Impact of diesel fuel and palm oil blend compositions on the performance of the fuel supply process in the diesel engine

E A Salykin, A V Kurapin, K E Tshibanda, V G Dygalo and V M Slavutskiy

1 PhD, Associate professor, Volgograd State Technical University, Russia, 400005, Volgograd, Lenin avenue, 28
2D. Sc., Professor, Volgograd State Technical University, Russia, 400005, Volgograd, Lenin avenue, 28
3Graduate student, Volgograd State Technical University, Russia, 400005, Volgograd, Lenin avenue, 28
E-mail: esalykin@gmail.com, dygalo@vstu.ru

Abstract. The world experience of using palm oil as a fuel for diesel engines was considered. The influence of the mixture composition on the indices of the injection process at a constant value of the active stroke of the plunger and the mass cyclic feeding of the mixture, corresponding to the nominal cyclic feeding in the case of using only diesel fuel is analyzed. A comparative analysis of the change in the parameters of spraying of diesel fuel mixtures and palm oil fractions from 0% to 60% is performed depending on the specific parameters of the fuel supply equipment and the mixture (working stroke of plunger, cyclic feed and heat input). It is shown that changes in the fuel supply equipment parameters when using mixed fuels based on palm oil are not required, since the corresponding change in the volume cyclic feed and active stroke of the plunger with a change in the proportion of palm oil in the mixture to 60% does not exceed 3%. According to the requirements of the standard, these deviations are within acceptable limits.

1. Introduction

In the last years, the leading countries of the world are giving a great deal of attention to the possibilities in the application of internal combustion engine biofuels made from vegetable oil feedstock in order to reduce the dependence of petroleum resources and significantly reduce greenhouse gas emissions [2].

Using biofuels in diesel engines is called biodiesel fuel or biodiesel. Biodiesel fuel can be used as a mixture with diesel fuel of petroleum origin, and in pure form. Each country has various kinds and stocks of biofuels and their use largely depends on the energy program of this country.

The most common types of biofuels are vegetables oils, therefore they are studied as diesel fuel substitutes and energy sources all over the world. In the European Union (EU) and the United States biodiesel fuel is called oil methyl ester from vegetable oils, basically rapeseed oil. The methyl ester of rapeseed oil as biodiesel is widely used in France, Austria and Germany [1, 3, 4, 19, 20, 21]. Esters of soybean oil are used in the US.

An actively developing research on the application of vegetable oils as a promising source of energy for diesel engines is also being carried out in Russia [1, 3, 4].

In the countries with tropical climate production of palm oil is widespread.
In Malaysia, Indonesia, Thailand, Colombia, Nigeria and other countries, where the conditions for growing oil palms are perfect, interest in the oil palm is increasing. In these countries the technical aspects of palm oil as an alternative fuel for the diesel engine are extensively studied and research is going on [14, 15, 16, 17]. A large number of research papers on engine performance and emission characteristics using a wide range of biodiesel feedstocks have appeared in the last decades. In this paper some results of the research carried out are observed.

1.1. Literature review

Mosarof M H and others [14] reported that many investigations around the world were carried out to study economic aspects, performance emission, wear characteristics and the effects of fuel properties such as cetane number, aromatic content and viscosity on emission characteristics. According to Ziejelewski and Kaufman [12], most researchers have concluded that vegetable oils used as motor fuel, can burn safely during short-time combustion in diesel engine. Others authors showed that high cetane number in a biodiesel methanolysis of ether or palm oil (51 and more) contributes to the reduction of the period of time delay of ignition and lessens the "hardness" of the engine's operation. Vedruchenko V R et al [6] carried out research based on analysis of effects of fundamental physics properties for same selected kinds of diesel fuels on process injection in the higher pression systems. They found that, the properties of using fuel in operating diesel engine have the effects on different indicators of power and efficiency of the engine. It is necessary to bring the stabilization into the process of injection and ignition using an effective device for controlling the viscosity, density and the compressibility.

Markov V A and others [7] carried out the experimental study, the analysis of which shows that, the dynamic development of the fuel jet for an operating diesel engine fuelled by mixed fuel has dependence on the concentration of components of a fuel blends. The maximum length of the jet, the maximum width and the opening angle of the jet during the period of ignition delay depends on the volumetric contents of components in the mixture of diesel and vegetable oils.

Yusaf and others [17] investigated the performance and emission of a 4-cylinder perking diesel engine fueled with 25%, 50% and 75% crude palm oil (CPO) blends. At higher engine speed, they found lower brake-specific fuel consumption (BSFC) and higher torque for the CPO blends, but the brake power produced was slightly lower. Oxygen and nitrogen oxides (NO) emissions were reduced, while carbon mono-oxide (CO) and exhaust gas temperature (EGT) were increased for CPO blends compared with diesel fuel. Ndayishimiyey and Tazerout [11] in 2011 conducted a study of the performance and assessment of the exhaust gases of single-cylinder diesel engine with direct injection combustion chamber, mixtures of crude palm oil and heated palm oil and mixtures of palm biodiesel and diesel fuel. Slightly higher values of specific effective fuel consumption for all tested biofuels in comparison with pure diesel fuel were detected. Effective efficiency of the engine is somewhat increased when using mixtures of crude palm oil, but decreases in all other tested biofuels. Emissions of CO and hydrocarbon (HC) have been significantly reduced (by 30...65%) for palm biodiesel, while NO emissions are increased. Rashid et al [18] in 2015 explored the work of an operating diesel engine fueled by biofuels based on palm (PB20), jatropha (JB20) and methyl ester moringa oil (MB20), in comparison with diesel fuel (B0). The results showed that the decrease in the effective power was up to 8.03 % for MB20, up 6.92 % for PB20, of 8.75 % for JB20 compared to B0. The increase in the effective specific fuel consumption was 8.39 % for MB20, of 7.15 % for JB20 and of 5.42 % for PB20. The reason for this is the low calorific value of the oils. Lowering CO emissions are 22.93 % – MB20, 27.23 % – JB20 and 32.65 % – PB20. This is due to the presence of a larger percentage of oxygen in the oil. Lower HC emissions are 30.26 % – PB20, 19.73 % of JB20, 11.84 % – MB20. It is also due to higher oxygen content, high cetane numbers and high in saturated fatty acids. The increase in NO, emissions is 6.91 % – PB20, 14.22 % – JB20 and 18.56 % – MB20. This is due to earlier combustion of biodiesel fuels and hence higher temperature at the end of combustion due to higher cetane numbers and higher content of oxygen in them. The results also showed the advantage of using a mixture with palm oil in all indicators.
Globally, a large number of literature from highly rated journals in scientific indexes were reviewed, including the most recent publications on palm oils as a biodiesel [14, 15, 16, 18]. However, it was observed that numerous investigations in palm oil as a biodiesel substitute have presented the tribological, environmental and economic aspects of using this type of oil. The effects of the palm oil, properties of its mixture with diesel fuel influencing the performance of fuel injection process in the fuel supply system have not been exhaustively analyzed in special literature, some efforts were made in only few papers.

1.2. The purpose and objectives
The paper presents numerical studies of effect of composition properties of fuel mixture on operation of fuel injection process in the fuel supply system, using selected technical solutions for the stabilizations of fuel supply process and the calorific value of the mixture, and the following problems have been solved:

1 – analysis of the effect of physical properties of palm oil in a mixture with diesel fuel mark L;
2 – analysis of the impact of structural-adjustment parameters of the high pressure pump when operating on mixed fuel. Using diesel fuel mark L active stroke of the plunger h, and injection quantity q, have been recorded. The values of these parameters correspond to those engines operating on diesel fuel.
3 – the analysis of the processes of fuel injection, while maintaining constant the calorific value of the mixture Q, = const, (H, = var) variables q, and h,.

2. Object and methods of research
In this research diesel engine type D-144 made in Vladimir tractor factory (VTZ, Russia) as an object of numerical studies is considered.

It is equipped with fuel pump type UTN-5 with the diameter of the plunger d, = 8 mm, plunger stroke h, = 8 mm, pump rotation speed n, = 1000 mn⁻¹, injectors type FD-22 with the standard nozzle and the pressure of the beginning injection is 17 MPa. The engine specifications are presented in table 1.

| Working compression ignition, 4 stroke |
|--------------------------------------|
| Diesel type direct injection, air refrozen |
| Number and arrangement of cylinder 4, inline vertical |
| Bore and Stroke 105x120 mm |
| Displacement 4.15 l |
| Compression ratio 16.5 |
| Maximum net power 44.1 kW at 2000 rpm |
| Maximum net torque 221.4 N·m at 1550 rpm |

As a base fuel diesel fuel (D100) is used and palm oil (PO) is used as addition to the base fuel. Mixture proportion is 10, 20, 30, 40, 50, 60 vol % of palm oil addition. We denote these mixtures, respectively PO10, PO20, PO30, PO40, PO50, PO60. Pure palm oil we denote as PO100. The basic properties of fuel blends are shown in table 2.

In order to assess the impacts of mixed fuel properties in the fuel supply system during transition from diesel fuel to mixed one, a numerical experiment was carried out using mathematical model integrated in the program complex "PC-injection", developed at the Department "Diesel engines" Moscow State Technical University Bauman.

The mathematical model underlying the PC is based on tested approaches and results of original fundamental research in modern injection modeling machines.
"PC Injection" taken into account here also applies the law of fuel supply and reflects the impact of fuel properties and the blends compositions on the dynamic indicators of the process of fuel injection in fuel supply system [9].

| Properties                                      | D100 | PO100 | PO10  | PO20  | PO30  | PO40  | PO50  | PO60  |
|-------------------------------------------------|------|-------|-------|-------|-------|-------|-------|-------|
| Kinematic viscosity at 40 °C (cSt)              | 3.9  | -     | 4.37  | 4.84  | 5.31  | 5.78  | 6.25  | 6.72  |
| at 100 °C (cSt)                                 |      |       | 8.6   |       |       |       |       |       |
| Density at 20°C (g/cm³)                         | 830.0 | 918.0 | 838.8 | 847.6 | 856.4 | 865.0 | 874.0 | 882.8 |
| Flash point (°C)                                | 250  | 315   | 260   | 270   | 280   | 290   | 300   | 289   |
| Calorific value (MJ/kg)                         | 42.5 | 37.1  | 42.01 | 41.33 | 40.73 | 40.32 | 39.98 | 39.20 |
| Theoretical quantity of air required for ignition 1kg of fuel. (kg/kg) | 14.45 | 12.7  | 14.14 | 13.98 | 13.82 | 13.66 | 13.5  | 13.34 |
| Oxygen content (% by mass)                      | 0.4  | 11.4  | 1.5   | 2.6   | 3.7   | 4.8   | 5.9   | 7     |
| Hydrogen content (% by mass)                    | 12.6 | 12.0  | 12.54 | 12.48 | 12.42 | 12.36 | 12.3  | 12.24 |
| Carbon content (% by mass)                      | 87   | 76.6  | 85.26 | 84.8  | 83.88 | 82.84 | 81.8  | 80.76 |
| Cetane number                                   | 46.5 | 49.0  | 46.75 | 47.0  | 47.25 | 47.5  | 47.75 | 48.50 |
| Heat emitted fuel (J)                           | 2539.8 | 2452.1 | 2534.7 | 2520.5 | 2501.2 | 2511.1 | 2515.8 | 2489.3 |

For the numerical experiment, the following parameters have been used: nominal volumetric cyclic flow 72 mm³, the cyclic mass flow of 0.06 g and density of diesel fuel 830 kg/m³. The values of the parameters correspond at nominal parameters of the engine operation with the diesel fuel.

To identify several factors affecting the efficient performance of the fuel supply, numerical experiments were carried out to study the multifactorial designs tests.
In the first stage, a series of numerical experiments aimed at investigating the effect of composition of diesel fuel mixture with palm on the characteristics of the fuel injection during fixation of the active stroke of the plunger were performed $h_\text{act} = \text{const}$.

In the second phase, the calculation was made to assess of the impact of composition blend on the characteristics of fuel injection process when fixing cyclic flow ($q_\text{cycl} = \text{const}$). A constant value of the active plunger stroke ($h_\text{act} = \text{const}$) and cyclic supply flow of fuel ($q_\text{cycl} = \text{const}$) corresponds to those in the engine operating on diesel fuel.

At the third stage of the numerical experiment we studied the influence of fuel mixture on the basis of diesel fuel with proportion of 10 to 60 vol% of the palm oil to the fuel injection parameters, while maintaining the calorific value of the mixture $Q_\text{см} = \text{const}$, $(H_u = \text{var})$ variables $q_\text{cycl}$ and $h_\text{act}$.

3. Results and discussion

In general, it should be noted that the increased density and viscosity of palm oil are the reason for the increase in mass of the cyclic flow, and the time flow of mixed fuel when it is used in a diesel engine in comparison with diesel fuel according to standards GOST 305-2013. This is confirmed by the following calculations. Calculate the density ($\rho_b$) and mass cyclic flow ($G_\text{cycl}$) for mixed fuel consisting of diesel fuel and palm oil. Take the density of diesel fuel 830 kg/m$^3$, density of palm oil is 918 kg/m$^3$ under normal conditions, volumetric cyclic fuel consumption $- 72$ mm$. The results of the calculations are shown in Fig. 1a.

![Figure 1](image)

**Figure 1.** (a) Dependence of the density $\rho_b$ and mass cyclic flow $G_\text{cycl}$ on volume fraction PO $g_{PO}$.
(b) Dependence of the mass cyclic flow $G_\text{cycl}$ on volume fraction PO $g_{PO}$ at a constant active stroke of the plunger.

In the first time, it was performed the calculations of the parameters of the fuel supply process for the mixed fuel at a constant active stroke of the plunger corresponding to the nominal cyclic feeding on pure diesel fuel, which is equal to 1.93 mm. The results of the calculations are presented in Fig. 1b and 2a. The analysis of these figures shows, that the increase of volume proportion of palm oil in the composition of the mixed fuel leads to the increase in mass of the cyclic flow of the mixture, the increase of average and maximum injection pressures and the total delivery time. This is due to the increase in the density and viscosity of the mixture. It should be noted that a greater increase in mass of the cyclic flow $G_\text{cycl}$ of the mixture with the increase volume proportion of palm oil in the mixture was obtained in the hydrodynamic calculation (see Fig. 1b), in comparison with the mass of the cyclic flow $G_\text{cycl}$ of the mixture obtained only by taking into account the density of the mixture (see Fig. 1a). This can be explained by a reduction in the leakage through the gaps in the piston pair due to the increase in viscosity of the mixture and the growth of palm oil volume proportion $g_{PO}$. 
For the reason of e stabilization of the cyclic mass flow $G_{cycl.b}$ of the mixture fuel with the increase of the volume proportion of palm oil in the mixture $g_p$, it is necessary to reduce an active stroke of the plunger, that is, to adjust the fuel equipment (see Fig. 3a). On that basis, a series of calculations of indicators of processed fuel were performed for the mixed fuel under the condition of constant mass of the cyclic flow $G_{cycl}$ of the mixture with the corresponding cyclic feeding on pure diesel fuel, which is equal to 0.06 g. The results of the calculations are shown in Fig. 2b.

![Figure 2](image1)

**Figure 2.** (a) Dependence of the average $P_{in,av}$ and maximum $P_{in,max}$ injection pressures on volume fraction PO $g_p$ at a constant active stroke of the plunger; (b) Dependence of the average $P_{in,av}$ and maximum $P_{in,max}$ injection pressures on volume fraction PO $g_p$ at a constant mass cyclic flow

![Figure 3](image2)

**Figure 3.** (a) Dependence of the active stroke of the plunger on volume fraction PO $g_p$ at a constant mass cyclic flow; (b) Dependence of the active stroke of the plunger on volume fraction PO $g_p$ at a constant amount of introduced heat

As can be seen from Fig. 3a, the active stroke dropped from 1.93 to 1.7 mm, however, the maximum and average injection pressures continue to increase with the increase of the volume proportion of palm oil in the mixture $g_p$ up to 24.9 MPa and 15.8 MPa respectively (see Fig. 2b), due to the increase of density and viscosity of the mixture.

Stabilization of the cyclic mass flow $G_{cycl}$ of the mixture with the increase of the volume proportion $g_p$ of palm oil in the mixture leads to a decrease in the amount of heat generated by the fuel in the
Combustion chamber along with a reduction of the calorific value of the mixture, which leads to lower power diesel. Figure 6 shows the change of in the combustion chamber at a constant cyclic mass flow $G_{cycl}$ of the mixture, which is equal to 0.06 g. The calorific value of diesel fuel is taken equal to 42500 kJ/kg, palm oil – 37100 kJ/kg.

In this regard, it seems appropriate to adjust the active stroke of the plunger with the constant amount of heat generated by the fuel into the combustion chamber. We have performed calculations of the parameters of the fuel supply process for the mixed fuel in consideration with these of these circumstances for a constant amount of the heat $Q_b$ equal to 2.54 kJ, and corresponding to pure diesel fuel at a nominal cyclic flow and is. The results of the calculations are presented in Figures 4b, 3b and 5.

![Figure 4](image1)

**Figure 4.** (a) Dependence of heat generated by the fuel in the combustion chamber on volume fraction PO at a constant cyclic mass flow of the mixture; (b) Dependence of mass cyclic flow $G_{cycl}$ and volume cyclic flow $V_{cycl}$ on volume fraction PO at a constant amount of the heat generated

![Figure 5](image2)

**Figure 5.** Dependence of the average $P_{in,av}$ and maximum $P_{in,max}$ injection pressures on volume fraction PO at a constant amount of the heat generated

The total duration of injection under these conditions remained virtually unchanged. Analysis of Figures 4b, 3b and 5 shows, that the mass and volume injection of the mixture increases as the mass flow of the mixture increases less than when maintaining a constant active stroke of the plunger (compare Fig. 1b). The active plunger stroke is reduced less when maintaining a constant mass of the
cyclic flow of the mixture (compare Fig. 3a). The average and maximum injection pressure increase less while maintaining a constant cyclic feed of the mixture (compare Fig. 2b).

In our opinion, for the practical use of the most valuable results presented on the calculations of fuel injection performed while maintaining a constant the amount of heat introduced by the fuel into the combustion chamber. The change in the mass and volumetric flow of mixed fuel and adjusting injection pump setting – the active stroke of the plunger when changing the volume fraction $g_p$ of palm oil in the mixture, for this case are shown in table 3.

**Table 3.** The variation of the adjusting parameters of fuel injection pump when changing the volume fraction of palm oil

| Variation of adjusting parameters | Units | D100 | PO10 | PO20 | PO30 | PO40 | PO50 | PO60 |
|----------------------------------|-------|------|------|------|------|------|------|------|
| Mass cyclic flow of the fuel mixture | g | 0 | 0.0006 | 0.0013 | 0.0019 | 0.0025 | 0.0032 | 0.0038 |
| % | 0 | 1.06 | 2.12 | 3.18 | 4.24 | 5.3 | 6.36 |
| Volumetric cyclic flow of the fuel mixture | cm³ | 0 | 0.0002 | 0.0003 | 0.0005 | 0.0008 | 0.001 | 0.0013 |
| % | 0 | 0.22 | 0.48 | 0.79 | 1.07 | 1.41 | 1.78 |
| Active stroke of the plunger | mm | 0 | 0.02 | 0.03 | 0.038 | 0.045 | 0.054 | 0.056 |
| % | 0 | 1.04 | 1.56 | 1.97 | 2.33 | 2.8 | 2.9 |

4. Conclusion

Thus, the use of fuel blends, having palm oil as one of the components in operating diesel equipment with injection system type direct injection, does not require additional adjustment of fuel injection pump to maintain constant power of the operating diesel engine. As such the required variations in the change of *volumetric* cyclic flow and the change in active stroke of the plunger in accordance with changing the proportion of palm oil in the mixture up to 60% do not exceed 3%. For diesels engines using a multi-fuel supply system, the deviations of up to 5% [22] at the nominal cyclic flow are admitted. However, these deviations for the injection system fuelling the operating diesel engine in this study are within acceptable limits, which allow the use of mixed fuel based on palm oil.

References

[1] Devyanin S N, Markov V A, Semenov V G 2008 Rastitelnye masla i topliva na ih osnove dlja dizelnyh dvigateley (Vegetable oils and fuels on their basis for diesel engines). FGOU VPO MGAU, Moskva

[2] Lukanin V N et al. 2007 Dvigateli vnutrennego sgoraniya. Kniga 1. Teoriya rabochih protsessov (The internal combustion engines. Book 1. The theory of working processes). Vyisshaya shkola, Moskva

[3] Markov V A, Gayvoronskiy A I, Grehov A V et al 2008 Rabota dizeley na netraditsionnyih toplivah (Operation of diesel engines on alternative fuels). Legion-Avtodata, Moskva

[4] Aleksandrov A A; Arharov I A; Markov V A et al 2012 Alternativnyie topliva dlja dvigateley vnutrennego sgoraniya. (Alternative fuel for internal combustion engines). OOO NITs «Inzhener», OOO «Oniko-M», Moskva

[5] Valeho P R et al 2014 Sravnitelnyie ispytaniya alternativnyih topliv dlja dizelnyh dvigateley
(Comparative tests of alternative fuels for diesel engines). Vestnik MGTU im. N. E. Baumana. Ser. “Mashinostroenie” 6:596.

[6] Vedruchenko V R, Kraynov V V, Litvinov P V 2016 Vliyanie svoystv raznosortnyih topliv dlya dizeley na karakteristikii toplivopodachi (The influence of the properties of different sorts of fuels for diesel engines on the characteristics of the fuel supply). Vestnik SibADI, Omsk. 2(48):44-49.

[7] Priyandaka A, Valeho P I et al 2003 Eksperimentalnoe opredelenie kineticheskih konstant vosplamneniyi rastitelnyih topliv v usloviyah DVS (Experimental determination of kinetic constants of ignition of vegetative fuels in the conditions of the internal combustion engine). Vestnik Rossiyskogo universiteta druzhby narodov: Inzhenernyie issledovaniya 1:29-31

[8] Markov V A 2014 Vliyanie sostava smesevogo biotopliva na parametryi protsess vpryiskivaniya topliva v dizele (The influence of composition of mixed biofuels on process parameters of injection of fuel in a diesel engine). Traktoryi i selhozmashinyi 12:3-9

[9] Grekhov L V, Gabitov I I, Negovora A V 2013 Konstruktiiya, raschet i tehnicheskiy servis toplivopodayuschih sistem dizeley (Design, calculation and technical services fuel supply systems of diesel engines). Legion-Avtodata, Moskva

[10] Moshin R, Majid Z A, Shimian A H, Nasri N S, Sharer Z 2014 Effect of biodiesel blends on engine performance and exhaust emission for diesel dual fuel engine. Energy conversion and management 88:821-828

[11] Januan J, Ellis N 2010 Perspectives on biodiesel as sustainable fuel. Renew sustain Energy Rev 14:1312-1320

[12] Ziejewski M, Kaufman K 1983 Vegetable oils as a potential alternate fuel in direct injection diesel engines. SAE technical paper.

[13] Martinez G, Sanchez N, Enginar J M, Gonzalez J F 2014 Fuel properties of biodiesel from vegetable oils and oil mixtures. Influence of methyl esters distribution. Biomass bioenergy 63:22-32

[14] Mosarof M H et al. 2015 Implementation of palm biodiesel based on economic aspects, performance, emission and wear characteristics. Energy conversion and management 105:617-629

[15] Ndayishimiye P, Mohamed Tazerout 2011 Use of palm oil-based biofuel in the international combustion engines: Performances and emissions characteristics. Energy 361:790-796

[16] Sanjid A et al. 2013 Impact of palm, mustard, waste cooking oil and calophyllum inophyllum biofuels on performance and emission of CI engine. Renewable and sustainable energy reviews 27:664-682

[17] Yusaf T F, Yousif B F, Elawad M M 2011 Crude palm oil fuel for diesel-engines: experimental and ANN simulation approaches. Energy 36:4871-4878

[18] Rashid M M et al. 2016 Performance and emission characteristics of a diesel engine fueled with palm, jatropha and moringa oil methyl ester. Industrial crops and products 79:70-75

[19] Azad A, Khan M, Ahasan T, Ahmed S 2015 Energy scenario: production consumption and prospect of renewable energy in Australia. Power Energy Eng 2:19

[20] Azad A, Uddin S A 2013 Performance study of a diesel engine by first generation biofuel blends with fossil fuel: an experimental study. Renew sustain Energy 5:013-118

[21] Shy E G (1993) Diesel fuel from vegetable oils: status and opportunities. Biomass bioenergy 4:227-242.

[22] GOST 10578-95 Nasosyi toplivnyie dizeley. Obschie tehnicheskie usloviya (Diesel engine fuel pumps. General specifications). Izdatelstvo standartov, Moskva.