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Model of CO emission level of exhaust gases in tractor engines fed with biofuels

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A b s t r a c t. The article presents results of research on the levels of emission of carbon monoxide (CO) in exhaust gases emitted by the S-4002 engine of an agricultural tractor depending on two variables: the horsepower *Ne* developed by the engine and the percentage of RME (rapeseed methyl ester) contained in the fuel mix with fuel oil. In this experiment six different mixtures of mineral oil and RME were used. They included 0, 20, 40, 60, 80, and 100% of RME, respectively. The differences of the levels of CO emissions produced by the S-4002 tractor-engine, at two different workload values (at maximum torque speed n_{Momax} of 1600 r.p.m. and at maximum power output speed n_{Nemax} of 2000 r.p.m.) were examined. Following the multiple regression analysis using the method of backward elimination for the 120 measurements made during the research, two regression equations were obtained for the per cent ratio of CO (*Ne*, RME) in the emitted fuel gases, in relation to the horsepower *Ne* developed by the engine and the RME biofuel content in the mix.

K e y w o r d s: fumes, biofuel, rapeseed methyl ester, statistical inference

INTRODUCTION

The present power supply system, based mainly on coal, crude oil and natural gas, cannot be continued in the future. This results primarily from the fact that these natural resources are being exhausted and there is a continuous degradation process of natural environment. Agriculture is one of the significant energy reservoirs. That is why there is a tendency to start feeding engines with so-called renewable fuels. Using biodegradable and biorenewable fuels is one of the methods of controlling pollution emission. The environmentally friendly fuels include vegetable oils which can occur in the form of pure refined oils or their methyl and ethyl esters (Chiaramonti and Tondi, 2003). In the application in diesel engines, vegetable oils derivatives (esters) are primarily taken into account due to similar properties to those of diesel fuel.

Basically, using rape oil esters as fuel does not involve any changes in engine design. This fuel is approved for use in Poland provided it conforms to the relevant European standard. Obtaining an approval for use of vehicles (especially agricultural tractors) supplied with the RME (rapeseed methyl ester) biofuel requires carrying out a lot of research. An example is studying the CO emission level in the exhaust of agricultural tractors engines fed with unconventional fuel under varied operating conditions.

Carbon oxide is characterised by a significantly higher affinity to haemoglobin than oxygen (app. 300 times). As a result, during poisoning with this gas, carboxyhaemoglobin is produced, which results in tissues anoxia and the occurrence of various adverse symptoms, including death. Examples of complications resulting from carbon oxide poisoning are degenerative changes in the central nervous system, neuralgia, pneumonia and, in the case of chronic poisoning, headaches, dizziness, fatigue, insomnia, changes in the central nervous system manifested by deterioration of memory and concentration.

METHODS

The research was carried out in the Department of Vehicles and Engines at the University of Agriculture, Lublin. It was concentrated on the ecological parameters concerning measurements of selected elements of exhaust gases in an S-4002 engine fed with RME and its mixes with fuel oil (ON). The results were obtained at the engine load characteristics corresponding to the maximum torque speed n_{Momax} (1600 r.p.m.) and the maximum power n_{Nemax} (2000 r.p.m.).

The initial results of the research, taking into account also some ecological aspects, were presented in the paper by Piekarski (1997). The continuation of the research is the

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presentation of statistical models of the emission level of exhaust gases: CO_2 (%), C_nH_m (ppm), NO_x (ppm) and involving temporary fuel consumption G_p (kg h^{-1}) and unit fuel consumption g_e (g kWh^{-1}) as several functions of $CO_2(N_e$ RME), $C_nH_m(N_e$ RME), $NO_x(N_e$ RME), $G_p(N_e$ RME) and $g_e(N_e$ RME) dependent on two variables: the developed power N_e (kW) and the per cent ratio of RME in the mix of RME with ON in the papers by: Piekarski and Tarasińska (2002) and Wawrzosek and Piekarski (2002).

In the present research on carbon monoxide, in order to construct a CO function (N_e, RME) six kinds of mixes of RME with ON were used, containing, respectively, 0, 20, 40, 60, 80, and 100% RME, and measurements were taken for ten levels of engine loading (2-32 kW). For the statistical analysis of the measurements taken the analysis of multiple regression was used applying the SAS software.

RESULTS AND DISCUSION

Following multiple regression analysis using the method of backward elimination (Muller and Fetterman, 2002) for the 120 measurements made during the research, the following regression equations were obtained for the per cent ratio of CO(N_e, RME) in the emitted exhaust gases, in relation to the power N_e developed by the engine and the RME content in the mix:

- for 1600 r.p.m.:

$$\begin{aligned} CO = {} & 0.274086 - 0.011509\, N_e - 0.311953\, \mathrm{RME} + \\ & + 0.000008\, N_e^3 + 0.355426\, \mathrm{RME}^2 + \\ & - 0.000260\, N_e^2\, \mathrm{RME} - 0.011378\, N_e\, \mathrm{RME}^2 + \\ & - 0.103313\, \mathrm{RME}^3 + 0.013782\, N_e\, \mathrm{RME} + \\ & + 0.000226\, N_e^2\, \mathrm{RME}^2 - 0.305807\, N_e^{-1} + \\ & + 0.371511\, N_e^{-2}; \end{aligned}$$

- for 2000 r.p.m.:

$$\begin{aligned} CO = {} & 0.290158 - 0.176444\, \mathrm{RME} - 0.000398\, N_e^2 + \\ & + 0.000010\, N_e^3 + 0.253708\, \mathrm{RME}^2 + \\ & - 0.146923\, \mathrm{RME}^3 + 0.000976\, N_e\, \mathrm{RME} \end{aligned}$$

The results of multiple regression for two rotation speeds, *ie* coefficients of equations with their errors and with the results of testing their significance, are shown in Table 1.

In choosing the best of the models, models with different number of parameters were compared, using adjusted R-square, which describes the fit of the model.

Table 1. Results or multiple regression for carbon monoxide (CO)

Rotation speeds	Terms	Coefficients of equations	Standard error of coefficients of equatios	Test of significance of coefficients t(48)	Observed level of significance, p
1600 r.p.m.	free term	0.274086	0.015616	17.551561	0.000000
	N_e	-0.011509	0.000865	-13.310369	0.000000
	RME	-0.311953	0.016243	-19.205735	0.000000
	N_e^3	0.000008	0.000001	11.169789	0.000000
	RME^2	0.355426	0.025178	14.116363	0.000000
	RME^3	-0.103313	0.014101	-7.326860	0.000000
	N_e RME	0.013782	0.002479	5.560253	0.000001
	N_e^2 RME	-0.000260	0.000091	-2.854854	0.006341
	N_e RME^2	-0.011378	0.002400	-4.741679	0.000019
	N_e^2 RME^2	0.000226	0.000089	2.551187	0.013978
	$1/N_e$	-0.305807	0.085266	-3.586491	0.000783
	$1/N_e^2$	0.371511	0.128061	2.901045	0.005598
2000 r.p.m.	free term	0.290158	0.003146	92.238773	0.000000
	RME	-0.176444	0.019840	-8.893333	0.000000
	N_e^2	-0.000398	0.000020	-19.762849	0.000000
	N_e^3	0.000010	0.000001	16.116153	0.000000
	RME^2	0.253708	0.047843	5.302982	0.000002
	RME^3	-0.146923	0.031414	-4.677050	0.000020
	N_e RME	0.000976	0.000278	3.513262	0.000914

Both models are characterized by the highest adjusted R-square which amounts: 0.989 at 1600 r.p.m. and 0.966 at 2000 r.p.m. Moreover, using the Mallows' Cp statistic the difference between the model including the most of the initially considered variables and the surface determined only by the variables of the final model was estimated. The Mallows' Cp statistics, amounting adequately 11.080 and 5.266, do rank this model on the second and first place in two groups of analyzed models. The Mallows' Cp statistics are quite similar to the number of parameters 12 and 7, included in both models, which vindicates the proper choice of those models. The significance of regression in both models was examined with use of the F-statistic with the F-Snedecor distribution. High values of this statistic – F(11;48)=499 for 1600 r.p.m. and F(6;53)=282 for 2000 r.p.m. do indicate the significance of regression in both of the models. Furthermore both models have parameters of which every single one is significant. It has been indicated by the t-Student statistics and corresponding p-values in the Table 1.

Using the R^2 statistics we ascertain, that the models almost ideally explain the variation of the CO levels in exhaust fumes – accordingly in 99.1% and 97%. Small standard errors s=0.003 and s=0.006 do describe the high precision of the models.

According to the German company TUV Bayeren Holding, it is possible to increase gradually the percentage of renewable fuels in the fuel sector up to 79% in 2050. Moreover, unstable energy safety in many economies as well as the changing conditions and the fluctuations at the biofuels market resulting from them will possibly result in the use of vehicle fuels with unstable RME proportion in combination with ON. That is why the vehicles approved for use should guarantee as low as possible emission of the exhaust, which is harmful to the environment, for any proportion of RME mix with ON under all normal vehicle operating conditions. Thus any of the existing diesel engines and of those being designed should have mathematical models of emission of individual exhaust components for typical conditions of use and any proportion of RME and diesel fuel mixes.

The graphs of the surface of statistical data (Figs 1-2) almost perfectly correspond to the graphs of the surface of multiple regressions (Figs 3-4).

The size of the CO remainders (Fig. 5), not involved in the regression, is insignificant.

In Fig. 6 it is possible to observe the differences in the levels of emission of carbon monoxide emitted by the S-4002 tractor engine, between two load characteristics: at the speeds of the maximum torque n_{Momax} (1600 r.p.m.) and the maximum power n_{Nemax} (2000 r.p.m.). These differences fall within the range from 0.08 % to 0.13 % and are the least significant for the fuel with a 100% RME content.

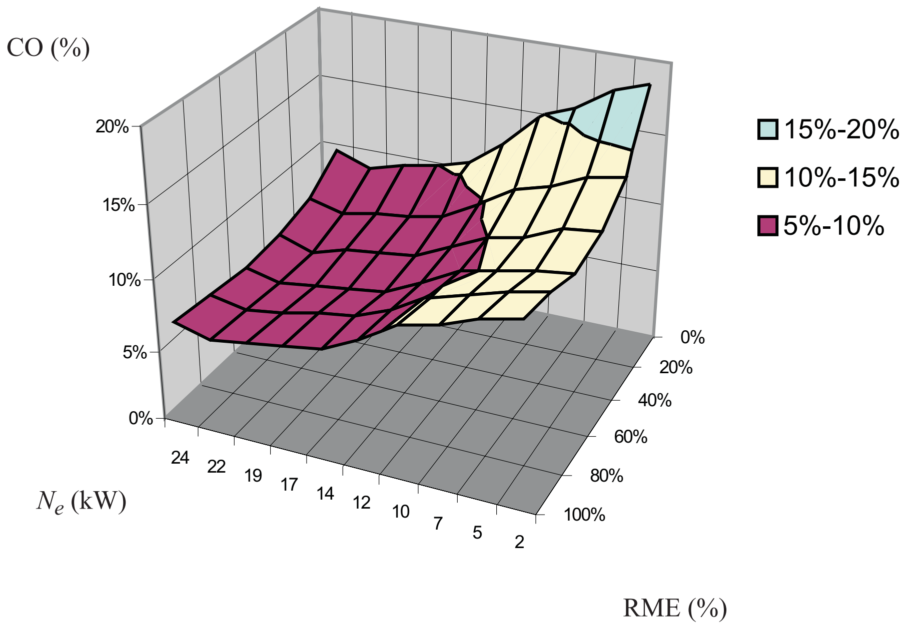

Fig. 1. Graph of CO (%) data for 1600 r.p.m.

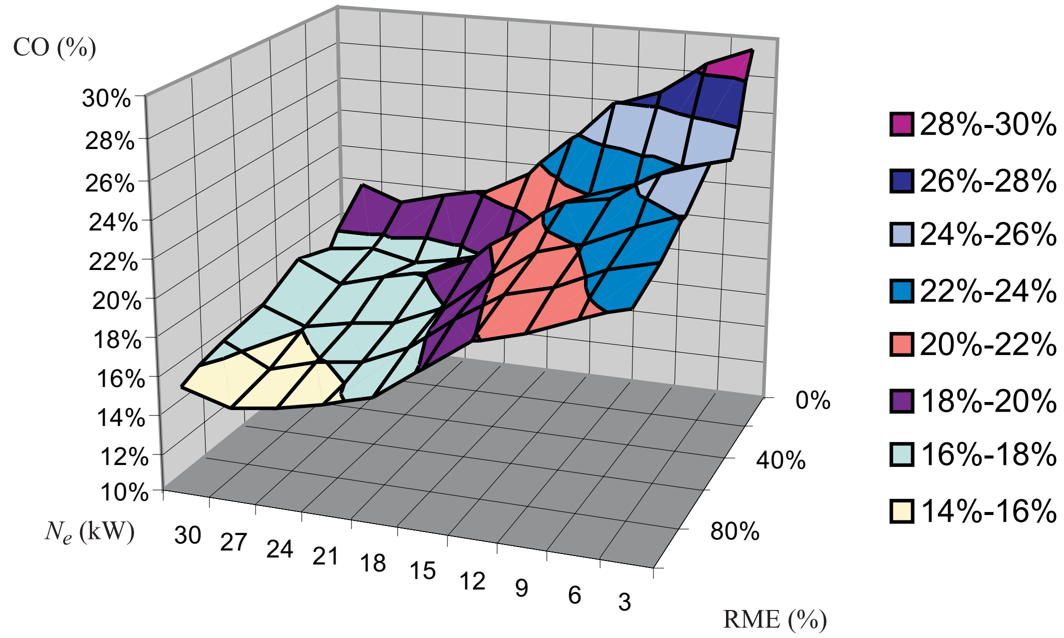

Fig. 2. Graph of CO (%) data for 2000 r.p.m.

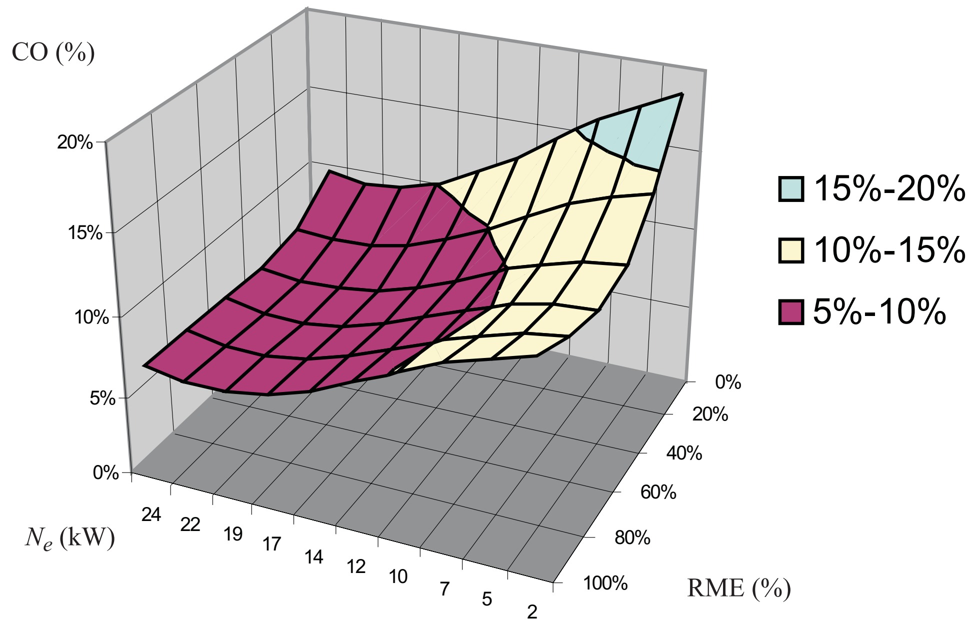

Fig. 3. Graph of regression CO(N_e RME) (%) for 1600 r.p.m.

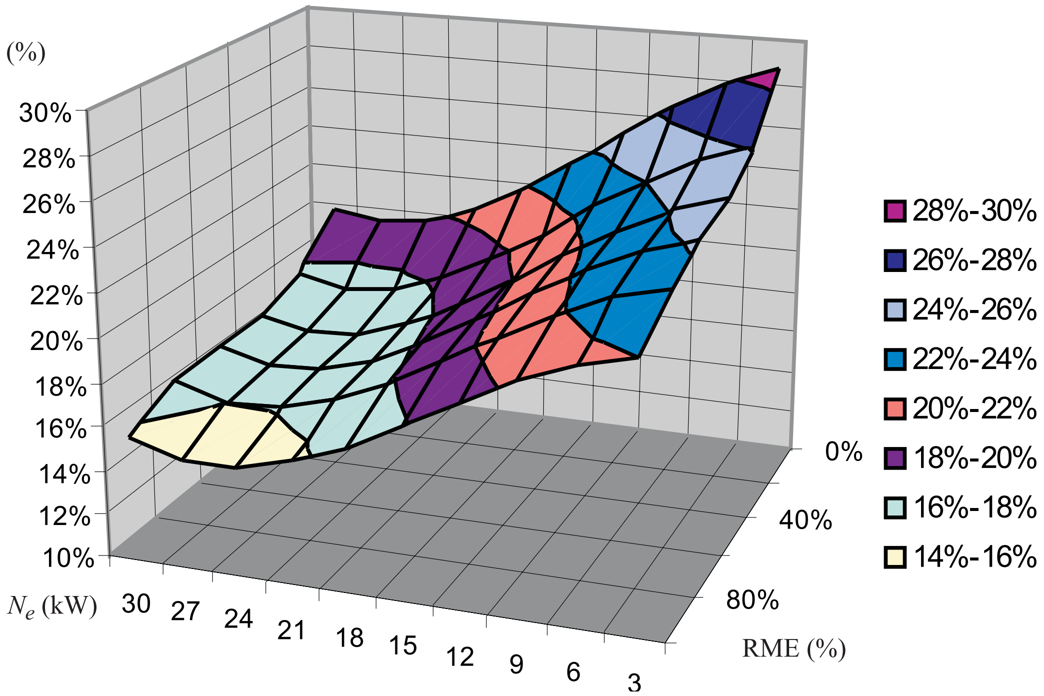

Fig. 4. Graph of CO (N_e RME) (%) regression 2000 r.p.m.

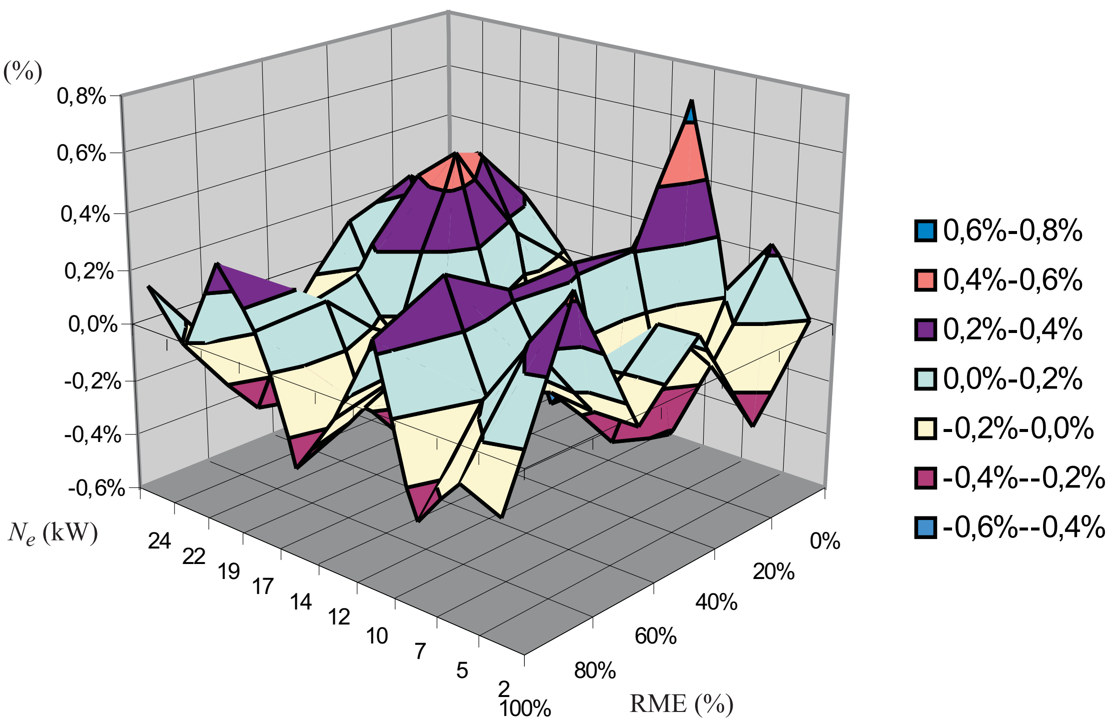

Fig. 5. Graph of CO (%) errors not taken into account in the model for 1600 r.p.m..

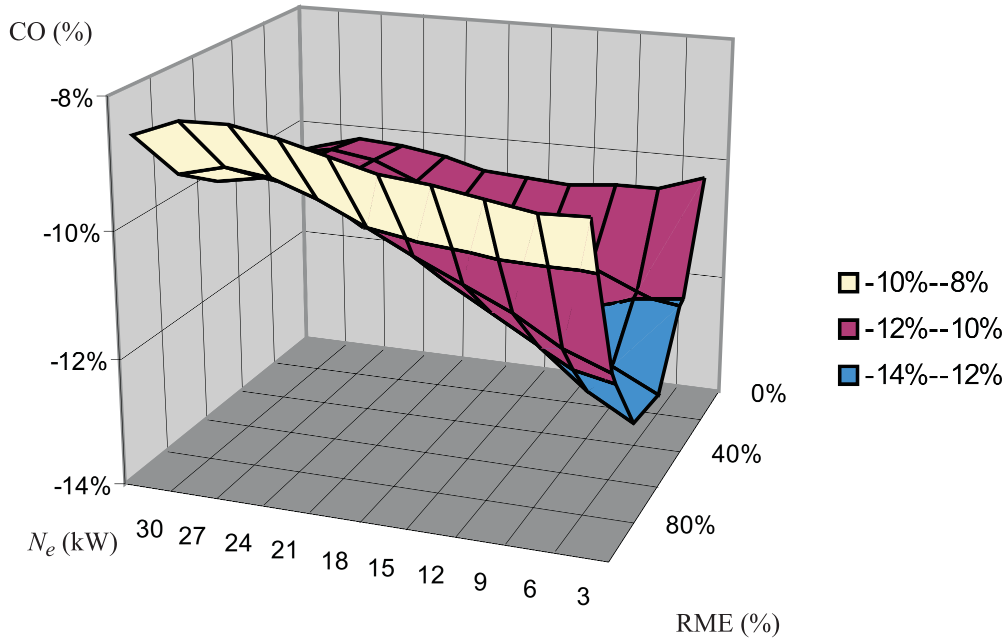

Fig. 6. Graph differences of CO (N_e RME) (%) for: 1600 and 2000 r.p.m.

CONCLUSIONS

1. The obtained regression equations CO(N_e, RME) are very well fitted to the measurement points, their determination coefficients are close to one.

2. The addition of rapeseed methyl ester (RME) at the rotation speeds of 1600 r.p.m. and of 2000 r.p.m. causes a decrease in emission levels of carbon monoxide, depending on the effective power N_e. The emission of carbon monoxide CO diminishes with the growth of engine power.

REFERENCES

Chiaramonti D. and Tondi G., 2003. Stationary Applications of Liquid Biofuels. Final Report. ETA Renewable Energies, PTA Contract, NNE5-PTA-2002-006, lot 36.

Muller K.E. and Fetterman B.A., 2002. Regression and ANOVA: An Integrated Approach Using SAS Software. Cary, NC: SAS Institute Inc.

Piekarski W., 1997. Analysis of the influence of tractor sets on natural environment (in Polish). Scientific Dissertations, University of Agriculture Press, Lublin.

Piekarski W. and Tarasińska J., 2002. Influence of the rape oil ester content in fuel mix on selected parameters of engine's work. Teka, Commission of Motorization and Power Industry in Agriculture, Polish Academy of Sciences, Branch in Lublin, 2, 158-163.

Wawrzosek J. and Piekarski W., 2002. The toxicity level of exhaust gases in tractor engines fed with biofuels. Teka, Commission of Motorization and Power Industry in Agriculture, Polish Academy of Sciences, Branch in Lublin, 2, 164-172.