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OPTIMIZATION OF ON-FIELD TESTS EXPERIMENT FOR EVALUATION OF TRACTOR UNIT'S FUEL CONSUMPTION

Summary

The effect of dehydrated ethanol and rapeseed methyl ester additives to diesel fuel on engine fuel consumption has been experimentally investigated. The used average capacity (18 kW) tractor was driven by unmodified direct injection (combustion chamber consists of a dished piston) four cylinder, two-cycle diesel engine D21A1. Multicomponent fuel blends were prepared by adding 5 and 10% (v/v) of ethanol as well as 30 and 50% (v/v) of biodiesel (RME) to diesel fuel obtained from Mazeikiu Nafta Petroleum Refinery Company (Lithuania). During the on-farm tests tractor's fuel consumption data range varied at the margin of error depending on the used type of fuel. In order to solve this problem the decision was taken to attempt to find the optimum number of test drives by using of statistical modeling on the basis of the mathematical theory of experiment. The use of this method is advised when there is a large number of interdependent factors which influence the final result.

ОПТИМИЗАЦИЯ ЭКСПЕРИМЕНТА ОПРЕДЕЛЕНИЯ РАСХОДА ТОПЛИВА ТРАКТОРНОГО АГРЕГАТА НА ПОЛЕВЫХ ИСПЫТАНИЯХ

Резюме

В этой статье представлены результаты детального анализа влияния добавок этанола и рапсово-метилового эфира (РМЭ) на расход топлива при испытании тракторного агрегата 18 кВт мощности, который был оборудован немодифицированным четырехцилиндровым дизельным двигателем D21A1 с камерой сгорания с прямым впрыском (с глубокой выемкой в поршне). Мультикомпонентные топливные смеси были приготовлены из 30 и 50% по объему биодизельного топлива и 5-10% дегидрированного этанола в дизельном топливе, поставляемым из НПЗ «Мажейкю нафта». На полевых испытаниях расход топлива тракторного агрегата часто колебался в пределах погрешности эксперимента, зависимо от топливной смеси. Чтобы избежать этого, опыт спланирован согласно стандартному плану с рандомизацией его точек, представлены условия планирования эксперимента и кодирования матрицы трехуровневого плана.

1. Introduction

Two oxygenated biofuels (biodiesel and ethanol) have received intensive attention as potential alternative fuels for heavy duty diesel engines due to their renewable property and reduction of fossil CO_2 discharge which most probably contributes to the global climate changes [1]. Biodiesel-ethanol-diesel (BE-diesel) is a new form of biofuel blend from renewable material that has energy values comparable to those of fossil fuels and has superior lubricity and environmentally friendly characteristics [2]. In recent years, the influence of biofuels on diesel engine fuel consumption has attracted many researchers' interesting [2-4].

On the basis of these assumptions a scientific hypothesis was formed that the use of ethanol additive in mineral diesel and RME blends would allow achieving their combustion characteristics close to pure mineral diesel. It was decided to assess the possibility to use three-component fuel blend made of mineral diesel (MD), rapeseed methyl ester (RME) and 5-10% of ethanol (E) in heavy duty transport means driven by unmodified direct injection (combustion chamber consists of a dished piston) diesel engines. Thus ensured a more complete fuel blend combustion in engine cylinders is related with the shortening of ignition delay time [5].

2. Objects and methods

Accomplished experiment planning of 18 kW capacity tractor unit comparative fuel consumption dependence on three parameters: tractor unit operating speed V_d, maximum traction force resistance R_m and maximum traction power P_{max}.. A short-term on-farm test was carried to collect experiment data needed for mathematical calculations. A loosening of stubble was performed using T-25A tractor unit fuelled with fuel blend 70%MD+30%RME with 5% ethanol additive. A typical 3^x plan, represented in the form of a Latin square [6, 7].

Basic data and coded designation (k=3) are presented in the table 1 and table 2. All calculations were performed using a standard methodology (table 3) [6; 7] with the help of computer programs Statistika 6.0 and Excel 2003. Following dependence of comparative fuel consumption on analyzed parameters was deduced:

$$Y = 604 - 296,25 \cdot x_1 - 48,75 \cdot x_2 + 1,25 \cdot x_3 + 37,5 \cdot x_1 \cdot x_2 . \quad (1)$$

According to data, presented in the table 2, equation of comparative fuel consumption dependence on selected factors can be written in a coded form [6]:

$$Y = a_1 + \sum a_i \cdot x_i + \sum a_i \cdot x_i \cdot x_j + a_1 \cdot x_1 \cdot x_2 \cdot x_2 . \quad (2)$$

Table 1. Levels of variable factors

Factor	Coded designation	Factor levels			Variation interval
		Lower -1	Lower -1	Lower -1	
V_d, tractor unit operating speed, m/s	x_1	1,2	1,3	1,4	0,1
R_m, maximum traction force resistance, kN	x_2	7,8	7,9	8,0	0,1
P_{max}, maximum traction power, kW	x_3	9,3	9,8	1,3	0,5

Table 2. Conditions under which experiments were performed

Test No.	x_1	x_2	x_3	$x_1.x_2$	$x_1.x_3$	$x_2.x_3$	$x_1.x_2.x_3$	Calculated parameter Y_i	Multiplier a_i
1	-1	-1	-1	1	1	1	-1	Y_1	a_1
2	1	-1	-1	-1	-1	1	1	Y_2	a_2
3	-1	1	-1	-1	1	-1	1	Y_3	a_3
4	1	1	-1	1	-1	-1	-1	Y_4	a_4
5	-1	-1	1	1	-1	-1	1	Y_5	a_5
6	1	-1	1	-1	1	-1	-1	Y_6	a_6
7	-1	1	1	-1	-1	1	-1	Y_7	a_7
8	1	1	1	1	1	1	1	Y_8	a_8

Table 3. Uncoded designation

Test No.	x_1	x_2	x_3	$x_1.x_2$	$x_1.x_3$	$x_2.x_3$	$x_1.x_2.x_3$	Calculated parameter Y_i	Multiplier a_i
1	1,2	7,8	9,3	9,36	11,16	72,54	87,05	231	231,125
2	1,4	7,8	9,3	10,92	13,02	72,54	101,56	230	-0,1250
3	1,2	8,0	9,3	9,60	11,16	74,40	89,28	230	0,1250
4	1,4	8,0	9,3	11,20	13,02	74,40	104,16	231	0,6250
5	1,2	7,8	10,3	9,36	12,36	80,34	96,41	232	0,3750
6	1,4	7,8	10,3	10,92	14,42	80,34	112,48	231	-0,1250
7	1,2	8,0	10,3	9,60	12,36	82,40	98,88	232	0,1250
8	1,4	8,0	10,3	11,20	14,42	82,40	115,36	232	-0,1250

Calculated Student criterion $t_{st.0,05;7} = 2.365$ [6, 7]. Following to a standard methodology we identified that meaningful coefficients are a_1, a_4 and a_5 (see table 3). After comparing their values with Fisher criterius $F_{5,8} = 1.538462$, we arrive at a conclusion that model is adequate [6; 7]. This can be written as [6]:

$$Y = 231.125 + 0.625 \cdot x_3 + 0.375 \cdot x_1 \cdot x_2 . \qquad (3)$$

Encoded equation (3) assumes a final approach, applied to describe a comparative fuel consumption influencing factors:

$$Y = 604 - 296.25 \cdot V_d - 48.75 \cdot R_m + 1.25 \cdot P_{\max} + 37.5 \cdot V_d \cdot R_m \cdot \qquad (4)$$

Figure 1 gives a calculated data of 18 kW capacity tractor unit comparative fuel consumption dependence on maximum traction force resistance, compared with on-farm test results.

Calculation data dispersion σ=0,204. This investigation also showed that deduced equation strongly relies on chosen variables and adequately describes tractor unit comparative fuel consumption estimated during the on-farm tests [6, 7].

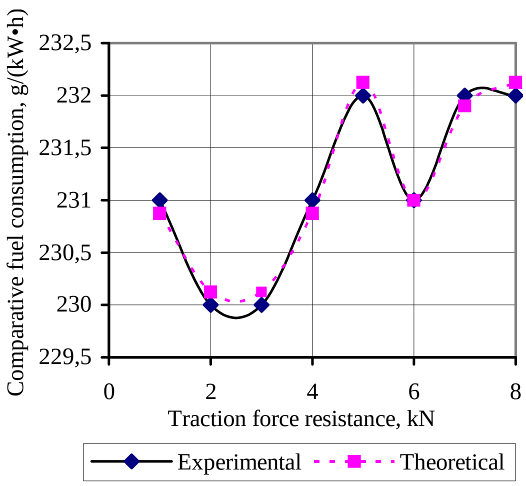

Fig. 1. 18 kW capacity tractor unit comparative fuel consumption dependence on maximum traction force resistance

3. Results and discussion

On-farm tests [8] were performed working with tractor of 18 kW capacity (see Fig. 2). Experiment performed in four different working speeds (four gears) at 1,5-2,7 m/s.

Comparative fuel consumption identified at variable engine loads.

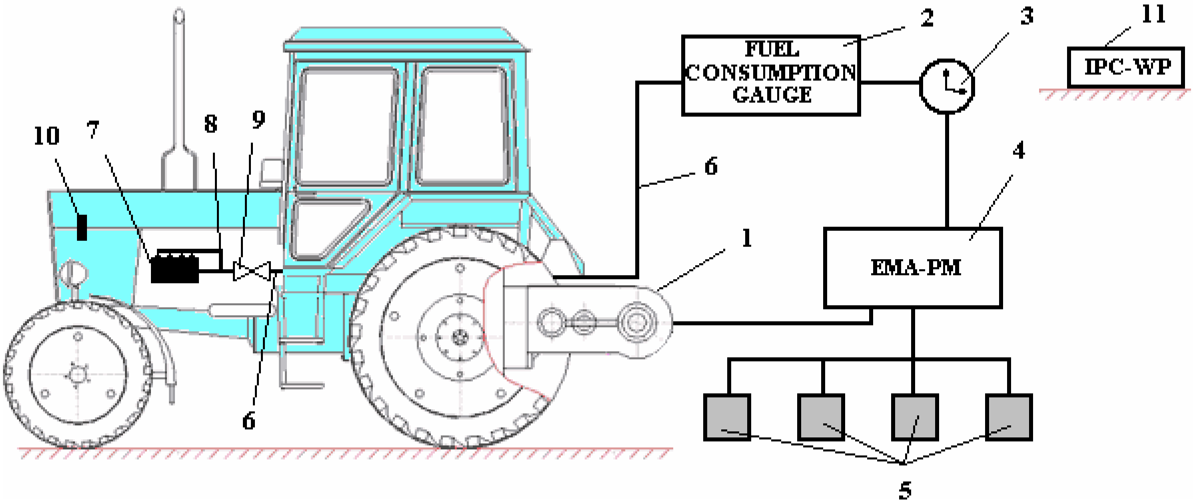

Fig. 2. Scheme of equipment used for tractor unit fuel consumption measuring: 1 – tensometric wheel rod; 2 – fuel consumption gauge, 3 – time meter, 4 – electronic integrator EMA-PM, 5 – wheel rotation, skid and traction sensors, 6 – pipe for feeding fuel to pump, 7 – high pressure fuel pump; 8 – fuel reflux pipe, 9 – fuel supply valve, 10 – temperature meter, 11 – electronic weighing–machine IPC–WP

Tractor unit operating speed and slip of the driving wheels was fixed with the help of wheel rotation sensors across the length of field, the total distance of 500 m. Traction force resistance R_m was identified using a tensometric equipment: 1,5-3,0 t traction catenary and EMA-PM register. Fuel consumption measured via volumetric gauge, integrated into diesel engine high pressure fuel pump supply system. Results were controlled when measuring a weight of volume with fuel before and after experiment with the help of electronic waterproof scale IPC-WP (class IP65, error ±0,5 g). Research with the same type of fuel and engine load was repeated for 8 times according 3^x plan.

During the on-farm tests comparative fuel consumption rates were achieved (see Fig. 3). Established fuel consumption of 18 kW capacity tractor unit working at maximum tractor's traction force P_{max} and nominal engine revolution speed under the same conditions with mineral diesel, RME and their blends with ethanol additive. Test drives were performed while loosening stubble by 18 kW capacity tractor. Soil moisture in the stubble was 17 %, hardiness – 810 kPa.

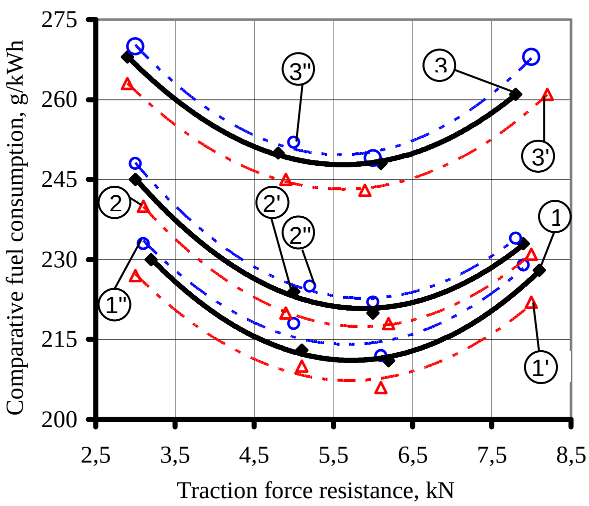

Fig. 3. 18 kW capacity tractor unit comparative fuel consumption dependence on traction force resistance. Basic types of fuel: 1 – MD, 2 – 70%MD+30%RME, 3 – 50%MD+50%RME; 1‘, 2‘, 3‘ – basic types of fuel with 5% ethanol additive; 1“, 2“, 3“ – basic types of fuel with 10% ethanol additive

The lowest comparative fuel consumption of the used tractor unit was achieved at average revolution speed of the engine's crankshaft (1200–1600 min^{-1}) and at full load, often near the maximum torque mode. It was established that the highest comparative fuel consumption was achieved when the engine operated at high frequency of crankshaft revolutions and at slimed down engine load. During the on-farm tests it was established that the optimum amount of ethanol to the basic fuel was 5% and the amount of biodiesel in the MD/RME blend – 30%.

This three-component fuel blend did not influenced the decrease of diesel engine capacity but determined fuel consumption economy of 4,0-8,5% compared with basic fuel of the same type. During the on-field tests it was established that the lowest fuel consumption at maximum traction force of 18 kW capacity tractor unit was: MD – 211±4 g/kWh, 70%MD+30%RME – 220±5 g/kWh. Having enriched 70%MD+30%RME blend with 5% E additive fuel consumption in its numerical value did not differ much from the ones obtained by operating on pure MD.

The proposed fuel blends are expedient to use in the areas especially sensitive to environmental pollution (forestry, ecological farms, etc.). The recomended three-component fuel blend can be used in part in public urban transport and navigation.

4. Conclusions

1. The use of statistical modeling on the basis of the mathematical theory of experiment strongly relies on chosen variables and adequately describes tractor unit comparative fuel consumption.
2. It was established, that having added 5% of ethanol in basic fuel 70%MD+30%RME, economic characteristics of a diesel engine were analogous within the total range of loads as operating on pure mineral diesel.

Modifications of a direct injection diesel engine (combustion chamber consists of a dished piston) are not required to use this type of fuel.
3. Using of 5% ethanol additive to the basic types of fuel, oxygen content in its chemical composition influenced combustion process positively by reducing of fuel consumption.
4. Using of 10% ethanol additive to the basic types of fuel is not recommendable due to uneven engine operation.

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