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IMPROVING OF TRANSPORT DIESEL ENGINES ENERGY EFFICIENCY AND ENVIRONMENTAL SAFETY BY FUMIGATION OF AIR CHARGE

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Abstract

The paper is devoted to the problem of improving of energetic efficiency and ecological safety of automotive diesel engines. To solve this problem, it is proposed to use the method of fumigation of air charge with different liquid activators (alcohol, biodiesel, gasoline, kerosene) in the diesel engine at the intake stroke. For the practical realization of such method, a concept of technical solution was formulated and a theoretical foundation was performed. An algorithm of device, performing automatic activator injection at different speed and load modes, was developed. The technical means (microprocessor unit, electromagnetic injectors and sensors) for single-point and multi-point injection of liquid activator into the intake manifold were designed, patented and researched. Depending on activator type and dose, fumigation of air charge with invented devices promotes to reduce exhaust smoke opacity by 10-50 percent and brake specific fuel consumption by 3-14 percent. Simultaneously, the brake power increases by 3-12 percent. These completed studies confirm the efficiency and practical applicability of fumigation of air charge on diesel-powered automotive machinery.

Key words*: diesel engine, ecological safety, fumigation of air charge, system, smoke opacity, transport.*

INTRODUCTION

Energetical efficiency and ecological safety of transport machinery powered by diesel engines, represents an actual and practically significant problem. One of the methods for solving such problem is the fumigation of air charge in the diesel engine at the intake stroke with liquid activators such as alcohol, gasoline, biodiesel, etc. (Imran et al., 2013; Ou et al., 2012).

The analysis of existent mechanical devices for fumigation of air charge was performed. It shows that these devices carburetor is the most used device for activator fumigation in diesel engine (Mariasiu et al., 2015), but it is not able to ensure the automatic regulating of required percentage (dose) of activator and fuel at the different diesel engine speed and load modes.

Improving the precision of activator dosage is possible with the help of electronic controlling over the electromagnetic injectors, placed on the diesel engine in the intake manifold (Stanglmaier, 2004).

MATERIALS AND METHODS

For the practical realization of this way, the single point and multi-point injection systems for hydrocarbon fumigation of air charge in the diesel engine were developed, manufactured and researched.

The quantity of activator supplied into the intake manifold usually amounts from 10 % to 20 % of standard motor fuel dose injected into the combustion chamber by the standard fuel system. This dose may be supplied at reduced cyclic feed of motor fuel (when fuel dose is partially replaced accordingly to activator dose) or at standard cyclic feed. In the first case, it leads to improving diesel engine parameters at all operating modes, in the second case - to boosting the diesel engine at short-term overload mode.

The single point injection system for fumigation of air charge supplies activator with electric pump (2) (Figure 1) to the electromagnetic injector (3) placed in the intake manifold (4)) of the diesel engine.

The functioning of injector is controlled by electronic control unit (ECU) 7 in according with signals from the engine crankshaft rotation speed sensor (5) and the high-pressure pump (HPP) rack motion sensor (6). When the control voltage supplied from ECU in the circuit of the electromagnetic injector is high (positive impulse), it injects the activator into the intake manifold. When the control voltage is low (zero impulse), the injection is stopped.

In depending on engine speed and load operational mode, the quantity of activator supply is changed by varying of control impulse (width of pulse is from 7 to 700 m/sec and pause is from 25 to 325 m/sec) in accordance with initial setting of adjustors (11) and (12) for certain percentage of diesel fuel and activator.

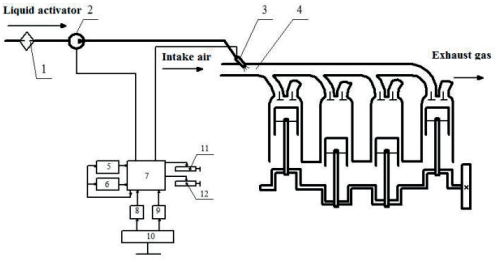

Figure 1. The single point injection system for fumigation of air charge with activator: 1 - filter; 2 - electric pump; 3 - electromagnetic injector; 4 - intake manifold of the diesel engine; 5, 6, 8, 9 - sensors of: crankshaft rotation speed, high pressure pump rack motion, temperature of coolant, onboard power voltage; 7 - electronic control unit; 10 - power source; 11, 12 - adjustors for initial settings of width and pause of impulse signal

The basic elements of the single point system for fumigation of air charge are shown in Figure 2.

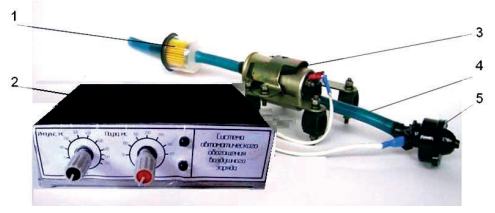

Figure 2. The basic elements of the single point system for fumigation of air charge: 1 - filter; 2 - electronic control unit; 3 - electric pump; 4 - connecting hoses; 5 - electromagnetic injector

A disadvantage of for single-point fumigation of air charge is some inequality of distribution of air and activator mixture, when it enters the cylinders of the diesel engine at the intake stroke. As a solution of this problem, the multi-point fumigation of air charge with activators may be used, when the number of electromagnetic injectors is equal to the number of engine cylinders. The injectors are placed in the engine inlet ports in close proximity to inlet valves of gas distribution mechanism (Figure 3).

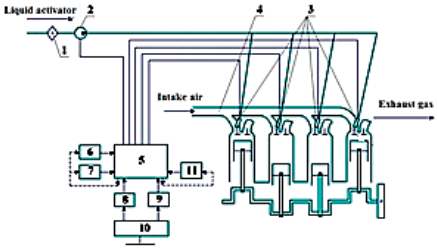

Figure 3. The multi-point injection system for fumigation of air charge with activator: 1 - filter; 2 - electric pump; 3 - electromagnetic injector; 4 - intake manifold of the diesel engine; 5 - ECU; 6, 7, 8, 9, 11 - sensors of: crankshaft rotation speed, high pressure pump rack motion, temperature of coolant, onboard power voltage and phase; 10 - power source

However, many diesel engines do not have separate branches of intake manifold for each cylinder, therefore the mounting of injectors requires the modification of the cylinder head. The most popular wheeled agricultural tractors in Russia is MTZ tractors powered with four-cylinder four-stroke D-243 diesel engine produced by the Minsk Motor Plant (Belarus). This engine has only two inlet ports in cylinder head per four cylinders. In their turn, such ports are connected with two branches of the intake manifold, and the fresh air charge arrives into a pair of neighbouring cylinders through them at the intake stroke.

For this reason, for the practical embodiment of multi-point injection of activator on diesel engines, fitted with such intake manifold, a two-point system for the fumigation of air charge is an effective technical solution.

The electromagnetic injectors (4) (Figure 4) are placed in the insertions (2) at the branches of the standard intake manifold (1). The upper flanges of the insertions (2) are connected with manifold's branches. The lower flanges of the insertions are connected with inlet ports of the cylinder head.

The input channels of the injectors (4) are placed at the outlet pipes of the rail (3), which is used as a pipeline for activator supply. A pressure governor (5) is placed at the dead end of the rail. It is intended for regulation of activator pressure and for bypassing of excess activator back to the tank.

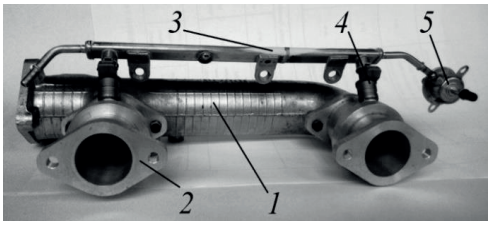

Figure 4. The intake manifold for two-point injection system for fumigation of air charge of the diesel engine: 1 - standard intake manifold; 2 - insertion; 3 - rail; 4 - electromagnetic injector; 5 - pressure governor

Two-point activator supply into the branches of the intake manifold is performed by two electromagnetic injectors: the 1st injector performs fumigation of air charge incoming into the 1st and 2nd cylinders; the 2nd injector - into the 3rd and 4th cylinders.

The order of operation of injectors is agreed to cylinders firing order (1-3-4-2). The quantity of activator supply should to correspond to the certain adjusted dose (10% or 20% of fuel consumption) at the different engine speed and load modes. Thus, for implementation of certain dose of activator supply, the primary objective is the development of operational algorithm of electromagnetic injectors and substantiation of parameters of control electrical impulses supplied on the injectors.

The firing order of cylinders is 1-3-4-2. The four-stroke four-cylinder diesel engine performs the intake stroke once per two rounds of the crankshaft in each cylinder. Thus, each electromagnetic injector, working for two cylinders, performs injection of activator once per every crankshaft revolution. So, the order of operation of electromagnetic injectors of two-point system for fumigation of air charge is 1-2-2-1.

As the electromagnetic injectors execute the injection of activator on cue of impulses formed by electronic control unit, so the datum point is the start of intake stroke in the 2nd cylinder.

In this case, the firing order of cylinders may be written as 2-1-3-4, so the order of operation of electromagnetic injectors will be 1-1-2-2. Thereby, the injectors perform pairwise cyclical injection of activator into the branches of the intake manifold.

A diagram of control impulses shown at Figure 5 is displaying the operational algorithm of the electromagnetic injectors of two-point system for fumigation of air charge.

It follows from the diagram, that each injector interchanges its angular phases between the moments of start of activator injection. These phases are 180 degrees and 540 degrees of crank angle (°CA).

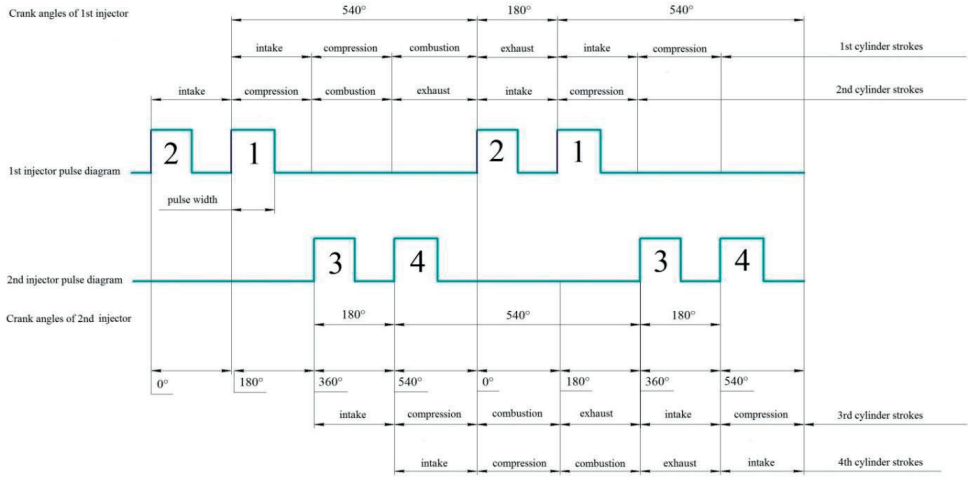

Figure 5. The control pulse diagram for multi-point fumigation of air charge on four-cylinder diesel engine with two electromagnetic injectors (1, 2, 3, 4 are the numbers of cylinders at the intake stroke)

For example, when a control impulse is supplied to the 1st injector, it injects a certain dose of activator into the 2nd cylinder at the start of intake stroke during a period *T* and angle φ. Then a pause between impulses ensues during φ = 180°CA («short-term» pause). Thereafter, the 1st injector injects activator into the 1st cylinder during the same period *T* and angle φ. After that, a pause between impulses follows during φ = 540°CA («long-term» pause) till the moment when the intake stroke in the 2nd cylinder will start again.

During the «long-term» pause in the 1st injector, the 2nd injector in the same order and with the same period *T*, injects activator into the 3rd cylinder, then into the 4th cylinder. Thereafter, «long-term» pause acts in the 2nd injector, the 1st injector turns on again, and the the duty cycle repeats. Thus, each injector interchange «long-term» pause and «short-term» pause between the control pulses.

It was theoretically determined, that to implement the multi-point fumigation of air charge, depending on the activator dose and the engine speed and load mode, the cyclic dose of activator amounts may be from 1 mg per cycle to 13 mg per cycle, while the activator injection duration is from 0.27 m/s to 3.5 m/s (Ryblov et al., 2018).

The design of two-point injection system for fumigation of diesel engine air charge is given at the Figure 6.

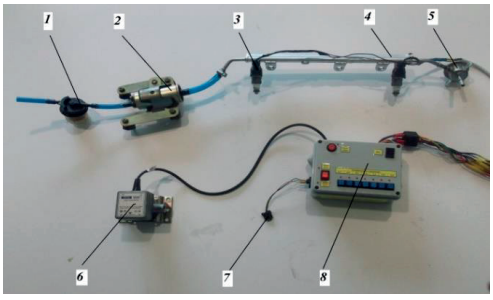

Figure 6. The design of two-point injection system for fumigation of air charge with liquid activator:
1 - filter; 2 - electric pump; 3 - electromagnetic injector;
4 - rail; 5 - pressure governor; 6 - fuel flow meter;
7 - phase and crankshaft rotation speed sensor;
8 - electronic control unit

The system contains filter (1), electric pump (2), two electromagnetic injectors (3) fixed in the outlet pipes in the rail (4), pressure governor (5), fuel flow meter (6), phase and crankshaft rotation speed sensor (7) and ECU (8).

The fuel flow meter (6) is used as an engine load mode sensor and serves to provide the required activator dose (10% or 20% of fuel consumption). It is placed low-pressure fuel pipeline of the standard fuel system of the diesel engine (between the coarse fuel filter and low-pressure feed pump). The phase sensor and crankshaft rotation speed sensor is united into one sensor designed on the base of Hall Sensor. The intake strokes in cylinders are determined by the angle of high-pressure fuel pump drive shaft.

The technical solutions used during the developing systems for single-point and multi-point fumigation of air charge are protected by 10 Patents of Russian Federation (No. 2392481, 2383757, 72018, 157301, 2518711, 176498, 2514544, 2515586, 177583, 2330173).

An experimental research of fumigation of air charge with liquid activators by the single point and multi-point injection systems were carried out on brake setup, including the four-cylinder four-stroke D-243 diesel engine, KS-56/4 dynamometer brake and measuring apparatus. The following activators were used: gasolines RON80, RON92 and RON95, aviation kerosene TS-1, summer diesel oil L-0.2-62, ethanol, methanol, rapeseed methyl ester (RME) and biodiesel blends: 50% RME + 50% diesel; 50% rapeseed oil + 50% diesel; 20% safflower oil + 80% diesel.

RESULTS AND DISCUSSIONS

The results of engine motor tests show that single-point fumigation of air charge with the dose 10% of gasoline RON80 or RON92 reduces exhaust smoke opacity by 4-6% (Figure 7). Simultaneously, the brake specific fuel consumption (BSFC) is less by 8-11%, when the brake power (BP) increases by 7-10% in comparison with the engine operation in standard specification without fumigation of air charge.

With the fumigation of air charge by the dose 10% of kerosene TS-1, smoke opacity reduces by 11%, BSFC decreases by 6%, BP increases by 5%.

With the 10% dose ethanol fumigation, smoke opacity reduces by 11%, BSFC decreases by 3%, BP increases by 3%.
More significant reduction of exhaust smoke opacity was observed with the 10% dose methanol fumigation (by 19%) and RME biodiesel (by 21%), but BSFC increases by 4-6%, when BP decreases by 3-4 %.

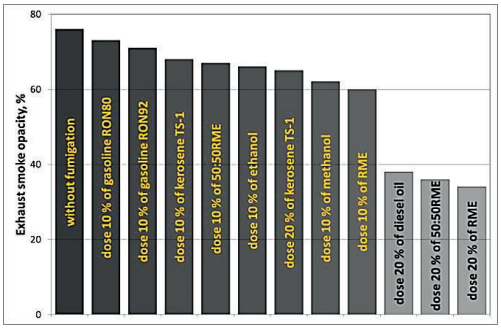

Figure 7. The exhaust smoke opacity of four-cylinder four-stroke D-243 diesel engine at the maximum torque at the engine speed 1400-1600 rpm

Fumigation of air charge with 20% dose of summer diesel oil L-0.2-62 leads to reducing smoke opacity by 22%, when shift of BP and BSFC is not significant.
The most significant reduction of exhaust smoke opacity was achieved with the 20% doses of RME and biodiesel blend 50% RME + 50% diesel: by 50% and by 45%, respectively. Simultaneously, BSFC increases by 5-6%, when BP decreases by 4-5%.
Two-point fumigation of air charge allows to improve diesel engine energetic parameters (BP and BSFC) by 3-4% in comparison with single-point fumigation. Simultaneously, the reducing of the exhaust smoke opacity is nearly the results obtained with single-point fumigation.
For example, Figure 8 shows the shift of engine exhaust smoke opacity with two-point fumigation of air charge by 10% doses of kerosene TS-1, ethanol, biodiesel blend 50% RME + 50% diesel, RME, as well as 20% doses of biodiesel blend and RME.
The most significant reduction of BSFC (by 14%) was achieved with the two-point fumigation of air charge by 10% dose of gasoline RON92, when brake power increased by 12%.

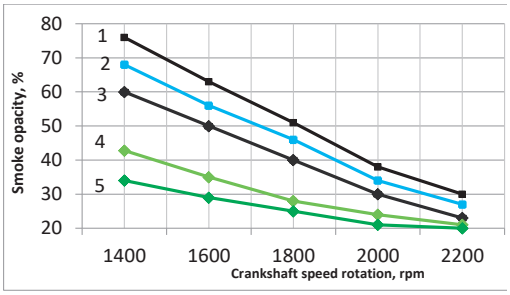

Figure 8. D-243 diesel engine exhaust smoke opacity with two-point fumigation of air charge:
1 - without fumigation; 2 - with fumigation by 10% dose of kerosene TS-1, ethanol or biodiesel blend;
3 - with fumigation by 10% dose of RME; 4 - with fumigation by 20 % dose of biodiesel blend; 5 - with fumigation by 20% dose of RME

CONCLUSIONS

As a result of study, the technical means for single-point and multi-point fumigation of air charge in the diesel engine were designed, patented and researched.
The results of diesel engine motor tests show that the best parameters are achieved with multi-point fumigation of air charge by activator dose 10% or 20%.
Fumigation of air charge in diesel engine allows to reduce exhaust smoke opacity by 10-50% and decrease brake specific fuel consumption by 3-14% when brake power may increase by 3-12%.
The performed study evidences the efficiency of activator fumigation in diesel engine. It promotes to improving of ecological and energetic parameters of diesel engines used on the transport machinery.

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