Effect of rapeseed methyl ester on fuel consumption and engine power

M. Pexa[1], K. Kubín[2]

[1]*Department for Quality and Dependability of Machines, Faculty of Engineering, Czech University of Life Sciences Prague, Prague, Czech Republic*
[2]*Research Institute of Agricultural Engineering, Prague, Czech Republic*

Abstract

Pexa M., Kubín K., 2012. **Effect of rapeseed methyl ester on fuel consumption and engine power**. Res. Agr. Eng., *58*: 37–45.

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;

Supported by the Internal Grant Agency of the Czech University of Life Sciences Prague, Czech Republic, Project No. 31190/1312/3128 and by the Ministry of Agriculture of the Czech Republic, Project No. MZE 0002703102.

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

Requirements	Diesel fuel	Rapeseed methyl ester (RME)
Density at 15°C (kg/m^3)	820–860	870–890
Kinematic viscosity at 40°C (mm^2/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

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

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

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 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)

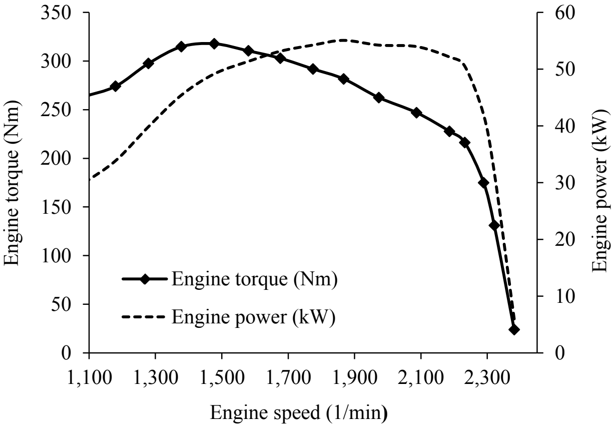


Fig. 2. An example of rated speed characteristic of the engine (power take-off, fuel from common fuel station)

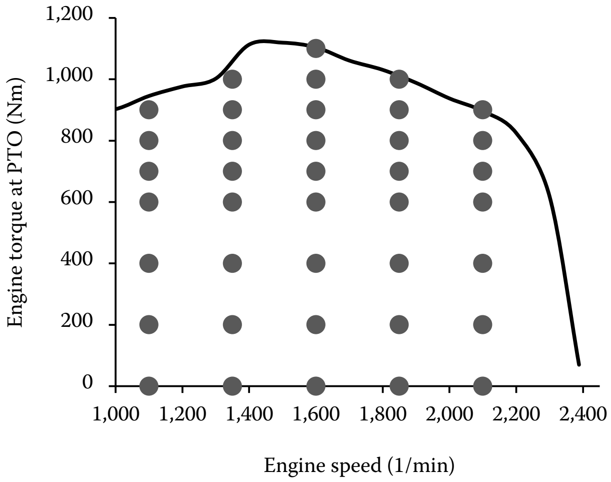


Fig. 3. An example of defined measurement points – 85/15 (diesel from fuel station/RME)

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.

$$\begin{aligned} &R = \mathrm{regress}(PlochaXY, PlochaZ, 3) \\ &Plocha(om, TM) = \mathrm{interp}\left[R, PlochaXY, PlochaZ, \begin{pmatrix} om \\ TM \end{pmatrix}\right] \end{aligned} \quad (1)$$

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 consumption) (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.

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

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-

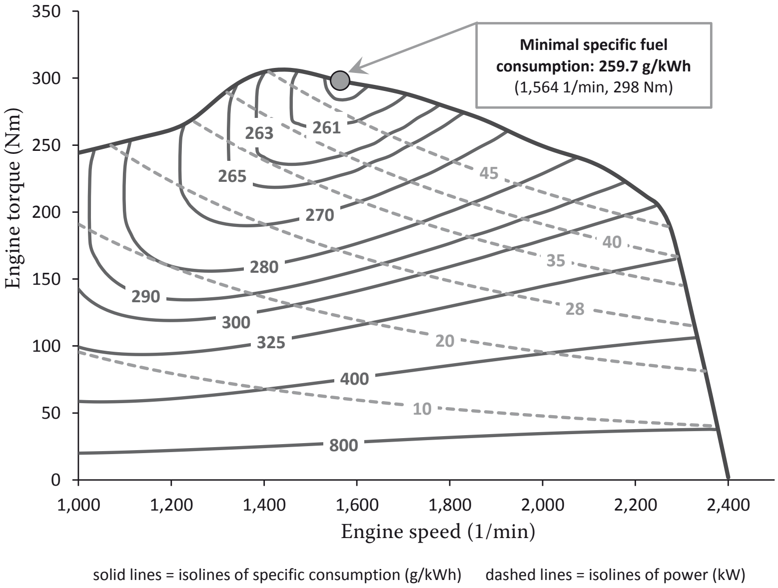
Table 5. Measured points and measured fuel consumption for each of test fuels

Fuel No. 1 (5.5% RME)			Fuel No. 2 (19.7% RME)			Fuel No. 3 (33.9% RME)			Fuel No. 4 (48.0% RME)			Fuel No. 5 (100.0% RME)		
n_M (1/min)	M_{PTO} (Nm)	M_p (g/h)	n_M (1/min)	M_{PTO} (Nm)	M_p (g/h)	n_M (1/min)	M_{PTO} (Nm)	M_p (g/h)	n_M (1/min)	M_{PTO} (Nm)	M_p (g/h)	n_M (1/min)	M_{PTO} (Nm)	M_p (g/h)
725	0	991	726	0	1,009	726	0	1,013	726	0	1,188	730	0	1,400
1,922	200	6,176	1,852	24	4,034	1,851	22	4,223	1,644	22	3,478	1,851	25	4,722
1,887	400	7,906	1,852	210	5,659	1,848	189	5,818	1,649	191	4,705	1,854	204	6,472
1,844	600	9,619	1,846	398	7,672	1,848	412	8,256	1,649	413	6,988	1,846	413	8,826
1,803	696	10,350	1,851	607	9,810	1,848	619	10,353	1,649	600	8,802	1,846	617	11,002
1,772	801	11,298	1,852	703	10,974	1,848	702	11,522	1,649	699	9,640	1,849	705	12,224
1,853	23	4,405	1,847	818	12,315	1,847	844	12,773	1,650	811	10,900	1,848	852	13,959
1,848	807	12,208	1,847	919	13,320	1,853	965	14,622	1,649	897	12,031	1,851	954	15,343
1,846	990	14,331	1,846	997	14,732	1,345	16	2,433	1,649	1,013	13,550	1,357	14	2,524
1,352	14	2,154	1,344	15	2,009	1,346	200	3,772	1,107	12	1,771	1,346	205	3,914
1,350	217	3,476	1,346	206	3,510	1,350	406	5,453	1,102	198	2,952	1,349	412	5,653
1,350	391	4,966	1,348	406	5,265	1,346	617	6,958	1,100	409	4,302	1,348	612	7,479
1,349	600	6,704	1,350	615	6,769	1,349	714	7,964	1,100	609	5,736	1,349	708	8,610
1,350	792	8,442	1,350	700	7,521	1,349	797	8,970	1,097	764	7,586	1,349	840	9,914
1,350	933	9,676	1,352	812	8,837	1,352	896	9,724	1,100	888	8,344	1,352	950	11,210
1,348	708	7,526	1,352	919	10,195	1,352	947	10,470	2,103	29	5,399	2,106	29	5,996
1,350	1,002	10,659	1,348	989	10,404	2,107	27	5,444	2,105	219	7,405	2,098	194	7,815
2,099	29	5,201	2,110	29	5,135	2,104	213	7,365	2,099	390	9,333	2,102	404	10,585
2,106	278	7,919	2,096	183	6,758	2,098	418	9,951	2,099	607	12,266	2,096	600	13,004
2,098	406	9,404	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	2,101	838	16,359
2,101	759	13,330	2,098	706	13,160	2,100	844	15,695	1,405	18	2,428	1,104	15	1,818
2,101	856	15,279	2,100	796	14,367	1,096	11	1,918	1,396	208	3,768	1,097	201	3,116

Table 5. to be continued

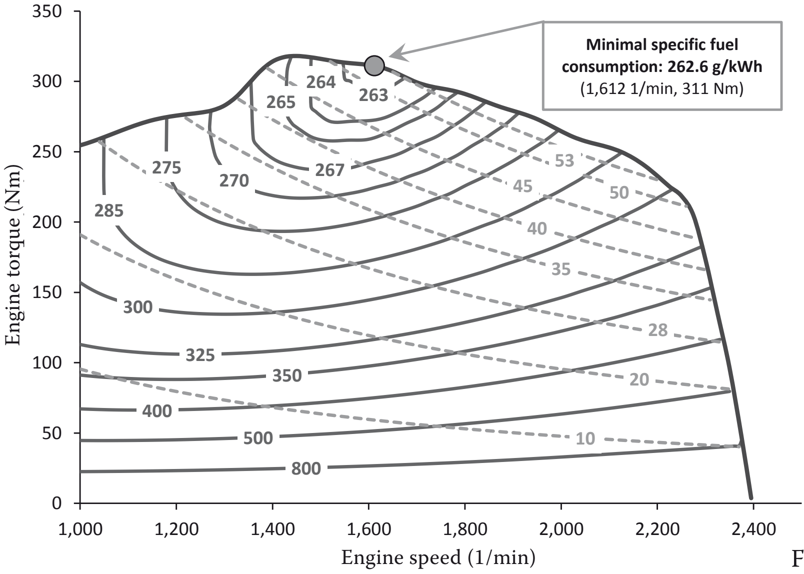
Fuel No. 1 (5.5% RME)			Fuel No. 2 (19.7% RME)			Fuel No. 3 (33.9% RME)			Fuel No. 4 (48.0% RME)			Fuel No. 5 (100.0% RME)		
n_M (1/min)	M_{PTO} (Nm)	M_p (g/h)	n_M (1/min)	M_{PTO} (Nm)	M_p (g/h)	n_M (1/min)	M_{PTO} (Nm)	M_p (g/h)	n_M (1/min)	M_{PTO} (Nm)	M_p (g/h)	n_M (1/min)	M_{PTO} (Nm)	M_p (g/h)
1,100	12	1,896	2,100	879	15,591	1,101	198	2,753	1,402	395	5,443	1,100	401	4,591
1,101	230	2,635	1,107	16	1,912	1,101	405	4,925	1,402	608	7,285	1,100	600	5,982
1,102	388	3,871	1,100	202	2,991	1,102	607	5,760	1,396	708	8,290	1,100	703	6,935
1,102	590	5,353	1,101	398	3,988	1,101	708	6,768	1,398	806	9,462	1,098	807	7,976
1,100	680	6,341	1,098	605	5,737	1,103	804	7,436	1,400	909	10,291	1,103	909	9,276
1,098	796	7,247	1,105	704	6,408	1,102	902	8,439	1,400	947	10,960	1,594	19	3,373
1,617	22	3,135	1,098	824	7,490	1,604	22	3,175	1,853	27	4,016	1,603	192	4,930
1,601	215	4,616	1,104	924	8,488	1,605	207	4,762	1,845	205	6,034	1,598	397	7,178
1,600	389	6,341	1,603	31	2,993	1,599	397	6,684	1,846	403	7,961	1,603	608	9,254
1,604	594	8,071	1,596	210	4,479	1,601	606	8,689	1,847	617	10,216	1,599	711	10,378
1,599	697	9,141	1,598	401	6,392	1,598	706	9,441	1,849	701	11,295	1,597	806	11,061
1,598	803	10,039	1,603	612	8,336	1,601	816	10,695	1,849	820	12,957	1,598	906	12,444
1,598	897	10,935	1,601	716	9,373	1,598	952	12,449	1,849	939	14,438	1,600	1,019	13,729
1,603	1,055	12,990	1,598	812	10,326	1,596	1,031	12,940						
			1,600	898	11,188									
			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)



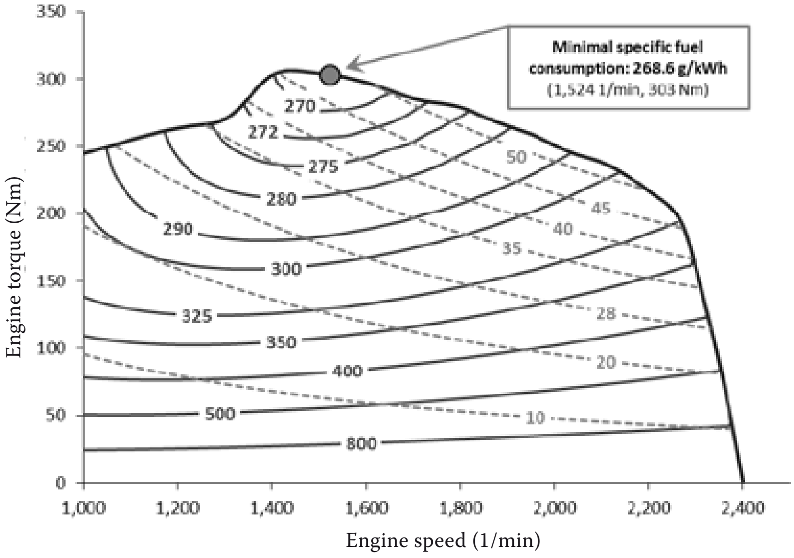
Minimal specific fuel consumption: 259.7 g/kWh
(1,564 1/min, 298 Nm)

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



Minimal specific fuel consumption: 262.6 g/kWh
(1,612 1/min, 311 Nm)

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



Minimal specific fuel consumption: 268.6 g/kWh
(1,524 1/min, 303 Nm)

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

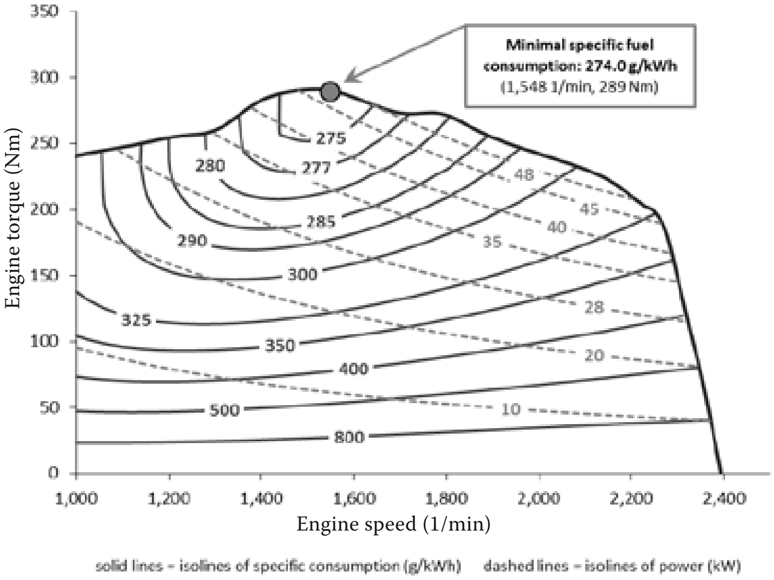


Fig. 7. Engine map for fuel No. 4 (48.0% RME)

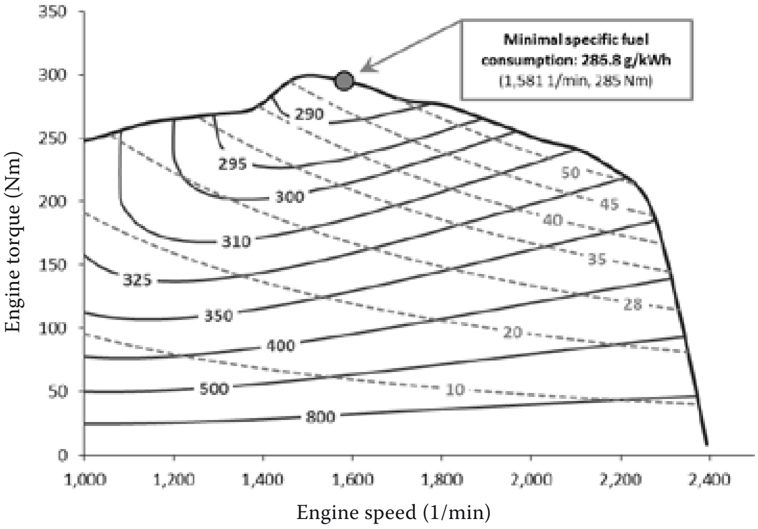


Fig. 8. Engine map for fuel No. 5 (100.0% RME)

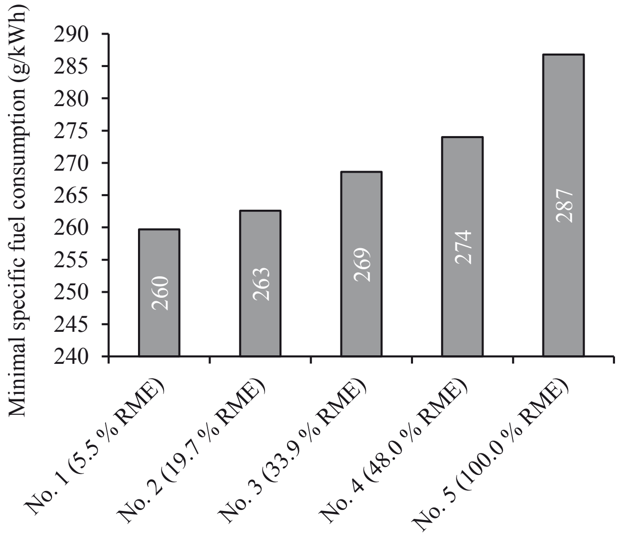


Fig. 9. Change of minimum specific fuel consumption on the power take-off with increasing proportion of RME

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.

References

Basha S.A., Gopal K.R., Jebaraj S., 2009. A review on biodiesel production, combustion, emissions and performance. Renewable and Sustainable Energy Reviews, *13*: 1628–1634.

Bauer F., Sedlák P., Šmerda T., 2006. Traktory (Tractors). Prague, Profi Press.

Brožová H., Růžička M., 2009. Quantitative analysis of environmental impact of transport projects. Scientia Agriculturae Bohemica, *40*: 216–225.

ČSN EN 590, 2010. Motorová paliva – Motorové nafty – Technické požadavky a metody zkoušení (Automotive Fuels – Diesel – Requirements and Test Methods).

ČSN EN 14214, 2004. Motorová paliva – Methyl estery mastných kyselin (FAME), palivo pro vznětové motory – Technické požadavky a metody zkoušení (Automotive Fuels – Fatty Acid Methyl Esters (FAME) for Diesel Engines – Requirements and Test Methods).

Holas J., 1996. Současný stav výroby a užití bionafty v České Republice (Current status of production and use of biodiesel in the Czech Republic). In: Proceedings of 13th Evaluation Seminar "The System of Production of Rape". November 26–28, 1996. Hluk, 162–168.

Hromádko J., Hromádko J., Kadleček B., 2007. Problems of power parameters measurement of constant-speed engines with small cylinder volume by acceleration method. Eksploatacja i Niezawodność – Maintenance and Reliability, *33*: 19–22.

Jílek L., Pražan R., Podpěra V., Gerndtová I., 2008. The effect of the tractor engine rated power on diesel fuel consumption during material transport. Research in Agricultural Engineering, *54*: 1–8.

Kubín K., Pexa M., 2010. Model jízdy traktorové dopravní soupravy – Energetické a exploatační ukazatele (Modeling of Tractor Transport Set – Energy and Exploitation Indicators). Agritech Science, *4*: 1–8.

Li Y.X., Mclaughlin N.B., Patterson B.S., Burtt S.D., 2006. Fuel efficiency and exhaust emissions for biodiesel blends in an agricultural tractor. Canadian Biosystems Engineering, *48*: 2.15–2.22.

Müller M., Chotěborský R., Hrabě P., 2009. Degradation processes influencing bonded joints. Research in Agricultural Engineering, *55*: 29–34.

Pexa M., Kubín K., 2010. Modeling of 8-mode test procedure for Zetor Forterra 8641 tractor. Scientia Agriculturae Bohemica, *41*: 149–155.

Vančurová P., 2008. Podmínky konkurenceschopnosti výroby bionafty v České republice (Conditions of Competitiveness of Biodiesel Production in the Czech Republic). [Ph.D. Thesis.] Prague, Czech University Life Sciences Prague.

Received for publication June 6, 2011
Accepted after corrections July 21, 2011

Corresponding author:

Ing. Martin Pexa, Ph.D., Czech University of Life Sciences Prague, Faculty of Engineering,
Department for Quality and Dependability of Machines, Kamýcká 129, 165 21 Prague 6-Suchdol, Czech Republic
phone: + 420 224 383 278, e-mail: pexa@tf.czu.cz