Petroleum Diesel Fuel and Linseed Oil Mixtures as Engine Fuels

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Abstract. The actual problem is the use of alternative biofuels in automotive diesel engines. Insufficiently studied are the indicators of toxicity of exhaust gases of these engines operating on biofuel. The aim of the study is to identify indicators of the toxicity of exhaust gases when using of petroleum diesel fuel and linseed oil mixtures as a fuel for automotive diesel engines. Physical and chemical properties of linseed oil and its mixtures with petroleum diesel fuel are considered. Experimental researches of D-245.12C diesel are carried out on mixtures of diesel fuel and corn oil with a different composition. An opportunity of exhaust toxicity indexes improvement using these mixtures as a fuel for automobiles engine is shown.

1. Physical and chemical properties of linseed oil and its mixtures with petroleum diesel fuel

Modern development stage of engine construction is characterized by a wider alternative engine fuels using [1]. The choice of one or another alternative fuel is firstly determined with a significant source of raw materials for its production. Byproducts are often formed during an agricultural manufacture. They can be used for alternative engine fuels yield. For example these are vegetable oils (sunflower, rapeseed, soybean) that are remained after protein food obtaining for cattle – oilcake, meal and etc. Another example of complex agricultural products using is flax growing. Its fiber goes to different cloth manufacture and linseed oil is produced from seeds. This oil is used as edible oil. Linseed oil is one of the best drying oils and has a big technical appliance at the same time. Attractiveness of raw materials source above for engine oils production is determined with com-parably low price of vegetable oils and this charge source renewability [1, 2].

The opportunity of vegetable oils using as motor oils determines with molecules composition and structure. These oils are mainly consist of triacylglycerides (95-97%) – organic compounds, esters of glycerin and different fatty acids, and also mono- and diacylglycerides. Acyglycerides in its turn contain molecules of various fatty acids which are joined with \( \text{C}_3\text{H}_5(\text{OH})_3 \) glycerin molecule [1, 2]. Vegetable oils contain mainly fatty acids with even number of carbon atoms (for example \( \text{C}_{14} \), \( \text{C}_{16} \), \( \text{C}_{18} \) b and etc.). Vegetable oils consist both of unsaturated fatty acids (oleic-, linoleic-, linolenic- and etc.) and saturated fatty acids (tetradecanoic, palmitic-, stearic- and etc.). Fatty-acid compound of linseed oil differs from similar composition sunflower oil which is the most common in Russia. So if sunflower oil is rich in linoleic acid, linseed oil contains linolenic acid having three unsaturated bonds. Thereby linseed oil is less stable in oxidizing processes compared with sunflower oil.
The carried out analysis of linseed oil physical and chemical properties confirmed an opportunity of its using as motor oil for diesels. However such appliance is not always possible because of linseed oil properties distinctions from similar petroleum diesel fuel characteristics. Thereby linseed oil is advantageous to use as engine oil only after its being refining or in mixture with diesel- or alternative fuels. The analysis of specified linseed oil appliance opportunities shows that its using in mixtures with petroleum diesel fuel is the most advisable. Un-refined linseed oil made by OOO “Aromavita” (Kurilovo village, Podolsky district, Moscow region) is researched for opportunity assessment of such linseed oil appliance. And its mixture with petroleum diesel fuel (L-mark under state standard № 305-82) of 5 and 9% (by volume) linseed oil is also explored (table 1).

Linseed oil differ noticeably with high density and viscosity compared with petroleum diesel fuel. Therefore diesel operation is advisable on diesel fuel and linseed oil mixtures. These components are well mixed between themselves forming stable mixtures. And besides, acceptable physical properties of mixture can be achieved by the way of mixture fuel composition selection. The considered mixture biofuels, having 5 and 9% of linseed oil, have heightened density and viscosity. But these properties are closer to the similar diesel fuel characteristics (mixture biofuel densities, having 9% of linseed oil, and diesel fuel ones are equal 837 and 830 kg/m$^3$ respectively, and their viscosities – 6.0 and 3.8 mm$^2$/s, table 1). Such physical properties differences of linseed oil (and also its mixtures with diesel fuel) from petroleum diesel fuel properties affect process parameters of diesel fuel supply, fuel spraying and mixing characteristics. Specified mixture biofuels differ from petroleum diesel fuel by a row of other physical and chemical properties: auto-ignition temperature, cetane number, calorific efficiency (low heat value) and etc. All of the factors affect indexes of fuel economy and diesel exhaust toxicity operating on indicated fuels above.

### Table 1. Physical and chemical properties of researched fuels.

| Physical and chemical properties | Fuel |
|---------------------------------|------|
|                                 | Diesel fuel | Linseed oil | 95% diesel fuel mixture and 5% linseed oil | 91% diesel fuel mixture and 9% linseed oil |
| Density at 20 °C, kg/m$^3$      | 830       | 912        | 834                                | 837                |
| Kinematic viscosity, mm$^2$/s   |           |            |                                    |                    |
| at 20 °C                        | 3.8       | 59.6       | 4.5                                | 6.0                |
| at 40 °C                        | 2.3       | 23.9       | -                                  | -                  |
| Surface tension coefficient s at 20 °C, mH/m | 27.1     | 30.0       | -                                  | -                  |
| Low heat value, kJ/kg           | 42500     | 37600      | 42200                              | 42000              |
| Cetane number                   | 45        | 38         | -                                  | -                  |
| Auto-ignition temperature, °C   | 250       | 300        | -                                  | -                  |
| Cloud point temperature, °C     | -25       | -12        | -                                  | -                  |
| Chilling temperature, °C        | -35       | -20        | -                                  | -                  |
| Air amount which is necessary for 1 kg substance combustion, kg | 14.3 | 12.62 | 14.23 | 14.16 |
| %-content by mass               |           |            |                                    |                    |
| C                               | 87.0      | 77.8       | 86.54                              | 86.17              |
| H                               | 12.6      | 12.0       | 12.57                              | 12.55              |
| O                               | 0.4       | 10.2       | 0.89                               | 1.28               |
| Common sulfur content (%) by mass | 0.20    | 0.002      | 0.190                              | 0.182              |
Note: “-” – properties were not determined; there is specified volumetric percentage content of components for mixtures

The row of published works is known. These works are dedicated to linseed oil using as motor fuels for diesel engines both in pure form [3, 4, 5] and after methyl ether output of linseed oil from it [6, 7, 8, 9]. Moreover diesel operation on diesel fuel mixtures and linseed oil is advisable in connection with indicated distinctions of linseed oil physical and chemical properties from similar characteristics of petroleum diesel fuel. But the problem of definition of indicators of toxicity of exhaust gases when using of petroleum diesel fuel and linseed oil mixture as a fuel for automotive diesel engines is poorly understood.

2. Researches of the diesel operating on mixtures of petroleum diesel fuel and linseed oil

Experimental researches of D-245.12C-type diesel (4CN 11/12.5) were carried out. It was made for the opportunity confirmation of petroleum diesel fuel and linseed oil using as a motor fuel. This diesel was made by Minsk Motor Factory and it was mounted on light commercial vehicles “Bychok”, on buses of Pavlovsky Bus Factory also and on “Belarus” tractors.

The diesel is researched at the motor stand on full-load curve mode and 13-mode test cycle ECE R49. Diesel settings by adjusting fuel injection advance angle (13° of crankshaft rotation to the top dead center) and by dosaging rail stop position (maximum fuel feed stop) were stayed constant at all considered fuel types using. Experiences of D-245.12C-type diesel have been carried out at the first researches stage. It has been made on clean diesel fuel and on mixture of 91%-diesel fuel and 9%-linseed oil in full-load curve modes. The results are shown in figure 1 and table 2.

It should be noted according to these data that availability of oxygen atoms in linseed oil molecules led to perceptible reduction of diesel exhaust smokiness operating on mixture biofuel. So transition from diesel fuel to mixture of 91%-diesel fuel and 9%-linseed oil accompanied exhaust smokiness reduction \(K_{g}\) from 16 to 11% on the Hartrige scale in maximum capacity mode at \(n=2400\text{rpm}\). And opacity was decreased from 43 to 36% on the Hartrige scale in maximum torque mode at \(n=1500\text{rpm}\).

The experimental researches results of D-245.12C in 13-mode testing cycle regimes of ECE R49 are shown in figure 2. According to the data it should be noticed that there is a trend of content reduction in exhaust of nitric oxides \(C_{NOx}\) (figure 2, b), carbon monoxide \(C_{CO}\) (figure 2, c) and unburned hydrocarbons \(C_{CHx}\) (figure 2, d).

The indexes of fuel economy and integrate specific mass exhausts of toxic components in 13-mode cycle \((e_{NOx}, e_{CO} \text{ and } e_{CHx} \text{ respectively})\) are calculated. It is realized in agreement with given characteristics (figure 2) of fuel consumption per hour \(G_T\) and content of normed toxicity components in exhaust (nitric oxides \(C_{NOx}\), carbon monoxide \(C_{CO}\), unburned hydrocarbons \(C_{CHx}\)) with appliance of practical standards. Toxic components concentrations in exhaust \((C_{NOx}, C_{CO}, C_{CHx})\) are determined and their hourly mass emissions \((E_{NOx}, E_{CO}, E_{CHx})\) are calculated at the integral toxicity estimation of engine exhaust in such cycle regimes in every mode. The obtained values of emissions are summarized for all cycle by every component with an allowance for weight coefficients \(K_i\) reflecting time fraction of every regime. And after that specific mass emissions of harmful substances are determined according to the formulas with division by conditional average capacity of the diesel for experimental cycle \(\sum(N_{e_i}, K_i)\) [2]:

\[
e_{NOx} = \frac{\sum_{i=1}^{13} E_{NOx_i} \cdot K_i}{\sum_{i=1}^{13} N_{e_i} \cdot K_i}, \quad e_{CO} = \frac{\sum_{i=1}^{13} E_{CO_i} \cdot K_i}{\sum_{i=1}^{13} N_{e_i} \cdot K_i}, \quad e_{CHx} = \frac{\sum_{i=1}^{13} E_{CHx_i} \cdot K_i}{\sum_{i=1}^{13} N_{e_i} \cdot K_i}.
\]

Assessment of operational fuel consumption in 13-mode cycle regimes is appraised by average (conditional) specific effective fuel consumption and conditional effective performance. They were determined using dependencies [2]
where \( G_T \) is fuel consumption per hour in \( i \)-mode; \( H_U \) is inferior calorific value, MJ/kg. The calculations results of showed parameters are represented in table 2.

**Figure 1.** Dependency of effective power \( (N_e) \), torque \( (M_e) \), fuel consumption per hour \( (G_T) \), air-fuel ratio \( (\alpha) \), exhaust smokiness \( (K_X) \) and specific effective fuel consumption \( (g_e) \) of D-245.12C-type diesel from crankshaft rotating speed \( (n) \). It happens in full-load curve mode using different fuels: 1-diesel fuel; 2-mixture of 91%-diesel fuel and 9%-linseed oil.
Table 2. D-245.12C-type diesel indexes operating in different fuels.

| Diesel indexes | Sort of fuel | Diesel fuel | 95% diesel fuel mixture and 5% linseed oil | 91% diesel fuel mixture and 9% linseed oil |
|----------------|-------------|-------------|----------------------------------------|----------------------------------------|
| Specific effective fuel consumption $g_c$, g/(kWe·h): | Diesel fuel | 248.4 | 250.8 | 252.1 |
| - in a maximum output mode | 226.2 | 228.9 | 230.1 |
| Effective diesel performance $\eta_c$: | Diesel fuel | 0.341 | 0.340 | 0.340 |
| - in a maximum output mode | 0.374 | 0.373 | 0.373 |
| Exhaust smokiness $K_X$, % on the Hartridge scale: | Diesel fuel | 16.0 | 12.0 | 11.0 |
| - in a maximum output mode | 43.0 | 37.5 | 36.0 |
| Integrates in 13-mode cycle regimes: | Diesel fuel | 247.97 | 248.72 | 252.26 |
| - effective fuel consumption $g_{c, cond}$, g/(kWe·h) | 0.341 | 0.343 | 0.340 |
| - effective performance $\eta_{c, cond}$ | Diesel fuel | 0.7018 | 6.230 | 6.441 |
| - nitric oxides $e_{NOx}$ | 1.723 | 1.631 | 1.511 |
| - carbon monoxide $e_{CO}$ | 0.788 | 0.695 | 0.664 |
| - unburned hydrocarbons $e_{CHx}$ | Diesel fuel |

The presented data in table 2 confirm an improvement opportunity of D-245.12C diesel ecological indexes which is transferred from diesel fuel to mixture of 91%-diesel fuel and 9%-linseed oil. So exhaust smokiness reduced at 16-31% compared with petroleum diesel fuel appliance. It occurred during submission into diesel combustion chamber of experimental mixture biofuel in maximum capacity and maximum torque modes. Specific mass emission of unburned hydrocarbons $e_{CHx}$ reduced from 0.788 to 0.664 g/(kWe·h), i.e. at 15.7%, in 13-mode cycle regimes. Specific mass emission of carbon monoxide $e_{CO}$ decreased from 1.723 to 1.511 g/(kWe·h), i.e. at 12.3%. Wherein specific mass emission of nitric oxides $e_{NOx}$ reduced from 7.018 to 6.441 g/(kWe·h), i.e. at 8.2%, and conditional diesel performance $\eta_{c, cond}$ remained practically constant (it decreased from 0.341 to 0.340 that was within accuracy limits of determination of this index).

The experimental results of D-245.12C-type diesel are presented in figure 1 and 2. They are obtained during this diesel operation on mixture biofuel of 91%-diesel fuel and 9%-linseed oil. But the question about mixture biofuel composition influence on diesel characteristics is the cause of particular interest. Thereby the analysis have been carried out of D-245.12C-type diesel indexes operating on clean petroleum diesel, mixture of 95%-diesel fuel and 5%-linseed oil, mixture of 91%-diesel fuel and 9%-linseed oil.

The carried out experimental researches results of D-245.12C-type diesel on indicated mixture fuels are presented in table 2 and figure 3, a. Linseed oil concentration increasing in mixture biofuel $C_{LO}$ from 0 to 5 and 9% leads to specific effective fuel consumption growth ($g_c$ increases from 248.4 to 250.8 and 252.1 g/(kWe·h)) and exhaust smokiness reduction $K_x$ from 16.0 to 12.0 and 11.0% in a maximum capacity mode at $n=2400rpm$. Similar increasing of $C_{LO}$ was accompanied with growth of $g_c$ from 226.2 to 228.9 and 230.1 g/(kWe·h) and reduction of $K_x$ from 43.0 to 37.5 and 36.0% in a maximum torque mode at $n=1500rpm$. The presented data proof that considered mixture biofuel appliance allowed reducing exhaust smokiness noticeably. Indicated increase of specific mixture biofuel consumption is explained with their lower inferior calorific value $H_U$ (table 2).
efficiency of combustion process was changing relatively weakly, during the linseed oil content increasing in mixture biofuel. So conditional effective diesel performance $\eta_{\text{cond}}$ was 0.341, 0.340 and 0.340 in a maximum capacity mode at $n=2400$ rpm, having such concentration of linseed oil in mixture biofuel: $C_{LO}=0; 5$ and 9%. And $\eta_{\text{cond}}$ was equal to 0.374, 0.373 and 0.373 in a maximum torque mode at $n=1500$ rpm (table 2).

![Graphs](image)

**Figure 2.** Dependence of fuel consumption per hour $G_T$ (a), volumetric concentration of nitric oxides $C_{NOx}$ (b), carbon monoxide $C_{CO}$ (c) and unburned hydrocarbons $C_{CHx}$ (d) in exhaust gases of D-245.12C-type diesel from rotating speed $n$ and torque $M_t$ using different fuels: 1 – diesel fuel; 2 – mixture of 91%- diesel fuel and 9%-linseed oil.

Integral values in 13-mode experimental cycle regimes of specific mass emissions of toxic components are illustrated in table 2 and figure 3, b. They confirmed an opportunity of perceptible ecological indexes improvement of researched diesel using mixture biofuels. Application of them allowed reducing emissions of all toxic diesel exhaust components: nitric oxides $NO_x$, carbon monoxide $CO$, unburned hydrocarbons $CHx$. Emissions of nitric oxides $e_{NOx}$ were respectively 7.018,
6.230 and 6.441 g/(kWe·h); carbon monoxide emissions $e_{CO} = 1.723, 1.631$ and 1.511 g/(kWe·h); unburned hydrocarbon emissions $e_{C_H}$ – 0.788, 0.695 and 0.664 g/(kWe·h) at linseed oil concentration in mixture biofuel $C_{LM} = 0, 5$ and 9%. Figure 3 data prove optimization conducting advisability of explored mixture biofuels composition with the aim of toxic components emissions minimization of diesel exhaust.

![Diagram](image)

**Figure 3.** Dependency of specific effective fuel consumption $g_e$, effective performance $\eta_e$, exhaust smokiness $K_X$ in full-load curve modes (a), specific mass emissions of nitric oxides $e_{NO_x}$, carbon monoxide $e_{CO}$ and hydrocarbons $e_{CH_x}$ in 13-mode regimes of diesel experimental cycle (b). The relation of D-245.12C-type diesel is shown from lin-seed oil content $C_{LO}$ in mixture biofuel: 1 - in maximum capacity mode at $n=2400$rpm; 2 - in maximum torque mode at $n=1500$rpm.

3. Conclusion

- Physical and chemical properties of diesel fuel and linseed oil mixtures with low content of the last (10%) are close to petroleum diesel fuels characteristics.
- Carried out experimental researches of D-245.12C diesel on mixtures of petroleum diesel fuel with linseed oil confirmed an opportunity of considerable ecological indexes improvement of researched diesel.
- Appliance of these mixtures as motor fuel allowed reducing all normed toxic components emissions of researched diesel exhaust – nitric oxides $NO_x$, carbon monoxide $CO$, unburned hydrocarbons $CH_x$.
- During the transfer of researched diesel from diesel fuel to mixture of 91%-diesel fuel and 9%-linseed oil nitric oxides emissions $e_{NO_x}$ reduced from 7.018 to 6.441 g/(kWe·h), carbon monoxide emissions $e_{CO}$ reduced from 1.723 to 1.511 g/(kWe·h), unburned hydrocarbons emissions $e_{CH_x}$ reduced from 0.788 to 0.664 g/(kWe·h).
- Increase of linseed oil concentration in mixture biofuel $C_{LM}$ from 0 to 9% in maximum capacity mode at $n=2400$rpm leads to exhaust smokiness reduction $K_X$ from 16.0 to 11.0% on the Hartrige scale, and from 43.0 to 36.0% in maximum torque mode at $n=1500$rpm on the Hartrige scale.
- Content optimization conducting of researched mixture biofuels is advisable with a view to emissions minimization of exhaust toxic components.
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