchno-prakticheskoj konferencii "Novye topliva s prisadkami"* (St. Petersburg) pp 60-3 [in Russian]

[8] Mokhnatkin E, Smerechuk V and Shabanov A 2008 Stendovye motornye ispytaniya avtomobil'nyx topliv kak vazhnejshaya chast' sistemy dobrovol'noj sertifikacii goryuche-smazochnyx materialov [Test-bed measurements of automotive fuel properties as a core part of fuels and lubricants voluntary certification system] *Trudy V Mezhdunarodnoj Nauchno-Prakticheskoj Konferencii "Novye topliva s prisadkami"* (St. Petersburg) pp 31-6 [in Russian]

[9] Poletaeva O Y, Movsumzade E M, Kolchina G Y and Bakhtina A Y 2018 Vliyanie stroeniya molekul vy`sokooktanovy`x komponentov benzinov i antiokislitel`ny`x prisadok k toplivam na e`ffektivnost` ix dejstviya [Influence of molecular structure of high octane gasoline components and fuel antioxidant additives on efficiency of their action] *Izvestiya Vysshikh Uchebnykh Zavedenii Khimiya Khimicheskaya Tekhnologiya* **59(12)** 49-56 [In Russian]

[10] Jehlik F, Lohse-Busch H, Iliev S and Hall C 2019 Capturing the Impact of Fuel Octane Number on Modern Gasoline Vehicles with Octane Indices *SAE Int. J. Fuels Lubrricants* **12(2)** 63-86

[11] Kontses A, Dimaratos A, Keramidas C, Williams R, Hamje H, Ntziachristos L and Samaras Z. 2019 Effects of fuel properties on particulate emissions of diesel cars equipped with diesel particulate filters *Fuel* **255(1)** 115879

[12] Spirkin V G, Lykov O P and Bel'dii O M 2001 E`kologicheski bezopasny`e dobavki dlya dizel`ny`x topliv [Environmentally Safe Additives for Diesel Fuels] *Khimiya i tekhnologiya topliva i masel* **6** 29-31 [In Russian]

[13] Fayyazbakhsh A, Pirouzfar V 2016 Investigating the influence of additives-fuel on diesel engine performance and emissions: Analytical modeling and experimental validation *Fuel* **171(1)** 167-77

[14] Zhang W, Ding H, Shuai S, Zheng B, Cantlay A, Natarajan V, Zhan Z S and Pu Y 2017 Effect of Fuel Detergent on Injector Deposit Formation and Engine Emissions in a Gasoline Direct Injection (GDI) Engine *SAE Technical Paper 2017-01-2247*

[15] Kak A, Kumar N, Gurjar B, Singh S and Gupta D 2015 Comparative Study of Emissions and Performance of Hydrogen Boosted SI Engine Powered by Gasoline Methanol Blend and Gasoline Ethanol Blend *SAE Technical Paper 2015-01-1677*

[16] Rockstroh T, Floweday G and Wilken C 2016 Options for Use of GTL Naphtha as a Blending Component in Oxygenated Gasoline *SAE Int. J. Fuels Lubrricants* **9(1)** 191-202