Methods of assessment of modernization of the tractor Belarus 922 to work on ethanol-containing fuel

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Abstract. The relevance of this work is due to the need to reduce environmental damage from the use of diesel engines, which can be achieved using alternative fuels. The aim of the work is a technical and economic analysis of the ecological efficiency of the use of ethanol-fuel emulsions. The work was carried out using a standard methodology for determining the economic efficiency of implementing environmental measures and assessing economic damage. The authors made an integrated assessment of the hazard of exhaust gases as a sum of hazard categories of substances included in these gases. The economic efficiency of using ethanol-fuel emulsion with 40% ethanol was calculated. Moreover, the authors performed a calculation and a comparative assessment of the ecological class of diesel fuel and ethanol-fuel emulsion. Based on the results of the research, conclusions were drawn on reducing the amount of harmful substances (carbon monoxide, carbon dioxide, nitric oxide, and soot particles) in waste gases using an ethanol-fuel emulsion and the economic effect of this solution. Using ethanol-fuel emulsion in the work of the tractor makes it possible to reduce the criterion of the environmental hazard of exhaust gases by more than 6 times and obtain an annual economic benefit from reducing the environmental hazard to 8500 rubles. The results of the research can be applied to developing alternative fuels which are used further in diesel engines in various sectors of the national economy.

1. Introduction

The use of alternative fuels in diesel engines is one of the most promising solutions to reduce the global energy crisis. Researchers all over the world are investigating the possibility to use various fuels.

Various methods of using alcoholic fuels (ethanol), biogas (BG), generator gas (GG), vegetable oils are being studied at Vyatka State University (VSU) for a long time. The researches are aimed to create fuels with the possible maximum ethanol content, which guarantee the operation of the diesel engine with the indices identical to its work on diesel fuel (DT) [1-9].

Currently, there is no universal methodology that allows to evaluate the comparative cost-effectiveness of various alternative and mixed fuels. Number of works offer to compare methods of reducing toxicity by the K indicator, which is equal to the cash costs connected with the application of each of the methods referred to a 1% reduction in the toxicity of the exhaust gas [10].

At the same time, it is necessary to evaluate the effectiveness of each new alternative fuel in terms of its creation, the cost of installing new devices, reducing the toxicity of exhaust gases, reducing the consumption of motor fuel, changing the operation of the diesel engine.
2. Materials and methods

The authors of the research used ethanol-fuel emulsions (EFE) on the basis of diesel fuel (DF) in accordance with GOST 305-2013 with additives of urea alkenyl succinimide and distilled water (up to 12%). The studies were carried out at the stand SAK 670N (figure 1) with a balancing pendulum and in the fields on the tractor Belarus-922 (figure 2).

\[ K = \frac{C_n}{\eta_i} \tag{1} \]

where \( C_n \) are costs applied for using the \( i \)-method, RUB;
\( \eta_i \) is the efficiency of reducing the concentration of the \( I \) toxic component.
In turn, costs are calculated by the formula (2):

$$C_n = aC_1 + b\Delta G_T T + C_2,$$  \hspace{1cm} (2)

where $C_1$ is the cost of the reduction in the toxicity of the exhaust gas, RUB; $a$ is the coefficient of annual change of the device, equal to the annual run or the operating time of the machine; $\Delta G_T$ is the change in diesel fuel consumption, kg/h; $b$ is the cost of the fuel, RUB/kg; $T$ is the operating time, h; $C_2$ is the cost of operation, maintenance and repair of constructive innovations, RUB.

The effectiveness of reducing the concentration of the toxic component is calculated by the formula (3):

$$\eta_i = (C_{i1} - C_{i2}) / C_{i1} \times 100\%,$$  \hspace{1cm} (3)

where $C_{i1}$ and $C_{i2}$ is respectively, the concentration of the i-th component without application and using the method of reducing toxicity, %.

According to [10], the effectiveness of the application of ethanol-fuel emulsion can be estimated by reducing the economic damage to the national economy of the country by environmental pollution.

The material damage from air pollution for each source can be determined by the formula (4) [10]:

$$V = \gamma \sigma f M,$$  \hspace{1cm} (4)

where $V$ is the amount of damage, RUB/year;
\( \gamma \) is the relative damage coefficient, RUB / kg;
\( \sigma \) is the relative air pollution hazard for specific conditions, the dimensionless quantity;
\( f \) is the correction taking into account the nature of the impurity scattering in the atmosphere, \( f = 10 \) for motor transport;
\( M \) is the resulted mass of annual emission of pollution, kg / year.

The latter value is calculated by formula (5) as a sum of all used impurities:

\[
M = \sum A_i m_i,
\]

(5)

where \( A_i \) is the index of relative aggressiveness of the impurity of the \( i \)-th species, cond. kg / kg;
\( m_i \) is the mass of annual release of impurity of the \( i \)-th species per year, t / year.

To calculate the economic efficiency, there was developed an original program, which makes possible to perform calculations using a computer. Table 1 shows the calculation data.

**Table 1.** Data on the calculation the effectiveness of the use of ethanol-fuel emulsions to reduce the toxicity of exhaust gases.

| Indicators                                      | DF | EFE |
|------------------------------------------------|----|-----|
| The cost of the emulsion dispensing agent \( C_1 \), RUB | -  | 1000 |
| Coefficient of annual device replacement      | 1.0| 1.0 |
| Cost of 1 kg of fuel, RUB                     |    | 38-50 |
| Change in diesel fuel consumption during emulsion operation, kg / h | - | +3.5 |
| Engine operating time, h                      |    | 1500 |
| Cost of operation, maintenance and repair \( C_2 \), rub/year |    | 4000 |
| Costs applied to the use of emulsion, \( C_m \), rub      |    | 8000 |
| The value of \( K \) при снижении NO\(_x\) в ОГ, RUB/% |    | 15.2 |
| Значение показателя \( K \) with reduction of \( C \) in exhaust gas, RUB/% |    | 16.7 |
| The economic effect of reducing the damage caused to the environment by exhaust gas, RUB / 1 tractor per year |    | 8500 |

Using only the quantitative characteristics of exhaust gas emissions, it is impossible to unequivocally judge which impurity content is the most dangerous in exhaust gas, which of the tested engines is environmentally more dangerous or more "clean", how to evaluate the environmental efficiency of the use of various fuels and various design solutions, what mathematical law shows a change in the environmental hazard of the vehicle's exhaust gas in the process of its operation, etc.

Thus, there is a need for an integrated assessment of harmful substances in the exhaust gas. For the integrated (complex) assessment of the toxicological hazard of each individual toxic substance in the engine we can use the so-called hazard category of the substance, which is calculated by the formula (6):

\[
VHC = \sum_{i=1}^{n} SHC_i = \sum_{i=1}^{n} \left( \frac{M_i}{MAC_i} \right),
\]

(6)

where \( SHC_i \) is the hazard category of the \( i \)-th substance, m\(^3\) / s;
\( MAC_i \) is the one-time maximum permissible concentration of substance, characterizing its toxicity, g / m\(^3\);
\( \sigma \) is the relative air pollution hazard for specific conditions, the dimensionless quantity;
\( f \) is the correction, taking into account the nature of the impurity scattering in the atmosphere, \( f = 10 \) for motor transport;
\( M_i \) is the amount of emissions of the \( i \)-th substance, g / s.
The engine exhaust gas hazard category is the sum of the hazards categories of various toxic and harmful substances that make up the exhaust gas. It serves as an integral characteristic of the environmental hazard of engine exhaust gases as a source of emissions of many pollutants into the air environment.

3. Results and discussion

This approach allows:

1. To summarize the hazard categories of various toxic and harmful substances, since they have a single physical meaning and a uniform dimension (\%). Due to this, one can know the general danger of all the toxic and harmful components emitted by the source in view of their harmful amount and toxicity;
2. To objectively compare and unambiguously evaluate the environmental hazard of exhaust gas from engines operating on various fuels;
3. To compare the ecological danger of a mobile source (tractor) with the environmental hazard of a stationary source (ecological class Euro-5).

To calculate the environmental hazard of an engine running on various fuels, it is necessary to know the values of the toxic components in the exhaust gas. The diesel engine of the Euro-5 ecological standard, effective in Russia from January 1, 2014, requires the following values:

\[
\begin{align*}
\text{CO} & \quad 0.5 \quad \%; \\
\text{NO}_x & \quad 0.18 \quad \%; \\
\text{CH} & \quad 0.5 \quad \%;
\end{align*}
\]

Suspension particles (PM) – 0.005 \%

The dimensionality of the hazard category of the substance (\%) means a virtual volume of air that is required to disperse the pollutants generated by the source at a specific space velocity to safe concentrations. It should be noted that this is, of course, a virtual conditional volume of the air environment, because in reality, atmospheric air is cleared not only by dispersing harmful substances in its volume (convective and molecular diffusion), but also by washing away harmful substances from the atmosphere with precipitation in the form of rain and snow.

Let’s consider the application of the proposed approach for a specific example. To do this, we use the data of the results of bench tests of the diesel engine 4CHN 11.0 / 12.5 (table 2).

**Table 2. Smoke and toxicity indicators of the diesel engine 4CHN 11.0 / 12.5 at \( n = 1800 \text{ min}^{-1} \), \%.

| Type of fuel          | CO  | CH₅ | C   | NOₓ |
|----------------------|-----|-----|-----|-----|
| DF                   | 0.05| 0.006| 19  | 0.0978 |
| 80%DF+20% ethanol    | 0.06| 0.0011| 14.5| 0.0814 |
| 60%DF+40% ethanol    | 0.06| 0.0017| 6.4 | 0.0620 |

Further, using data on the amount of emissions of toxic and noxious substances from exhaust gases and the values of one-time maximum permissible concentrations of these substances, we shall determine the categories of their danger.

\[
\begin{align*}
VHC_{df} &= 0.05 + 0.0006 + 19 + 0.0978 = 19.1484 \%, \\
VHC_{df+20\%ethanol} &= 0.06 + 0.0011 + 14.5 + 0.0814 = 14.6425 \%, \\
VHC_{df+40\%ethanol} &= 0.06 + 0.0017 + 6.4 + 0.0620 = 6.5237 \%.
\end{align*}
\]

The criterion for the ecological hazard of exhaust gases from the \( K_d \) engine gives an accurate idea of how the total environmental hazard of all harmful components of the exhaust gas of an engine is correlated with the exhaust gas hazard of a reference motor that meets the regulatory requirements.

\[
K_d = \frac{VHC}{VHC_{etalon}},
\]

(7)
where $VHC_{etalon}$ is the hazard category of reference motor; 

$VHC_i$ is the hazard category of the tested engine in service.

A certain car equipped with an internal combustion engine and certified according to the European toxicity standards "Euro-5" is considered to be a reference engine.

We put the summarized toxicity values in the formula (2) for each fuel type.

$$K_{dg} = \frac{57.2215}{0.915} = 62 \text{ (environmental class).}$$

$$K_{dg+20\text{\% ethanol}} = \frac{8.2412}{0.915} = 9 \text{ (environmental class).}$$

4. Conclusions

1. At present, ethanol is one of the promising fuels for diesel engines. The required stability of ethanol-fuel emulsions can be achieved by introducing additives based on urea alkenyl succinimide.

2. The operation of a diesel engine using ETE with a 40% ethanol content reduces the emission of carbon oxides CO by 2.5 times in carbon monoxide, carbon dioxide dioxide by 21%, total NOx by 4.6 times and soot particles by a factor of 7. At the same time, there is an increase in the emission of unburned polycyclic hydrocarbons CxHy in the exhaust gas of the diesel engine by a factor of 2.4.

3. The use of EFE allows to obtain an economic effect from reducing the damage caused to the environment by the exhaust gas up to 8500 rubles per 1 tractor per year.

4. The operation of the tractor on fuels with ethanol additives reduces the criterion of the environmental hazard of the engine's exhaust gases by more than 6 times.

5. The work of the tractor on fuels with ethanol additives reduces the criterion of environmental hazard of engine exhaust gases by more than 6 times.

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