Programmed research techniques for alternative-fuel diesel engine performance

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Abstract. The relevance of this work is due to the need of preliminary engineless assessment of performance factors for diesel engines working on alternative fuels. The aim of the work is a development of programmed techniques for performance characterization of a diesel engine. The work was carried out according to a standard methodology for determining combustion procedure performance factors developed by the Central Research Diesel Institute and Bauman Moscow State Technical University. The authors suggested performance calculation algorithms for preparatory and master phases of the combustion procedure in a diesel engine cylinder working on composite fuel and emulsions doped with aliphatic alcohols and plant oils. A calculation and a comparative assessment of precision of measurements in design and experimental data of an ignition delay period, cycle peak pressure and combustion procedure inflexibility were performed. Based on the results of the research, conclusions were drawn on the possibility of a preliminary performance assessment of diesel engines working on alternative fuels and potential effect of suggested research methods. Using the suggested makes it possible to forecast the performance of a diesel engine working on liquid alternative fuels. The results of the research can be applied to developing new kinds and compositions of alternative fuels as well as to assessing necessary remodeling of diesel engines in their practical application.

1. Introduction

Saving of petroleum engine fuel by replacing it with alternative fuel of synthetic or biological origin is a generally accepted global trend. Researchers of the leading nations are conducting theoretical studies and experimental investigations to put different kinds of fuel to the wide-spread application in the nearest future. Considering the fact that motor characteristics of new fuels substantially differ from those of conventional petroleum fuels, it is generally recognized that this circumstance directly restricts the extent of their application.

Theoretical research and experimental investigations on applying liquid (alcohols, plant oil) and gaseous (producer gas, manure gas) fuels in electric power installations of land vehicles are being conducted at Vyatka State University (VSU). This work is aimed to solve problems concerning the optimal makeup of fuel compositions, the development of reworked feed system units, and the assessment of structural reliability and cost-effective performance of diesel engines working on new fuels [1-3].

The works in this field offer considerable amount of analytical methods for calculating performance factors of a diesel engine working on alternative fuels. Unfortunately, these techniques
make it possible to conduct the performance assessment according to one or two factors only. Standardized indices and special terms are used insufficiently. Moreover, obtaining the desired data is closely connected with the need of having special theoretical background and research facilities as well as highly qualified specialists. Furthermore, the possibility of assessing the reliability and durability indices of a diesel engine is not observed [11-13].

In the view of above stated, the urgent objective of the present time is the early development of relatively inexpensive and widely used simple programmed techniques that allow the performance character of diesel engine working on basic kinds and compositions of alternative fuels to be forecast fully, quickly, with sufficient accuracy and reliability.

2. Materials and methods
The authors of the research used fuel compositions on the basis of diesel fuel with additives of methanol (MFE), ethanol (EFE) and colza oil (CO) (figure 1, figure 2).

![Figure 1. General view of fuel compositions doped with alcohols.](image)

Physical-chemical characteristics of fuel compositions were assessed in according with GOST 305-2013. The calculation of performance factors of combustion procedure was done by the designed software programs [4-10] on a personal computer based on Intel Pentium processor (1 GHz 32-bit (x86)/64-bit (x64) or higher, / compatible analogs). To obtain comparative experimental data we used SAK 670N engine stand (figure 3) with a balancing pendulum and 4CHN 11,0/12,5 diesel engine mounted on the stand.

Due to the theoretical studies conducted by the authors, we developed and debugged mathematical models for rating cetane number (CN) of mixed fuel, evaluating combustion delay period (CDP) in a tractor diesel cylinder when working on fuel compositions with additives of methanol, ethanol and colza oil. These models allow the character of preflame processes to be forecast by the engineless way. The calculation of CN of total fuel was done according to the formula (1):
\[ CN_2 = CN_{\text{ad}} - \Delta CN = CN_1 \times M_1 + CN_2 \times M_2 - \Delta CN, \]  

(1)

where \( M_1, M_2 \) is, respectively, the additional fuel part and DF; \( M_2 = 1 - M_1; CN_1; CN_2 \) is, respectively, the additional fuel CN and DF; \( \Delta CN \) is the correction factor.

\[ \Delta CN = \frac{\ln (100M_1) - 1}{\ln CN_2}, \]  

(2)

where \( CN_2 \) is the cetane number of high-cetane (basic) fuel.

The comparison of calculation values of cetane numbers with the received experimental data is given in tables 1-3. The shown calculation values draw us to conclusion that actual data cohere with calculated data sufficiently.

### Table 1. Calculation values of CN for methanol mixtures and DF.

| % of methanol in mixture | \( CN_{\text{ad}} \) | \( \Delta CN \) | Initial data | Calculation data | Precision % |
|--------------------------|--------------------|----------------|--------------|-----------------|-------------|
| 0                        | -                  | -              | 53           | -               | -           |
| 15                       | 45,4               | 6,8            | 43           | 39              | 9           |
| 25                       | 40,5               | 8,8            | 33           | 32              | 3           |
| 35                       | 35,5               | 10,1           | 26           | 25              | 4           |
Here, CN=53 for diesel fuel, CN=3 for methanol.

Figure 3. General view of 4CHN 11,0/12,5 diesel engine on the test stand.

Table 2. Calculation values of CN for ethanol mixtures and DF.

| % of ethanol in mixture | CN<sub>i</sub> | ΔCN | Initial data | Calculation data | Precision % |
|------------------------|--------------|-----|--------------|------------------|-------------|
| 0                      | 47,4         | -   | 47,4         | 47,4             | -           |
| 10                     | 43,5         | 5   | 40,4         | 39               | 4           |
| 20                     | 39,5         | 7,7 | 33,8         | 32               | 5           |
| 30                     | 35,6         | 9,3 | 29,3         | 26               | 11          |
| 40                     | 31,6         | 10,4| 24,5         | 21               | 14          |

Here, CN=47 for diesel fuel, CN=8 for ethanol.

To evaluate fuel combustion delay period the following calculation model (3) was used and texts on a programming language were designed [4-10].

$$
\varphi_1 = \frac{\varphi_i}{\varphi_{\text{amp}}} = \sqrt{6 \cdot n \cdot 10^{-4} \left( \ln \left( \frac{O_{\text{out}}}{K_i - O_{\text{in}}} \right) - \frac{A}{2} \left( 1 - \frac{O_{\text{out}}}{O_{\text{in}}} \right) \right) + \frac{A^2}{2} \left( 1 - \frac{O_{\text{out}}}{O_{\text{in}}} \right) \sqrt{\alpha_1 - 1}}
$$

The comparison of calculation values of fuel combustion delay period with the received experimental data for different working modes of diesel engine and different makeup of fuel
compositions is given in tables 4-6. The sufficient convergence of actual data and calculated data is clearly seen.

Table 3. Calculation values of CN for CO mixtures and DF.

| Fuel makeup     | CN<sup>a</sup> | CN<sub>1</sub> % | CN<sub>2</sub> % | CN<sub>3</sub> % | CN<sub>4</sub> % | CN<sub>5</sub> % | CN<sub>6</sub> % |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 100% DF         | 48              | 41,2            | -14             | 49,6            | 3               | 52,9            | 10              | 53,9            | 12              | 44,9            | -6              | 48,0            | 0,0             |
| 95% DF+5% CO    | 47,4            | 42,7            | -10             | 49,2            | 4               | 52,8            | 11              | 53,6            | 13              | 45              | -5              | 47,9            | 1,1             |
| 90% DF+10% CO   | 46,8            | 43,4            | -7              | 47,1            | 1               | 52,4            | 12              | 53              | 13              | 42,3            | -10             | 47,3            | 1,1             |
| 80% DF+20% CO   | 45,6            | 45,9            | -3              | 51,9            | 14              | 52              | 14              | 39,3            | -14             | 46,4            | 1,8             |
| 70% DF+30% CO   | 44,4            | 49,6            | 12              | 42,7            | -4              | 51,9            | 17              | 51,4            | 16              | 34,3            | -23             | 45,0            | 1,3             |
| 60% DF+40% CO   | 43,2            | 54,3            | 26              | 41,4            | -4              | 52              | 20              | 50,9            | 18              | 31,2            | -28             | 43,9            | 1,6             |
| 50% DF+50% CO   | 42,0            | 64,1            | 53              | 35,8            | -15             | 50              | 19              | 48,6            | 16              | 24,7            | -41             | 42,3            | 0,8             |
| 40% DF+60% CO   | 40,8            | 73,8            | 81              | 35,2            | -14             | 48,4            | 19              | 46,6            | 14              | 22              | -46             | 40,9            | 0,4             |
| 30% DF+70% CO   | 39,6            | 88              | 122             | 29,9            | -24             | 46,8            | 18              | 44,7            | 13              | 22,1            | -44             | 39,8            | 0,5             |
| 20% DF+80% CO   | 38,4            | 103,6           | 170             | 26,9            | -30             | 44,7            | 16              | 42,4            | 10              | 23,3            | -39             | 38,6            | 0,6             |
| 10% DF+90% CO   | 37,2            | 124,4           | 234             | 27,1            | -27             | 44,1            | 19              | 41,2            | 11              | 24,6            | -34             | 37,2            | 0,1             |
| 100% CO         | 36              | 173,8           | 383             | 25,1            | -30             | 43,2            | 20              | 39,8            | 11              | 23,3            | -35             | 35,9            | -0,3            |

<sup>a</sup>Here, CN is an experimental value, CN<sub>1</sub>-CN<sub>6</sub> are the values according to the calculation types.

Table 4. Calculation data of CDP for fuels with methanol additives.

| Fuel makeup     | \( \alpha \) | \( \varphi_i \) (degree) |
|-----------------|--------------|--------------------------|
| DF              | 1,70         | 12,39                    |
| 90% DF + 10% M  | 1,60         | 13,88                    |
| 80% DF + 20% M  | 1,70         | 15,02                    |
| 70% DF + 30% M  | 1,60         | 16,83                    |

Table 5. Calculation data of CDP for fuels with ethanol additives.

| Fuel makeup     | Rotation frequency (min<sup>-1</sup>) | Value \( \varphi_i \) degree at \( \theta_{on,xpr} \) |
|-----------------|----------------------------------------|--------------------------------------------------------|
|                 | 18          | 20          | 22          | 24          | 26          |
| DF              | 1800        | 6,53        | 6,70        | 6,90        | 7,14        | 7,44        |
| 95% DF+5% E     | 1800        | 6,79        | 6,97        | 7,18        | 7,43        | 7,74        |
| 90% DF+10% E    | 2200        | 7,28        | 7,45        | 7,65        | 7,88        | 8,17        |
| 80% DF+20% E    | 1800        | 7,16        | 7,34        | 7,56        | 7,83        | 8,15        |
| 70% DF+30% E    | 1800        | 8,61        | 8,81        | 9,04        | 9,32        | 9,65        |
The comparative analysis of experimental data and CDP calculation data in a diesel engine in basic working modes (table 3-6) shows their sufficient convergence. The obtained results make it possible to recommend the suggested methods of a preliminary performance assessment of diesel engines working on alternative fuels.

3. Results and discussion
Developed and improved mathematical models of rating of cetane number in mixed diesel fuels and evaluating fuel combustion delay period in a tractor diesel cylinder when working on fuel doped with methanol, ethanol and colza oil allow us to perform forecasting the character of preflame processes analytically, to compare objectively and to estimate definitely the reliability and durability of engines working on different fuel compositions.

4. Conclusions
The comparative analysis of experimental and calculation data of mixed diesel fuels CN shows their good convergence.

The conducted analysis of experimental and calculation data of CDP in a diesel engine also displays their good convergence.

The suggested proportions can be recommended for preliminary theoretical assessment of motor characteristics in new fuel compositions.

The designed programmed techniques can be recommended to forecast the performance character of a diesel engine working on different alternative fuels.

Based on the obtained analytical data we have the opportunity to assess the reliability and durability indices of a diesel engine.

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