TRANSPORT PROBLEMS 2018 Volume 13 Issue 2
PROBLEMY TRANSPORTU DOI: 10.20858/tp.2018.13.2.6

Keywords: fuel; biodiesel; diesel; fuel mixture; dynamic regulation

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DYNAMIC REGULATION OF THE PERCENTAGE COMPOSITION OF THE MIX DIESEL AND BIODIESEL FUEL

Summary. The use of internal combustion engines increase environmental pollution and dependence on fossil fuels. The biodiesel fuel, which is renewable, more environment friendly, and cheaper, is a good alternative for diesel engines. The use of biodiesel fuel leads to a drop in diesel power and an increase in fuel consumption. To prevent these shortcomings, it is proposed to use dynamic regulation of the percentage composition of a mixture of diesel and biodiesel fuel. The modernization of diesel engines for their transfer to work on a mixture of fuels with a dynamic regulation of its percentage composition is possible at service stations serving diesel engines.

1. INTRODUCTION

Internal combustion engines have become an indispensable attribute of the present. Their widespread use requires a large amount of fuel, the requirements of which are constantly changing. In Ukraine, the volume of fuel production from its own raw materials cannot meet the needs of domestic consumers, therefore, mainly imported fuel is used, and it pushes scientists to find alternative, renewable fuels and their way of using.

The world community pays much attention to the state of ecology and requires a conscious attitude towards the environment. The physicochemical properties of alternative fuels determine some of the peculiarities of the working processes in engine cylinders and affect its technical, economic, and environmental performance. The use of alternative fuels influences the flow of working processes, which leads to a decrease in engine power and deterioration of its economic performance. The scientists pay more attention to the development of recommendations for the adaptation of the diesel power supply system and the improvement of the algorithms for the organization of work processes of internal combustion engines when converting them to work on alternative fuels.

An example of this is the Kyoto Protocol, the regular review of the norms of the environmental standard "euro" (which regulates the content of harmful substances in the exhaust gases), etc. Emissions of harmful substances in the exhaust gases of engines approximately make up 39% of the total amount of harmful emissions, and in cities reach 70-90 % [1]. Therefore, the use of alternative fuel, in addition to the possibility of its production directly in Ukraine, should provide an opportunity to reduce the number of harmful substances in the exhaust gases of the engine.

Biodiesel fuel has been known and properly studied for many years, but modern technologies and active work of scholars and researchers make it possible to find fundamental new technologies for its production and efficient use.

2. LITERATURE REVIEW AND DEFINING THE PROBLEM

The use of biodiesel fuel for a diesel engine through the use of various technologies and, in particular, dynamic regulation of its content in a mixture with the diesel fuel, makes it possible to increase the technical and economic performance of a diesel engine. Till date, the complete transition of a diesel engine to biofuel is not economically viable. Since in the case of its operation only on it, despite the improvement of environmental indicators, the performance of the engine is reduced, and the cost of such system is significant. Because of which, the issue of modernizing the existing diesel engine power supply system for realizing the possibility of its operation on biodiesel fuel is topical.

To determine the impact of the use of biodiesel fuel and its mixture with diesel fuel on the efficiency of the engine based on the characteristics of the spraying process, the research work was carried out [2]. In addition, it has been proven that the variation in the percentage of biodiesel fuel in diesel can positively affect the process of preparation of the fuel-air mixture at the combustion stage.

The study of the influence on the technical, economic, and ecological parameters of the diesel fuel using the fuel mixture of diesel fuel (DF) and vegetable oil (VO) of a stable percentage composition was conducted [3]. It was established that when using a fuel mixture with a volumetric VO content of 25%, the techno-economic and environmental parameters of the engine were improved, rather than when using the DF. The rational values of the diesel parameters and the power supply system settings, namely: the compression ratio ε = 15.5-16.5; the fuel injection advance angle θ_{inj}= 7-11° of the crankshaft rotation angle (c. r.) to the top dead center; the fuel injection duration φ_{inj} = 14°angle of c. r.; the boost pressure is p_s = 0.215-0.24 MPa. The variation of these parameters in the specified ranges reduces the effective consumption of the fuel mixture by 10-15 g / kWh, nitrogen oxide emissions up to 2.8 g / kWh, and smoke up to 15% [3].

Gas-diesel engines with internal mixture formation work on a mixture of two fuels: DF and liquefied gas. According to the results of the study [4], it has been determined that the efficiency of the gas-diesel engine deteriorates by 10-15% compared with the base engine, reducing the toxicity of the exhaust gases by NO_x oxide emissions by about 20%, and the smokiness by 40-60%.

A significant number of works are devoted to the study of the impact on the technical, economic, and ecological indicators of diesel engines toward the use of fuel mixtures of DF and biodiesel fuel (BDF) of stable percentage composition. Because of the differences in the physicochemical properties of DF and BDF, there is the so-called "stratification" of the fuel mixture. Therefore, in the work [5], the ultrasonic treatment of a mixture of fuels (80% DF and 20% BDF) was proposed to ensure homogeneity. The results of the study demonstrate that the use of this fuel mixture with and without ultrasonic treatment affects the technical, economic, and environmental performance of the engine. The effective power is reduced by 4% and 9%, the specific fuel consumption is increased by 5% and 14%, the smoke of the exhaust gases is decreased by 18% and 8% respectively. The process of wearing the friction pairs when applying the fuel mixture of DF and BDF with ultrasonic treatment leads to a decrease in wear rate by 16% compared with the use of the mixture without processing.

To obtain a homogeneous fuel mixture of DF and VO, mixing and heating devices are used. The research of techno-economic and ecological indices of the diesel was carried out using a fuel mixture of 70% DF and 30% VO [6]. It was found that the power of the engine with the regular power system was reduced, the profitability was negligible, the environmental performance was better. The use of a mixing and heating combustion device to compensate for differences in the physicochemical properties of the fuel mixture components can increase engine power by 0.4%, reduce fuel consumption by 4.7%, and reduce the smoke of the exhaust gases from 84% to 67 % compared with the utilization of a mixture of DF and VO without stirring and heating.

To improve the performance of workflows in the engine cylinders, when operating on a mixture of DF and BDF, the correction of the fuel injection advance angle and the change of compression ratio can be used [7]. The influence on the technical, economic, and environmental parameters of the diesel engine during its conversion to work on a fuel mixture of a stable percentage composition (20% BDF, 80% DF) was investigated. According to the results of the study, the value of the fuel injection advance angle (θ_{inj} = 8° c. r.) and the compression ratio (ε = 18) was determined to provide the best

economic and environmental performance of the diesel. The application of the specified values allows to reduce the fuel mixture consumption by 3.26-3.47% in comparison with the base engine. The total emissions of the harmful substances, on an average, were reduced by 6.12% in the maximum torque regime (n_{∂} = 1700 rpm) and by 3.36% in the maximum power mode (n_{∂} = 2800 rpm).

Most of the studies on the use of BDF in engines were carried out with a mixture of fuel with a constant percentage composition of DF and BDF. However, with a constant percentage of the mixture of fuel, it is not ensured that the working processes of the diesel engine are effectively flowing in different modes of its operation [8]. The use of a mixture of fuels with a low BDF content has little significance not only on the course of work processes, but also on the economic and environmental effects.. With the increase in the BDF content in the mixture, its negative impact on the flow of working processes is developed, especially when the diesel engine is operating in the mode of maximum load. Therefore, in our opinion, it is expedient to use a mixture of DF and BDF of variable percentage composition in internal combustion engines, depending on the modes of its operation.

To improve the environmental performance of the diesel, the scientists have developed a technique for determining the basic characteristic of adjusting the optimal ratio of the components of the DF and BDF mixture, depending on the mode of operation of the diesel engine [9]. The use of the developed methodology results in reduction of emissions of all normalized toxic components of the exhaust gases. Thus, when the engine is running on a mixture of fuels with the adjustment in the optimum component ratio, the NO_x emissions are reduced by 9%, carbon oxide CO by 13.5%, C_mH_n hydrocarbons by 36% compared with the engine running at DF. To implement the developed methodology, the authors proposed a scheme of the device for mixing DF and BDF in various proportions, depending on the operating modes of the diesel engine. The regulation of the fuel mixture composition is proportional to the DF pressure in the fuel lines of high pressure. The speed of such a device is about two adjacent fuel cycles. The drawback of this method is that the percentage composition of the fuel mixture depends on the frequency of rotation of the crankshaft and does not take into account the degree of engine load.

According to experts [10, 11], the use of a mixture of fuels with a BDF content up to 60%, does not substantially reduce the diesel engine power of the Д-245.12 and does not require additional regulation of its power system. In accordance with the results of experimental studies, it was found that when the engine is running on an external speed characteristic, the smoke of the exhaust gases is reduced by 2.5 to 3 times, the specific mass emission of carbon monoxide CO is decreased by 30%. However, the emissions of nitrogen oxides NO_x and hydrocarbons C_mH_n increase at some diesel engine operating modes. With the enhanced content of BDF in the fuel mixture and when the diesel engine is operating at idling speed, emissions of the normalized toxic components in the exhaust gas are reduced. It should be noted that the use of a mixture of fuels to maintain engine power performance causes an increase in cyclic fuel supply, which leads to the deterioration of the economic performance of diesel.

Special attention is given to the study on the influence of the practical use of a mixture of fuels on engine performance [12-16] when working on different load modes. So, the operation of the diesel engine 3Ч8,8/8,2 at the crankshaft speed n_{∂} = 1600 rpm, the use of a mixture of fuels with a BDF content of 50% leads to an increase in carbon monoxide CO emissions [16]. The emissions of nitrogen oxides NO_x and smoke emissions of exhaust gases are reduced throughout the range of engine operating modes.

Thus, the use of a mixture of fuels DF and BDF with a constant percentage composition provides an improvement in the environmental performance of diesel engines, but their technical and economic performance worsens. In this case, any modernization of the diesel power supply system makes it impossible for the engine to operate equally efficiently on DF and on a mixture of fuels, that is, the dual fuel diesel is complicated. The studies on the regulation of the composition of the fuel mixture during the operation of the diesel engine, provided that its technical characteristics are maintained, but not found. Therefore, in this article it is suggested to use dynamic regulation of the percentage composition of the mixture of DF and BDF, depending on the operating modes of the engine.

3. RESEARCH OF THE EFFICIENCY OF THE USE OF MIXTURE DIESEL AND BIODIESEL FUELS

It is promising to use biodiesel fuel on previously developed engine models with minor changes to the power system; this minimizes the cost of developing and manufacturing the engine and leaves the possibility, in the absence of biodiesel fuel, to use standard diesel fuel with or without minimal modifications.

The use of biodiesel makes it possible to reduce fuel costs and dependence on the traditional petroleum fuels, and improves the environmental performance of the engine. To achieve the maximum effect from the use of biodiesel fuel a diesel engine power system was developed with dynamic adjustment of the percentage composition of the fuel mixture, depending on its mode of operation [2]. The developed system provides starting-up, warming-up, and stopping of the diesel on diesel fuel, and on the other modes of engine operation the percentage composition of the fuel mix varies. When the diesel engine is operating at low loads, the efficient operation of the working processes while maintaining the technical parameters of the device is ensured by the use of biodiesel fuel. With increasing load on the crankshaft of the engine, in order to maintain its technical parameters, it is necessary to increase the amount of heat held in the diesel cylinder by increasing the cyclic supply of biodiesel fuel until an efficient flow of work processes is provided. The further increase of the cyclic supply of biodiesel fuel does not ensure an efficient flow of working processes, therefore, to increase the quantity of heat held into the cylinder, it is necessary to increase the energy content of the fuel mixture by increasing the diesel fuel content in it. Taking into account the fact that the lower heat of combustion of biodiesel fuel is less, in order to maintain the technical parameters of the diesel when using a mixture of fuels, it is necessary to alter the amount of cyclic feed by 10-15%, while the amount of heat supplied to the diesel cylinder can grow up to 7-10%. At maximum loads and high frequencies of rotation of the crankshaft of the diesel engine, in order to maintain its technical performance, it is necessary to make the transition to work on diesel fuel.

To improve the efficiency of the diesel engine when working on biodiesel, an improved system is proposed. The scheme of the proposed system is shown below – Fig. 1.

The proposed system consists of a diesel engine, a high-pressure fuel pump, a mixer, and a mechanism for adjusting the composition of the mixture. The composition of the fuel mixture varies in the mixer when the vehicle is moving, in addition, the mixer is used to create a congenerical mixture. The mixture composition of diesel and biodiesel fuel is influenced by various external and internal factors (the positions of the fuel pedal $\varphi_q(t)$, the magnitude of the moment of the external load M_{load}, etc.). Depending on the value of the moment of external load and the position of the pedal fuel supply, the electronic control unit (ECU) determines the composition of the mixture of diesel and biodiesel fuel supplied to the diesel engine of the car.

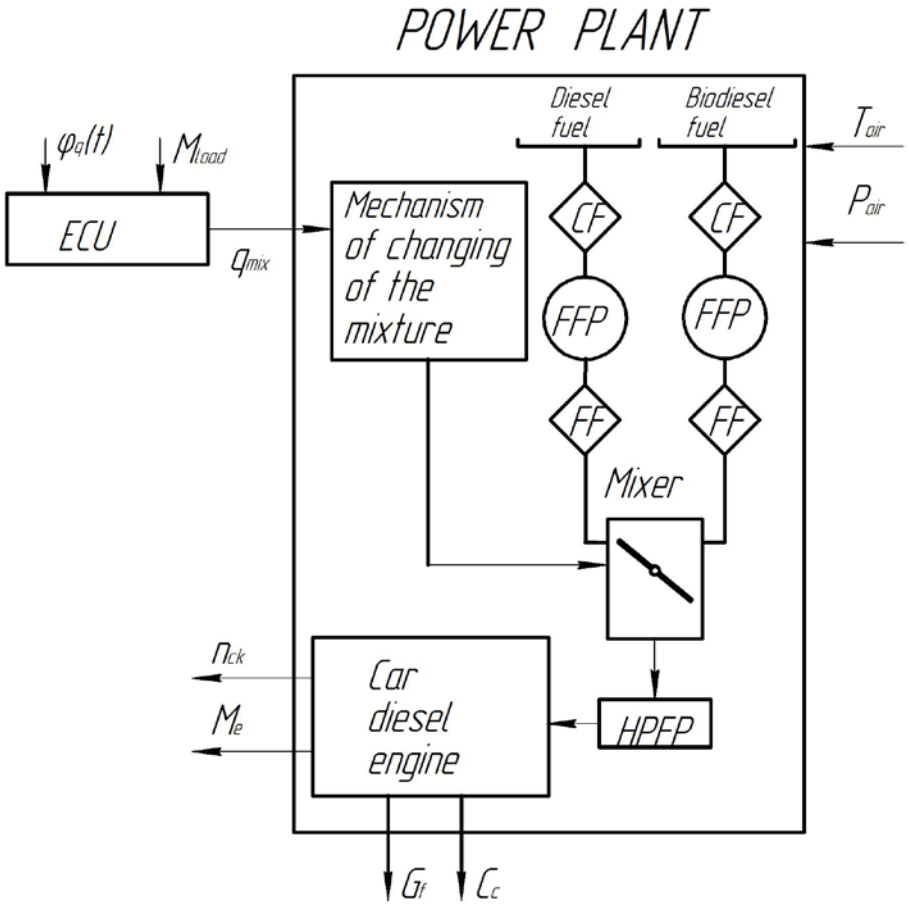
To confirm the efficiency of the proposed power supply system for a diesel engine of a car with a change in the composition of a mixture of diesel and biodiesel fuel, experimental studies were carried out, depending on the speed, the conditions of the vehicle's motion, and its loading.

The research was carried out on a Volkswagen Passat B6 with a diesel engine.

In carrying out experimental studies on the Volkswagen Passat B6, transient processes were fixed during its driving by driving cycles in accordance with GOST 20306-90.

Testing programs on the Volkswagen Passat B6 car included the definition of dynamic and fuel-economic characteristics when using the system of dynamic fuel composition adjustment. During the summer road tests, summer diesel fuel was used in accordance with the requirements of DSTU 4840: 2007 and EN 590: 2004, and biodiesel (rapeseed oil methyl esters) according to the requirements of DSTU 6081: 2009. The study of the Volkswagen Passat B6 was carried out in accordance with the requirements of GOST 20306-90 over the main cycle on the road for vehicles with a gross vehicle weight up to 3.5t.

The conducted road tests showed the efficiency of the improved power system of the diesel engine and made it possible to determine that it is possible to achieve the greatest effect by dynamically controlling the supply of a mixture of diesel and biodiesel fuel.



The scheme of improved diesel engine power system: *CF* – coarse mesh filter, *FF* – fine mesh filter, *FFP* – fuel feed pump, *HPFP* – high-pressure fuel pump, $\varphi_q(t)$ – positions of the fuel pedal, M_{load} – the magnitude of the moment of the external load, q_{mix} – the total injection rate of diesel and biodiesel fuel mix, n_{ck} – crank-shaft speed, M_e – torque output, G_f – fuel consumption, C_c – the concentration of soot in the exhaust gases, T_{air} – temperature of the air, P_{air} – pressure of the air.

Fig. 1. The scheme of the proposed system

To demonstrate the economic benefits of using the developed system, a computational study was carried out applying the mathematical model to the system "Engine-power system with a mixture of diesel and biodiesel fuel" [3]. Analyzing the market of petroleum products in Ukraine [17-21] it was found that the cost of biodiesel is 19-30% less than diesel. So, as of September 2016, the cost of diesel fuel at gasoline stations averages 18.45 UAH / litre, the cost of biodiesel is 14.5 UAH / litre, so these values of fuel cost were used in the calculation study. The calculation of the cost of the spent mixture of fuels for the diesel engine of the Volkswagen Passat B6 was conducted and the results are shown below.

The base price was chosen for the diesel fuel and that's why we can see zero at the first line of the table. In the calculation, we have three scenarios: first - we use only diesel fuel, second - vary the percentage of biodiesel fuel in the mixture of the diesel and biodiesel fuels, and finally, regulate components in the mixture dynamically. We can see that increase of the BDF percentage leads to increase in mixture consumption. If we use only BDF, its consumption will be 11,61% higher than if we use only DF. Also if we use dynamic regulation of a fuel mixture, we have to burn only 5,89% more fuel mixture then if we use only DF, but this amount is less than using only BDF without DF. The third column shows us that increase of the BDF in mixture, reduce the price of the mixture but as we said earlier, with higher percent of BDF in mixture we increase the mixture consumption. Finally,

if we use proposed system of the dynamic regulation, we will have less mixture cost but at the same time, not so big increase in mixture consumption, which means that here we can find a balance between reducing cost and consumption.

Table 1

Results of calculation of the cost of the spent mixture of fuels
for the diesel engine of the Volkswagen Passat B6

Composition of a fuel mixture	Increase in the fuel mixture consumption relative to diesel fuel	Reducing the cost of a fuel mixture relative to the cost of diesel fuel
100 % DF	+ 0 %	0 %
25 % BDF	+ 2,23 %	4,27 %
50 % BDF	+ 4,90 %	8,77 %
75 % BDF	+ 8,08 %	13,61 %
100 % BDF	+ 11,61 %	19,08 %
Dynamic regulation of a fuel mixture	+ 5,89 %	8,60 %

While transferring a diesel engine to work on a mixture of fuels with the dynamic adjustment of its percentage, the cost of the additional equipment for small and large-displacement diesel engines is close in value, but an improved power system is more appropriate for large-displacement engines, since their fuel consumption is higher, so the payback period of their equipment will be minimal. These can be large-displacement diesel engines and diesels that are intensively exploited. It is also possible to use a diesel power system with the dynamic adjustment of the percentage of diesel and biodiesel fuel mixture on small-displacement diesel engines, but the economic effect of this will be negligible, and the payback period will increase significantly. Therefore, it is expedient to use the improved system for small-displacement engines only, for the purpose of reduction of harmful emissions of exhaust gases in a diesel engine.

Biodiesel fuel is renewable, with the use of which the number of harmful emissions of the exhaust gases is significantly reduced, namely: CO - by 12%, C_nH_m - by 35%, soot by 50% [9]. For this reason, and from the environmental point of view, it is advisable to use a refined diesel power system with the dynamic regulation of the percentage composition of diesel and biodiesel fuel in places with a high density of the population (city) and in recreational zones. It is effective to use the refined system on vehicles equipped with large-displacement diesel engines being operated within the city. These may be city buses or utility vehicles.

Most of the machinery in the agro-industrial complex is equipped with large-displacement diesel engines, which have a great potential for the use of biodiesel fuel. The agricultural machinery is equipped with diesels operating in a constant mode, there are no sharp accelerations and decelerations; accordingly, the percentage change in the composition of the fuel mixture will be without sudden fluctuations, minimizing the effect of inertness of the change in the percentage composition of the fuel mixture on the operation of the diesel engine. So, it is appropriate to use an improved diesel power system with dynamic regulation of the percentage composition of the mixture of diesel and biodiesel fuel. The advantage of agricultural enterprises is the possibility of organizing the biodiesel production directly at the enterprise. The installations for the production of biodiesel fuel are constructively simple and can be of various capacities, which makes it possible to produce biodiesel fuel in the volumes required for the needs of the enterprise. At the same time, the cost of fuel becomes equal to its cost price, there is no need to deliver it and there is no dependence on price fluctuations in the fuel market. The enterprise receives autonomy in fuel issues.

An improved diesel power supply system with dynamic regulation of the percentage composition of diesel and biodiesel fuel should be used on diesel engines equipped with mobile power plants. As a rule, there are no sharp load differences in diesel generators, which neutralize the inertness of the dynamic regulation of the percentage composition of the fuel mixture. Mobile power plants are

equipped with diesel engines of significantly higher power than the generators themselves, and this leads to the fact that when the diesel generator operates in the mode of maximum load, the engine operates in a partial load mode at a crankshaft rotation frequency close to the rated speed. Hence, the diesel will always operate in modes where it is expedient to use mixtures of fuels with a high biodiesel fuel content, and the diesel power system with dynamic regulation of the percentage of fuel mixture will provide an easy start of the engine on diesel fuel even at low temperatures, and eliminate the negative effects of using biodiesel fuel with an unheated engine.

To increase the efficiency of biodiesel use it is advisable to create one's own production on the basis of large fuel consumers, which will enable the creation of new jobs (social effect) and reduce the dependence on imported energy carriers. In Ukraine, it is possible to disperse the production of biodiesel fuel to all parts of the country (there are raw materials for its production almost everywhere), which will reduce the cost of transporting biodiesel and the number of intermediaries between the producer and the consumer . The need for an extensive logistics center system is eliminated.

When using biodiesel, it is important to take into account that it is chemically corrosion-intensive. Thus, contact with it may possibly soften and decompose natural rubber, synthetic rubber, some adhesives, and plastic, which can lead to the fuel leakage. Some types of paints and coatings may dissolve in the long-term contact with biodiesel. The components containing polypropylene, polyvinyl, polyethylene and the compounds of lead, copper, brass, bronze, zinc should be protected from the contact with biodiesel. For this reason, when moving a diesel engine to work on a mixture of diesel and biodiesel it is necessary to replace the parts that come in contact with the mixture for biodiesel-resistant fuels. It should be noted that the biodiesel fuel materials are used in the most of modern diesel engines.

Besides, while operating diesel engines on a mixture of diesel and biodiesel, it is necessary to pay attention to the fact that biodiesel fuel is more aggressive than the diesel one, so all the deposits in the fuel system remaining after using diesel fuel will break down and increase the intensity of pollution of fuel filters. This results in the earlier maintenance of the engine after its retooling with the replacement of fuel filters.

When using biodiesel, it is necessary to take into consideration the improvement of the lubrication of the engine parts to increase the lifetime of the elements of the power supply system, where the lubrication occurs precisely with the fuel. The results of experimental studies show that the overall lubricating properties of biodiesel are better than diesel, which causes an increase in engine life and fuel pump by 60%. Even the addition of 1% of biodiesel to diesel provides an improvement of 30% of the quality of lubrication of friction pairs [10].

The changeover of a diesel engine to work on a mixture of diesel and biodiesel fuel with the dynamic regulation of its percentage requires the addition of the basic power supply system with additional elements. Most of them are standard components for the base diesel (fuel tank for biodiesel, low-pressure pump for biodiesel, fine and coarse filters, low-pressure pump from an additional tank). A number of other elements are also standard (electromagnetic, reverse and bypass valves, fuel heaters, and a fuel tank for return fuel). A fuel mixer with the ability to control dynamically the percentage of diesel and biodiesel fuel was developed specially for the advanced diesel power supply system.

4. CONCLUSIONS

For effective use of a mixture of diesel and biodiesel fuel, the power system of a diesel engine with dynamic regulation of the mixture composition is improved when the car moves, depending on its speed, driving conditions, and loading.

The conducted experimental researches confirmed the efficiency of such a system and allowed to obtain data on the basis of which the economic feasibility of re-equipment of the existing power supply system to an improved one was made. As we can see from the conducted researches, despite an increase in the consumption of the fuel mixture, the cost is reduced. So, when using a fuel mixture, savings amount to 19%, and with the dynamic regulation of the percentage composition of the fuel

mixture, the cost savings will be 8.6% compared with the use of diesel fuel, which is approximately equivalent to 40% biodiesel.

The use of proposed diesel power supply system with dynamic regulation of the percentage composition of the fuel is expedient for the large-displacement diesel vehicles, as well as to improve the ecological situation in cities – for diesel automobiles that are used as municipal buses and communal transport.

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Received 07.07.2016; accepted in revised from 30.05.2018