# AN ANALYSIS OF AN INFLUENCE OF RAPE OIL ESTER CONTENT IN FUEL ON SMOKINESS LEVEL IN THE SI ENGINE FUMES BY STATISTICAL METHOD

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Ecological demands imposed by the 21st century standards require from the constructors optimal technical solutions, which means, in the categories of exploitation system, the use of optimal exploitation parameters. The current tendency promotes 'environmentally friendly' vehicles and machines and is realized by technical and organizational improvements such as technologies based on the recycling of materials, use of oxygenating-reducing catalysts and particulate matter filters, introduction of alternative fuels etc. The toxic contents of fumes which pollute the environment involve among others: carbon oxide CO, hydrocarbons  $C_nH_m$ , nitroxides  $NO_x$ , sulphur oxides  $SO_x$ , particulate matter – soot with hydrocarbon sediments especially from the group PAH and sulphur acid particles, carbon dioxide  $CO_2$  (having no immediate toxic effect, but causing the greenhouse effect), suspension dust etc. Soot emission is considered to be the most significant problem involved in the contamination of fumes from engines with self-ignition [2].

In recent years Poland has also become seriously engaged in the protection of environment. Reduction of pollution emission from motorization is of great interest not only for environmental and vehicle construction specialists but also for architects or road engineers.

## AIM OF THE PAPER

The present and anticipated in the nearest future rules concerning environmental protection impose greater and greater demands on energy carriers (fuels and fuel mixtures). The demands involve wider and wider range of the whole process of using combustion engines. Research on fuel modification and mixing biofuels with engine oil is currently in the focus of interest at scientific centers [1, 3, 4]. The present paper aims at a statistical analysis of an influence of rape oil methyl ester 'RME' content in fuel mixture on the smokiness of fumes from the tractor engine S-4002/S-4003.

Research on the emission levels of soot in fumes were carried out using load characteristics at the maximum moment's velocity  $n_{Momax}$  (1600 rpm) and the maximum power's velocity  $n_{Nemax}$  (2000 rpm). The present tests involved six kinds of mixtures consisting of RME (rape oil methyl ester) and engine oil ON, containing respectively: 0, 20, 40, 60, 80, 100% RME, and the measurements were made for ten levels of engine loads in the range 20-200 N. The program Maple V Release was used for the calculations.

## RESULTS

The dependencies based on the smokiness level results of tests carried out according to the filter method are presented graphically. Fig. 1 and 2 present graphs of the dependencies of the level of fumes smokiness on an engine's power  $N_e$ . RME in the graphs' legend denotes the variable describing the rape oil ester content in fuel.



Fig. 1. Graph of the dependency of smokiness on power at the rotation speed 1600 rpm



Fig. 2. Graph of the dependency of smokiness on power at the rotation speed 2000 rpm

An analysis of the Fig. 1 and 2 shows that there is a clear dependency between fumes smokiness and the effective power  $N_e$ , so a significant part of the smokiness variability is explained by the variable  $N_e$ . That's why, in order to test the statistical influence of the content of RME ester in fuel on smokiness, it was decided to use the statistical method called the analysis of covariance (ancova). This method employs the content of RME as a factor (grouping) variable, smokiness level B as a response variable and the effective power  $N_e$  as a covariate variable [5]. This analysis allows to remove the known source of variation ( $N_e$ ), so that the influence of the factor (RME) on the response variable B can be visible.

The preliminary statistical analysis showed that in the analysis of covariance the covariate  $N_e$  must be taken into consideration together with its square  $N_e^2$  and cube  $N_e^3$ . In the simplest model of ancova it is assumed that at each value of the grouping variable (factor level) there is a regression of the shape  $B = \alpha_i + \beta_1 N_e + \beta_2 N_e^2 + \beta_3 N_e^3$ , where coefficients  $\beta_1$ ,  $\beta_2$  i  $\beta_3$  are common for all the groups (values RME) and  $\alpha_i$  are different for different groups (with us i = 1, 2, ..., 6 denote successive levels of RME content in fuel).

However, in the considered case this simplest model turned out to be incorrect, as the regression curves at the particular RME ester content levels are not parallel (the hypothesis of parallelism was rejected on the significance level 0.05). Hence, the following starting model was accepted:  $B = \alpha_i + \beta_{0i}N_e + \beta_{1i}N_e^2 + \beta_{2i}N_e^3$  (*i* = 1,...,6), *i* = 1 for 0% RME content, *i* = 2 for 20% RME content, ..., *i* = 6 for 100% RME content. The above starting model was only reduced (by not rejecting the hypothesis of the equality of the coefficients  $\beta_{11} = K = \beta_{16}$  and  $\beta_{21} = K = \beta_{26}$ ) to the model  $B = \alpha_i + \beta_{0i}N_e + \beta_1N_e^2 + \beta_2N_e^3$  (*i* = 1,...,6).

Non-parallelism of the regression curves means there is a significant interaction of the factor RME with the covariate  $N_e$ . Table 1 presents the results of the testing of this interaction at 1600 rpm, and Table 2 at 2000 rpm.

Table 1. The results of the testing of the interaction RME  $\times N_e$  at the rotation speed 1600 rpm

Sums of squares		Degrees of freedom	Mean squares	F	p-value
Interaction	15.189	5	3.038	46.338	0.000000
Error	3.016	46	0.0656		

Table 2. The results of the testing of the interaction RME  $\times N_e$  at the rotation speed 2000 rpm

	Sums of squares	Degrees of freedom	Mean squares	F	p-value
Interaction	13.588	5	2.718	46.799	0.000000
error	2.671	46	0.0581		

The regression curves are not parallel, hence the distance between them depends on the value of the covariate  $N_e$ . Fig. 3 presents the adjusted means of smokiness at  $N_e = 10$  kW and  $N_e = 15$  kW for 1600 rpm and 2000 rpm.



Fig. 3. The chart of adjusted means of smokiness at the selected power values

An analysis of the changeability of the fume smokiness level shows that it drops with the rise of RME ester content in fuel with one exception, namely, of the smokiness rise at the RME rise from 0% to 20% at the rotation speed 1600 rpm.

In order to test whether the differences in the smokiness level at different RME contents were statistically significant, the analysis of contrasts was carried out based on the test F. For each comparison a limiting value of power  $N_e$  was found, above which the difference in the smokiness level is significant on the level 0.05. In Table 3 these values  $N_e$  are presented, and the upper value corresponds to the rotation speed 2000 rpm whereas the lower one to 1600 rpm. It must be noted that we take into consideration only the values  $N_e$  from the intervals which appeared in the experimental data, i.e. at the speed 1600 from the interval 2-25 kW and at the speed 2000 from the interval 3-32 kW.

Table 3.  $N_e$  values above which the difference in the smokiness level is significant on the significance level 0.05

			Rotation speed				
		20%	40%	60%	80%	100%	rpm
RME	0%	4.80 6.21	2.60 10.14	2.18 4.04	each 2.30	each 2.34	2000 1600
	20%		7.00 4.85	4.57 3.33	each 2.32	each 2.35	2000 1600
	40%			non 5.43	1.22 3.19	each 3.05	2000 1600
	60%				2.34 8.61	each 5.71	2000 1600
	80%					6.54 10.63	2000 1600



Fig. 4. The chart of the function  $F(N_e)$  for the hypothesis of no differences in the smokiness levels between the RME contents of 60% and 80% at the rotation speed 1600 rpm

The values given in Table 3 are the solutions of the equation  $F(N_e) = 4.025$ , where  $F(N_e)$  is the value of the test statistics for a proper contrast, and the number 4.052 is the critical value of F-distribution with 1 and 46 degrees of freedom corresponding to the significance level 0.05. An exemplary graph of the function  $F(N_e)$  for the hypothesis of no differences in smokiness at the RME contents of 60% and 80% (speed 1600 rpm) is presented in Fig. 4.

### CONCLUSIONS

The carried out statistical analysis, based on the results of experimental tests, showed a significant influence of the content of RME rape oil ester on the smokiness levels of fumes.

The differences among various RME contents depend on the values of an engine's power and:

– at the rotation speed of 1600 rpm the smokiness level of fumes drops together with the rise of RME content in fuel (Fig. 3). The only exception is the ester content 20%, at which the smokiness level is higher than at pure oil. Differences in the smokiness levels are statistically significant for the high enough values of an engine's power  $N_e$  (Tab. 3).

- at the rotation speed 2000 rpm the smokiness level drops together with the rise of RME ester content in fuel. The only difference which is insignificant for any power value (in the interval 3-32kW) is the difference between the smokiness level at the 40% and 60% of RME content.

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#### SUMMARY

The aim of the paper is the analysis of an influence of rape oil methyl ester 'RME' content in fuel mixture on the smokiness of fumes from the tractor engine S-4002/S-4003. The statistical analysis of covariance with the engine's power as a covariate was applied to experimental data.