Effect of rapeseed methyl ester on fuel consumption and engine power

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Abstract

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This paper describes the effect of a mixture of rapeseed methyl ester and diesel oil on fuel consumption and power parameters of tractor engine. The hydraulic dynamometer was used to load the engine of Zetor Forterra 8641 tractor over rear power take-off. The measured tractor is almost new with less than 100 h worked. The measurements were realized for several ratios of diesel oil and rapeseed methyl ester (from pure diesel to pure rapeseed methyl ester). The engine was loaded by the dynamometer in several working points which were predefined by engine speed and its torque. The fuel consumption was measured by the flow meter in each of these points. The reduction of engine's power parameters and the increase of specific fuel consumption are expected due to the nature of rapeseed methyl ester such as e.g. lower calorific value.

Keywords: biofuel; speed characteristic; engine map

Although rapeseed methyl ester (RME) differs chemically from petroleum products, its density, viscosity, calorific value and process of combustion are very close to diesel fuel (LI et al. 2006; Vančurová 2008). Table 1 lists the specific technical requirements for diesel oil and RME (ČSN EN 14214:2004; ČSN EN 590:2010).

The literature says that in terms of power parameters the maximum value will decrease by about 3–5% for the fuel with 31% content of RME. The fuel consumption will slightly increase by approximately 7% for this fuel (BASHA et al. 2009). It is also necessary to take into account that RME evaporates worse than diesel and so it can enter the oil filling of the engine (Holas 1996).

Characteristics of internal combustion engines are used as proof of the properties of the engine (BAUER et al. 2006). They are presented in graphic form and the measured values are often corrected to standard conditions according to applicable regulations or standards. The characteristic of the combustion engine means the relationship between the main engine operating parameters such as engine speed, torque (or mean effective pressure), power, specific fuel consumption, exhaust temperature, pressure of filling air etc. The basic characteristics of internal combustion engine are:

Speed (RPM) – engine speed is the independent variable, the characteristic is measured at a constant setting of the engine speed governor;

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Requirements	Diesel fuel	Rapeseed methyl ester (RME)
Density at 15°C (kg/m³)	820-860	870-890
Kinematic viscosity at 40°C (mm²/s)	2.0-4.5	3.5-5.0
Freezing point (°C)	-4/-22	-8/-20
Flash point (°C)	over 55	over 110
Carbon residue (% weight)	0.10-0.30	0.05
Sulfur (% weight)	max 0.05	0.02
Ash (% weight)	max 0.01	max 0.02
Mechanical impurities (mg/kg)	max 24	max 24

Table 1. Selected technical requirements for diesel and rapeseed methyl ester (ČSN EN 590, ČSN EN 14214)

Load – the engine load which is represented by the mean effective pressure engine torque is the independent variable, this characteristic is measured at constant engine speed;

Engine map – this map shows the curves of constant power, constant specific fuel consumption and constant curves of the other quantities depending on the engine speed and its torque.

Any change in single characteristic indicates change in engine settings or degradation of the technical condition of the engine which is affected by the operational wear (MÜLLER et al. 2009). Emerging fault can be detected by checking these characteristics and so the maintenance or repair can be done timely. Engine characteristics can be measured on a roller dynamometer, on a dynamometer connected to rear power take-off or using dynamic measuring methods (HROMÁDKO et al. 2007). Different driving cycles can be simulated based on mathematical modelling of these characteristics (Jílek et al. 2008; Brožová, Růžička 2009; Kubín, Pexa 2010; Pexa, Kubín 2010).

Tractor Zetor Forterra 8641 which is located in the laboratories of the Department for Quality and Dependability of Machines was used to verify the effect of RME share in fuel on engine map of an internal combustion engine. The engine of the tractor had less than 100 worked hours and laboratory measurements represent most of its previous work. Several ratios of diesel fuel which is available on the common fuel station and RME was selected as fuel. The ratios of diesel and RME changed from pure diesel to pure RME as follows:

- fuel No. 1: 100% diesel fuel,
- fuel No. 2: 85% diesel fuel and 15% RME,
- fuel No. 3: 70% diesel fuel and 30% RME,
- fuel No. 4: 55% diesel fuel and 45% RME,
- fuel No. 5: 100% RME.

The use of diesel fuel from the common fuel station was chosen mainly because of its easy accessibility. In terms of practice there is a significant fact that the majority of agricultural tractors use this fuel. Diesel fuel supplied to the network of fuel stations (ČSN EN 590:2010) includes mandatory share of biofuels (RME) in accordance with the EU legislation. This represents a partial complication for measuring the effect of RME share in fuel on the engine map of tractor engine. In the Czech Republic there is currently prescribed 6% share of biofuel in diesel supplied in the market for a longer period of time (valid from 1. 6. 2010). The amount of biofuel in diesel shall not exceed 7%. Therefore the share of biofuels in diesel fuel at the fuel station is not clearly defined and fluctuates around 6%. It was necessary to analyse all of test fuels to determine the actual percentage of RME in each of them. Founded proportion of RME in test fuels is as follows:

- fuel No. 1: 5.5% RME (diesel from fuel station),
- fuel No. 2: 19.7% RME,
- fuel No. 3: 33.9% RME,
- fuel No. 4: 48.0% RME,
- fuel No. 5: 100.0% RME.

MATERIAL AND METHODS

Measuring devices were gradually attached to the measured tractor Zetor Forterra 8641 (Zetor Tractors a.s., Brno, Czech Republic) (Table 2). Hydraulic dynamometer (Fig. 1) was connected to the rear power take-off of the tractor. Basic parameters of the dynamometer AW NEB 400 (AW Dynamometer Inc., North Pontiac, USA) which was used are shown in Table 3. The fuel box which contains two flow meters Macnaught MSeries M2ASP-1R (Mac-



Fig. 1. Tractor Zetor Forterra 8641 with attached dynamometer AW NEB 400

Table 2. Basic technical parameters of the engine Zetor 1204 in Zetor Forterra 8641 tractor (manufacturer's data according to ECE R24)

Parameter	Value
Rated power (kW)	60
Rated speed (1/min)	2,200
Max. torque (Nm)	351
Specific fuel consumption at rated power (g/kWh)	253
Max. speed (1/min)	2,460
Idling speed (1/min)	750

naught Pty, Ltd., Turrella, Australia) was used to measure fuel consumption of the engine. The first flow meter measures the amount of fuel supplied to the engine and the second flow meter measures the amount of fuel that returns to the tank. The main

Table 3. Basic technical parameters of the dynamometer AW NEB 400

Parameter	Value
Max. torque at power take-off (Nm)	2,850
Max. power take-off speed (1/min)	3,200
Max. braking power (kW)	343
Max. braking power at power take-off speed 540 1/min (kW)	149
Max. braking power at power take-off speed 1,000 1/min (kW)	298
Error in measurement (%)	2

Table 4. Basic technical parameters of the flow meter M2ASP-1R

Parameter	Value
Max. flow rate (l/h)	500
Resolution (pulses/l)	400
Error in measurement (%)	1

parameters of the flow meter M2ASP-1R are shown in Table 4. The fuel tank of the tractor was completely disconnected during the measurement and an auxiliary tank for currently tested fuel which has 30 l capacity was used instead of it. No other modification of the tractor fuel system was performed. The following sensors were also connected: air temperature and pressure sensor, engine oil temperature sensor and fuel temperature sensor.

Once the tractor was ready for testing the test fuel was prepared (diesel and RME). The mixtures of 100/0, 85/15, 70/30, 55/45 and 0/100 (diesel from a fuel station/RME) were mixed. A sample of diesel (purchased at fuel station) was taken for laboratory analysis which showed 5.5% share of RME in this fuel.

The flushing of the tank and fuel system was realized after each change of fuel mixture to ensure the removal of any previous fuel mixture (mixed proportions of pump overflow were captured and completely excluded from measurements). The tractor engine was warmed up after filling the tank with selected fuel to reach its operating temperature. The rated speed characteristic (governor of engine speed at maximal position) of the engine was measured after heating the engine (Fig. 2). This characteristic was used to determine the appropriate measuring point for creating of the engine map (Fig. 3). The measurement points (about 35)

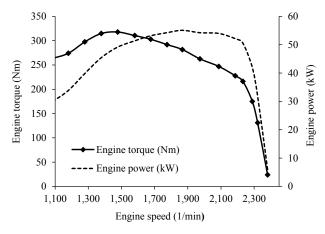


Fig. 2. An example of rated speed characteristic of the engine (power take-off, fuel from common fuel station)

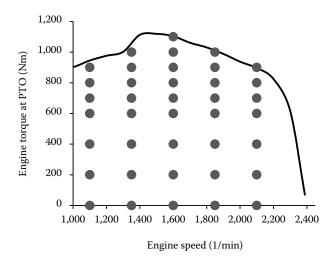


Fig. 3. An example of defined measurement points -85/15 (diesel from fuel station/RME)

are defined so that most of them are in the working area of the engine. Defining of these points was followed by their measurement. After turning the power take-off on the dynamometer and the governor of engine speed were set so that the engine has stabilized in the desired measuring point. Engine speed, torque, fuel consumption and other monitored quantities were registered after stabilization of the engine. Engine power was then calculated from engine speed and its torque.

The dependence of density on temperature was found for each of test fuels. The gravimetric and specific fuel consumption were calculated from measured values using this dependence. Values of torque and shaft speed which were measured on power take-off were converted to engine values using the appropriate gear ratio (3.543). The power losses in transmission between the engine and power take-off which can be regarded as constant are not significant for comparison of the effect of fuel type on engine map. Therefore these losses are not considered in evaluation of the measurement. So the calculated values of specific fuel consumption correspond to engine power on the power take-off.

Measured values were then processed using functions of the MathCAD software (PTC Corporate Headquarters, Needham, USA) into continuous surfaces. REGRESS and INTERP functions were used to create continuous surfaces. REGRESS function allows selecting a suitable degree of the polynomial. Quadratic or cubic polynomials are sufficient for fuel consumption. Surfaces thus created are stored in a file in a text format, where a matrix of 41×41 points

is created (1,681 points). SPLINE function is used in further work with this matrix. This function which uses interpolation from points of the matrix allows determining the value of a monitored variable at any engine operating point.

RESULTS

Table 5 shows all measured points and measured fuel consumption for each of test fuels. The function REGRESS together with the functions INTERP (1) interleave the measured points in fuel consumption *PlochaZ* with pre preset cubic polynomial set cubic polynomial. *PlochaZ* is in coordinates *PlochaXY* (*om* and *TM* are coordinates of engine speed and torque). The result is a continuous surface *Plocha(om, TM)*. A square matrix of 41 × 41 (1,681 points) is created from this surface for further processing.

$$R = \operatorname{regress}(PlochaXY, PlochaZ, 3)$$

$$Plocha(om, TM) = \operatorname{interp}\left[R, PlochaXY, PlochaZ, \binom{om}{TM}\right]$$
(1)

where:

PlochaXY – matrix giving the coordinates of

engine speed and torque om and TM

PlochaZ – single column matrix of data of the processed quantity (e.g. fuel con-

processed quantity (e.g. fuel con sumption) (g/h)

3 – degree of the polynomial (optional)

Plocha(om,TM) - continuous surface of processed

quantity (g/h)

om – coordinates of engine speed (1/min)

TM – coordinates of engine torque (Nm)

The matrix of 1,681 points is interleaved using the SPLINE function (2) in the further processing. The SPLINE function interleaves the surface exactly in the points which are defined in 41×41 matrix.

$$Plocha(om, TM) = interp \left[cspline(PlochXY, Plocha), \\ PlochaXY, Plocha, \begin{pmatrix} om \\ TM \end{pmatrix} \right]$$
(2)

where:

Plocha – matrix of measured quantity in 1,681 points (g/h)

The procedure of making surfaces (1, 2) is applied to all of test fuels and the results are shown in form of engine maps in Figs 4–8. The point where the en-

Table 5. Measured points and measured fuel consumption for each of test fuels

M_{PTO} M_p M_{PTO} M_p M_{PTO} M_{PTO} M_{PTO} M_{PTO} M_{PTO} M_p													
0 991 726 0 1,003 726 0 1,013 726 0 1,1188 200 6,176 1,852 24 4,034 1,851 22 4,223 1,644 22 3,478 400 7,906 1,852 210 5,659 1,848 112 8,256 1,649 191 4,705 600 9,619 1,846 398 7,672 1,848 619 10,353 1,649 600 8,082 801 11,298 1,845 702 11,522 1,649 600 8,093 801 11,298 1,847 848 702 11,522 1,649 609 8,040 803 1,847 1,848 702 11,522 1,649 600 8,040 804 1,128 1,844 12,349 702 1,4522 1,649 609 9,040 807 1,234 1,848 702 1,4522 1,649 600		$n_M = (1/\mathrm{min})$	M_{PTO} (Nm)	$M_p \choose (g/h)$	$n_M = (1/\mathrm{min})$	$M_{PTO} \ m (Nm)$	$M_p \ (g/h)$	$n_M = (1/\mathrm{min})$	$M_{PTO} \ m (Nm)$	$M_p \ (\mathrm{g/h})$	$n_M = (1/\mathrm{min})$	M_{PTO} (Nm)	$M_{\stackrel{p}{p}}$ (g/h)
200 6,176 1,852 24 4,034 1,851 22 4,223 1,644 22 3,478 400 7,906 1,852 2,10 5,659 1,848 189 5,818 1,649 191 4,705 600 9,619 1,846 398 7,672 1,848 619 1,649 619 698 801 1,1298 1,851 607 9,810 1,848 702 1,649 609 8,802 801 1,1298 1,847 818 1,231 1,848 702 1,649 609 8,802 802 1,1298 1,847 818 1,349 702 1,522 1,649 609 8,640 807 1,236 1,847 818 1,345 1,62 1,649 8,97 1,030 807 1,236 1,847 81,44 1,723 1,462 1,649 8,97 1,013 807 1,431 1,346 1,346 <td< td=""><td></td><td>726</td><td>0</td><td>1,009</td><td>726</td><td>0</td><td>1,013</td><td>726</td><td>0</td><td>1,188</td><td>730</td><td>0</td><td>1,400</td></td<>		726	0	1,009	726	0	1,013	726	0	1,188	730	0	1,400
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807 12,208 1,847 919 13,320 1,853 965 14,622 1,649 897 12,031 990 14,331 1,846 997 14,732 1,345 16 2,433 1,649 1,013 13,550 11 2,154 1,344 15 2,009 1,346 607 5,453 1,102 198 1,771 217 3,476 1,346 617 6,958 1,100 409 2,952 391 4,966 1,346 6,76 1,346 617 6,958 1,100 609 5,736 600 6,704 1,350 76 1,349 797 8,970 1,00 609 5,736 708 8,442 1,350 8,837 1,352 896 9,724 1,100 809 5,346 933 9,676 1,352 8,837 1,352 896 9,724 1,100 888 8,344 1,002 1,348 9,89		1,847	818	12,315	1,847	844	12,773	1,650	811	10,900	1,848	852	13,959
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14 2,154 1,344 15 2,009 1,346 200 3,772 1,107 12 1,771 217 3,476 1,346 206 3,510 1,350 406 5,453 1,102 198 2,952 391 4,966 1,348 406 5,265 1,349 714 7,964 1,100 409 4,302 600 6,704 1,350 615 6,769 1,349 797 8,970 1,097 764 7,586 933 9,676 1,352 812 8,837 1,352 896 9,724 1,100 888 8,344 1,002 1,352 919 10,195 1,352 947 10,470 2,103 5,396 1,002 1,364 10,404 2,107 2,144 2,105 2,19 2,495 1,002 5,201 2,116 2,185 2,194 2,195 2,199 2,195 2,199 2,196 2,196 2,196 2,1		1,846	266	14,732	1,345	16	2,433	1,649	1,013	13,550	1,357	14	2,524
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3914,9661,3484065,2651,3466176,9581,1004094,3026006,7041,3506156,7691,3497147,9641,1006095,7367928,4421,3507007,5211,3497978,9701,0977647,5869339,6761,3528128,8371,35294710,4702,103888,3441,0021,35291910,1951,35294710,4702,103295,3991,0021,34898910,4042,1072,1042,1052,0993909,3332,732,1042,0961836,7582,0952,0993009,3334069,4042,0983858,9952,10560412,2822,09970113,599		1,346	206	3,510	1,350	406	5,453	1,102	198	2,952	1,349	412	5,653
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933 9,676 1,352 8,837 1,352 896 9,724 1,100 888 8,344 708 7,526 1,352 919 10,195 1,352 947 10,470 2,103 29 5,399 1,002 10,659 1,348 989 10,404 2,107 27 5,444 2,105 219 7,405 29 5,201 2,110 29 5,135 2,104 213 7,365 2,099 390 9,333 278 7,919 2,096 183 6,758 2,098 418 9,951 2,099 607 12,266 406 9,404 2,098 385 8,995 2,105 604 12,282 2,099 701 13,599		1,350	200	7,521	1,349	797	8,970	1,097	764	7,586	1,349	840	9,914
708 7,526 1,352 919 10,195 1,352 947 10,470 2,103 29 5,399 1,002 10,659 1,348 989 10,404 2,107 27 5,444 2,105 219 7,405 29 5,201 2,110 29 5,135 2,104 213 7,365 2,099 390 9,333 278 7,919 2,096 183 6,758 2,098 418 9,951 2,099 607 12,266 406 9,404 2,098 385 8,995 2,105 604 12,282 2,099 701 13,599		1,352	812	8,837	1,352	968	9,724	1,100	888	8,344	1,352	950	11,210
1,002 10,659 1,348 989 10,404 2,107 27 5,444 2,105 219 7,405 29 5,201 2,110 29 5,135 2,104 213 7,365 2,099 390 9,333 278 7,919 2,096 183 6,758 2,098 418 9,951 2,099 607 12,266 406 9,404 2,098 385 8,995 2,105 604 12,282 2,099 701 13,599		1,352	919	10,195	1,352	947	10,470	2,103	29	5,399	2,106	29	2,996
29 5,201 2,110 29 5,135 2,104 213 7,365 2,099 390 9,333 278 7,919 2,096 183 6,758 2,098 418 9,951 2,099 607 12,266 406 9,404 2,098 385 8,995 2,105 604 12,282 2,099 701 13,599		1,348	686	10,404	2,107	27	5,444	2,105	219	7,405	2,098	194	7,815
278 7,919 2,096 183 6,758 2,098 418 9,951 2,099 607 12,266 406 9,404 2,098 385 8,995 2,105 604 12,282 2,099 701 13,599		2,110	29	5,135	2,104	213	7,365	2,099	390	9,333	2,102	404	10,585
406 9,404 2,098 385 8,995 2,105 604 12,282 2,099 701 13,599		2,096	183	6,758	2,098	418	9,951	2,099	209	12,266	2,096	009	13,004
		2,098	385	8,995	2,105	604	12,282	2,099	701	13,599	2,099	759	15,072
2,101 605 11,529 2,105 617 11,994 2,098 747 13,953 2,103 833 15,755 2,		2,105	617	11,994	2,098	747	13,953	2,103	833	15,755	2,101	838	16,359
2,101 759 13,330 2,098 706 13,160 2,100 844 15,695 1,405 18 2,428 1,		2,098	902	13,160	2,100	844	15,695	1,405	18	2,428	1,104	15	1,818
2,101 856 15,279 2,100 796 14,367 1,096 11 1,918 1,396 208 3,768 1,		2,100	962	14,367	1,096	111	1,918	1,396	208	3,768	1,097	201	3,116

Table 5. to be continued

n, n	nel N	Fuel No. 1 (5.5% RME)	RME)	Fuel N	Fuel No. 2 (19.7% RME)	RME)	Fuel N	Fuel No. 3 (33.9% RME)	RME)	Fuel N	Fuel No. 4 (48.0% RME)	RME)	Fuel N	Fuel No. 5 (100.0% RME)	RME)
1,896 2,100 879 1,5591 1,101 198 2,753 1,402 608 5,443 1,100 401 2,635 1,107 16 1,912 1,101 405 4,925 1,402 608 7,285 1,100 600 3,871 1,100 202 2,991 1,102 607 5,760 1,396 708 8,290 1,100 600 6,341 1,103 605 5,737 1,103 804 7,436 1,400 909 1,109 703 807 7,247 1,104 606 8,439 1,400 947 1,098 807 1,598 807 1,403 807 1,098 807 1,604 947 1,090 909 1,090 1,098 807 1,098 807 1,098 1,098 1,098 807 1,098 807 1,098 807 1,098 807 1,098 807 1,098 1,098 1,098 1,098 1,098		M_{PTO} (Nm)	$M_p \choose (g/h)$	$n_M = (1/\mathrm{min})$	$M_{PTO} \ m (Nm)$	$M_p \ (\mathrm{g/h})$	$n_M = (1/\min)$	M_{PTO} (Nm)	$M_p \ (\mathrm{g/h})$	$n_M = (1/\mathrm{min})$	$M_{_{PTO}} \ m{(Nm)}$	$M_p \choose (g/h)$	$n_{_M}$ (1/min)	$M_{PTO} \ m (Nm)$	$M_p \choose (g/h)$
2,635 1,107 1,61 1,91 4,92 1,402 608 7,285 1,100 600		12	1,896	2,100	628	15,591	1,101	198	2,753	1,402	395	5,443	1,100	401	4,591
3.871 1,100 202 2,991 1,102 67.760 1,396 708 82.90 1,100 703 5,353 1,101 398 3,988 1,101 708 6,768 1,398 806 9,462 1,098 807 6,341 1,098 66,34 1,101 804 7,436 1,400 997 1,098 807 9,462 1,098 807 1,609 999 1,098 807 1,098 807 1,609 999 1,599 1,599 1,609		230	2,635	1,107	16	1,912	1,101	405	4,925	1,402	809	7,285	1,100	009	5,982
590 5,353 1,101 398 1,101 708 6,768 1,398 806 9,462 1,098 806 9,462 1,103 804 7,436 1,398 806 1,103 804 7,436 1,400 909 10,291 1,098 807 794 7,247 1,108 6,438 1,102 902 8,439 1,400 947 1,096 1,594 1,997 1,698 1,699		388	3,871	1,100	202	2,991	1,102	209	5,760	1,396	708	8,290	1,100	703	6,935
680 6.341 1,098 66.34 1,103 804 7,436 1,400 909 10,291 1,103 909 736 7,247 1,105 6,408 1,102 902 8,439 1,400 947 10,960 1,594 19 215 3,135 1,098 824 7,400 1,604 20 3,175 1,853 20 1,594 1,696 1,699 1,699 1,699 1,699 1,699 1,845 1,846 403 7,961 1,698 397 804 8,011 1,598 4,479 1,601 606 8,689 1,847 403 1,599 1,599 1,849 7,91 1,603 608 807 9,141 1,598 1,601 606 8,689 1,849 7,91 1,599 7,11 808 1,003 1,61 6,332 1,591 1,61 1,61 1,61 1,61 1,61 1,849 1,849 1,438 1,609 1,		290	5,353	1,101	398	3,988	1,101	208	6,768	1,398	908	9,462	1,098	807	7,976
796 7,247 1,105 704 6,408 1,102 902 8,439 1,400 947 10,960 1,594 1,69 21 3,135 1,098 824 7,490 1,604 22 3,175 1,853 27 4,016 1,693 1,693 1,694 1,695 1,695 1,695 1,845 1,845 6,034 1,598 1,993 1,699 1,845 1,846 403 7,961 1,693 1,993 1,698 1,847 6,17 1,012 1,698 1,849 1,849 6,17 1,693 1,11 1,698 1,11 1,849 1,849 1,691 1,691 1,849 1,849 1,693 1,11		089	6,341	1,098	909	5,737	1,103	804	7,436	1,400	606	10,291	1,103	606	9,276
21 4,616 1,604 22 3,175 1,853 27 4,016 1,603 1,604 1,604 1,604 1,605 1,845 1,845 6,034 1,509 1,509 1,845 1,845 1,603 1,598 1,599 1,847 1,845 1,603 1,599 1,603 1,845 1,846 403 7,961 1,603 608 594 8,01 1,598 1,601 1,601 1,601 1,601 1,603 1,849 1,021 1,599 7,11 803 1,003 1,601 8,336 1,601 816 1,849 820 1,599 </td <td></td> <td>962</td> <td>7,247</td> <td>1,105</td> <td>704</td> <td>6,408</td> <td>1,102</td> <td>905</td> <td>8,439</td> <td>1,400</td> <td>947</td> <td>10,960</td> <td>1,594</td> <td>19</td> <td>3,373</td>		962	7,247	1,105	704	6,408	1,102	905	8,439	1,400	947	10,960	1,594	19	3,373
215 4,616 1,104 924 8,488 1,605 207 4,762 1,845 6,684 1,846 6,684 1,846 6,684 1,846 6,684 1,846 6,634 1,596 397 6,684 1,846 6,17 1,603 6,083 1,594 1,694 <td></td> <td>22</td> <td>3,135</td> <td>1,098</td> <td>824</td> <td>7,490</td> <td>1,604</td> <td>22</td> <td>3,175</td> <td>1,853</td> <td>27</td> <td>4,016</td> <td>1,603</td> <td>192</td> <td>4,930</td>		22	3,135	1,098	824	7,490	1,604	22	3,175	1,853	27	4,016	1,603	192	4,930
389 6,341 1,603 3,159 397 6,684 1,846 403 7,961 1,603 6,88 594 8,071 1,596 210 4,479 1,601 606 8,6889 1,847 617 1,599 711 697 9,141 1,598 706 9,441 1,849 701 1,599 711 803 1,603 612 8,336 1,601 816 1,598 1,849 820 12,957 1,598 906 1,055 10,935 1,601 1,636 1,636 1,031 12,449 1,849 939 14,438 1,600 1,019 1,056 1,058 1,031 1,031 12,940 1,849 939 14,438 1,600 1,019 1,059 1,108 1,1188 1,188 1,294 1,244 1,843 1,600 1,019 1,019 1,019 1,019 1,019 1,019 1,019 1,019 1,019 1,019 1,019 <td></td> <td>215</td> <td>4,616</td> <td>1,104</td> <td>924</td> <td>8,488</td> <td>1,605</td> <td>207</td> <td>4,762</td> <td>1,845</td> <td>205</td> <td>6,034</td> <td>1,598</td> <td>397</td> <td>7,178</td>		215	4,616	1,104	924	8,488	1,605	207	4,762	1,845	205	6,034	1,598	397	7,178
594 8,071 1,596 210 4,479 1,601 606 8,689 1,847 617 10,216 1,599 711 697 9,141 1,598 706 9,441 1,849 701 11,295 1,597 806 803 1,603 1,601 816 1,601 816 1,649 820 1,598 906 1,055 1,093 1,598 1,598 1,031 1,2940 1,849 820 14,438 1,600 1,019 1,056 1,093 1,1188 1,699 1,031 12,940 1,849 939 14,438 1,600 1,019 1,058 1,118 1,596 1,031 1,2940 1,294 1,438 1,600 1,019 1,599 1,018 1,2483 1,018 1,601 1,801 1,438 1,600 1,019 1,599 1,018 1,598 1,031 1,601 1,601 1,601 1,601 1,601 1,601 1,60		389	6,341	1,603	31	2,993	1,599	397	6,684	1,846	403	7,961	1,603	809	9,254
697 9,141 1,598 401 6,392 1,598 706 9,441 1,849 701 11,295 1,598 806 803 10,039 1,601 8,336 1,601 816 15,449 1,849 820 12,957 1,598 906 1,055 1,093 1,598 1,598 1,031 12,940 1,849 939 14,438 1,600 1,019 1,056 1,598 1,1188 1,031 12,940 1,2940 1,843 1,600 1,019 1,598 1,011 12,483 1,011 12,483 1,031 1,2940 1,843 1,600 1,019 1,598 1,011 12,483 1,011 12,483 1,011 1,		594	8,071	1,596	210	4,479	1,601	909	8,689	1,847	617	10,216	1,599	711	10,378
10,039 1,601 612 8,336 1,601 816 10,695 1,849 820 12,957 1,598 906 10,935 1,601 716 9,373 1,596 1,031 12,949 1,849 939 14,438 1,600 1,019 12,990 1,598 1,138 1,031 12,940 12,940 12,438 1,600 1,019 1,598 1,011 12,483 1,011 12,483 1,600 1,315 1,848 1,848 1,611		269	9,141	1,598	401	6,392	1,598	902	9,441	1,849	701	11,295	1,597	908	11,061
10,935 1,601 716 9,373 1,598 952 12,449 1,849 939 14,438 1,600 1,019 12,990 1,598 812 10,326 1,596 1,031 12,940 12,940 1,610 1,618 1,1188		803	10,039	1,603	612	8,336	1,601	816	10,695	1,849	820	12,957	1,598	906	12,444
12,990 1,598 812 10,326 1,596 1,031 1,600 898 11,188 1,188 1,598 1,011 12,483 1,062 13,155		897	10,935	1,601	716	9,373	1,598	952	12,449	1,849	939	14,438	1,600	1,019	13,729
898 1,011 1,062		1,055	12,990	1,598	812	10,326	1,596	1,031	12,940						
1,011				1,600	868	11,188									
1,062 13,				1,598	1,011	12,483									
				1,599	1,062	13,155									

 n_{M} – engine speed (1/min); M_{PTO} – engine torque measured on power take-off (Nm); M_{p} – gravimetric hourly fuel consumption (g/h)

350 Minimal specific fuel consumption: 259.7 g/kWh 300 (1,564 1/min, 298 Nm) Engine torque (Nm) 250 250 100 50 0 1,000 1,200 1,400 1,600 1,800 2,000 2,200 2,400

Fig. 4. Engine map for fuel No. 1 (5.5% RME)

solid lines = isolines of specific consumption (g/kWh) dashed lines = isolines of power (kW)

Engine speed (1/min)

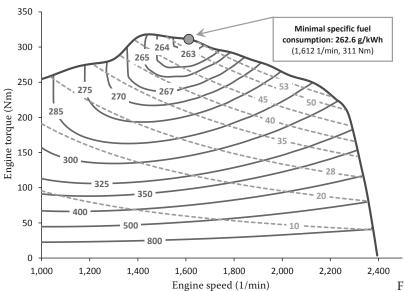


Fig. 5. Engine map for fuel No. 2 (19.7% RME)

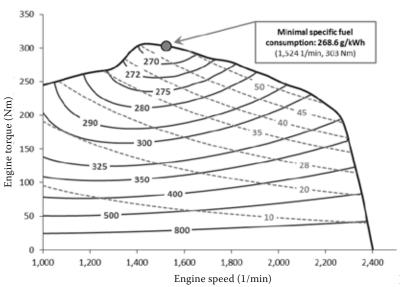


Fig. 6. Engine map for fuel No. 3 (33.9% RME)

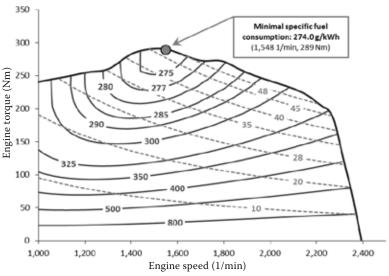


Fig. 7. Engine map for fuel No. 4 (48.0% RME)

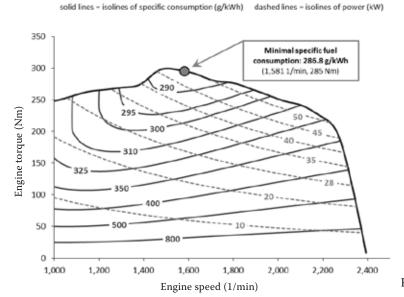


Fig. 8. Engine map for fuel No. 5 (100.0% RME)

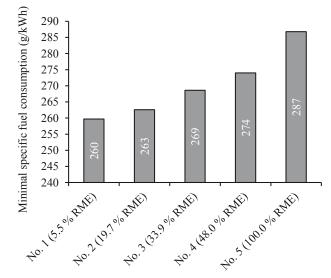


Fig. 9. Change of minimum specific fuel consumption on the power take-off with increasing proportion of RME

gine reaches minimum specific fuel consumption is marked in each map. There are also mentioned engine speed and torque of this point.

The increase of RME proportion in diesel fuel is reflected by increasing the specific fuel consumption. The lowest minimum specific fuel consumption of 259.7 g/kWh was achieved on diesel, which contained only the proportion of RME which is given by the legislation (5.5%). On the other hand, the highest minimum specific fuel consumption of 286.8 g/kWh was achieved at a pure RME (Fig. 9). The section of engine map with lowest specific fuel consumption remained maintained at all measured fuels. The engine speed is in this case in the range between 1,530 and 1,630 1/min and the torque reaches values near to its maximum at this engine speed.

DISCUSSION AND CONCLUSION

The use of RME in the internal combustion engine of agricultural tractors is accompanied with a reduction of power parameters and an increase of specific fuel consumption. It is stated that the drop in power parameters is 3–5% and the increase in fuel consumption is around 7% for the diesel with 31% of RME (Holas 1996, Vančurová 2008).

The share of RME mainly reflects in the increased specific fuel consumption as it can be seen on the presented engine maps. The minimum specific fuel consumption of 259.7 g/kWh (power take-off) was achieved when the engine of the tractor Zetor Forterra 8641 operates on diesel from common fuel station (5.5% RME). When the engine was operating on pure RME the reached minimum specific fuel consumption was 286.8 g/kWh. This represents an increase of about 10%. The operating area of the engine where the minimum specific fuel consumption is achieved remains unchanged. The engine speed is 1,530–1,630 1/min in this area and the torque is very close to its maximum at this speed (Figs 4–8).

The increase in specific fuel consumption is mainly associated with a reduction in tractor engine power parameters. The maximum torque of 318 Nm which was reached for the diesel from fuel station decreased to 299 Nm when the engine operates on pure RME. This means that the reduction is approximately 6%.

The choice of operating modes of the engine remains unchanged and so it is possible to operate the tractor in the same way. The advantage of using RME is also the ability to use it without any technical modification of the engine (most of new engines is ready for using RME). However, it is necessary to take into account the properties of RME and it is also important to take care of fuel system, particularly with regard to the removal of water and other sediments.

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