ANALYSIS OF THE NRSC TEST DURING THE USE OF BIOFUELS FOR THE ZETOR FORTERRA TRACTOR

M. Pexa[1], J. Čedík[1], R. Pražan[2]

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

Abstract
Production of solid particles increases significantly the degree of danger of combustion engines. Currently there are many design solutions which aim to reduce smoke of combustion engines. One of the most significant solutions suggests the increase of injection pressures up to the limit of 250 MPa and filtering the exhaust gases. The paper compares different fuels and biofuels and their effect on emissions of supercharged engine. The comparison uses the 8-point NRSC test during which the following fuels were used: diesel, rapeseed methyl ester, and hydrogenated oil.

Key words: engine, biofuels, emissions, smoke.

INTRODUCTION

Environmental protection makes the polluters reduce production of harmful substances. This restriction significantly affects automotive industry as well, i.e. cars, trucks and agricultural machinery. Agricultural machines are driven mainly by diesel combustion engines. The most harmful products of diesel combustion engines are particles, smoke and nitrogen oxides.

The literature describes several basic possibilities how to reduce smoke of diesel combustion engines in order to meet increasingly strict limits set by the international regulations:

- Increasing the injection pressure – injection pressure is continuously increased from several MPa to several hundred MPa. Injection of the fuel under higher pressure causes finer atomization of fuel which is better burnt in the combustion chamber of the engine. (WOO ET AL., 2016; LIU ET AL., 2015; HWANG ET AL., 2014)
- Filter of solid particles – combustion products such as solid particles are collected by filters at the outlet of the combustion chamber. When the filter is full, the particles collected by filters are additionally burnt at a higher temperature. (ARMAS ET AL., 2013; SUN ET AL., 2013)
- Selective catalytic reduction (SCR) – gradual reduction of nitrogen oxide limits brought the system of injecting urea into the exhaust pipe. This system helps to reduce the amount of nitrogen oxide and smoke. The smoke is reduced by up to 30%. However, inappropriate doses of ammonia may cause increased number of particles in exhaust gases. (CAO ET AL., 2016; KANG & CHOI, 2016; ATHAPPAN ET AL., 2015; AMANATIDIS ET AL., 2014)
- Use of more appropriate fuel – many kinds of biofuels are tested within the research and practice, especially biofuels from renewable resources. Fuels which are preferred have a positive impact on emissions and smoke and the influence on performance parameters are not too negative. (HÖNIG ET AL., 2015A,B; MÜLLER, ŠLEGER ET AL., 2015; MARTÍNEZ ET AL., 2014; MOGHADDAM & MOGHADDAM, 2014; VALLINAYAGAM ET AL., 2014; MÜLLER, CHOTĚBORSKÝ ET AL., 2015; MÜLLER ET AL., 2013; KUČERA & ROUSEK, 2008)

The aim of this paper is to verify the possibility of reducing the smoke by using different kinds of biofuels. The verification is done by means of the 8-point NRSC test applied on a turbocharged engine Zetor Forterra 8641.

MATERIALS AND METHODS

The measurement was done using the tractor engine Zetor 1204 prefilled by means of turbocharger and placed in the tractor Zetor Forterra 8641. It is in-line 4 cylinder engine, its volume is 4.156 and rated power 60 kW (it is 53.4 kW on PTO according to the measurement made by Deutsche Landwirtschafts-Gesellschaft), the maximum torque is 351 Nm, the nominal specific fuel consumption is 253 $g.kWh^{-1}$ and the rated speed is 2200 min^{-1}. The fuel is delivered to the engine by means of mechanical in-line injection pump. It is one injection with pressure 22 MPa, 12° before top dead center. The operation time of the mentioned engine does not exceed 100 operation hours.

The engine was loaded by the dynamometer AW NEB 400 connected to PTO, torque was recorded by the torque sensor MANNER Mfi 2500 Nm_2000U/min with accuracy 0.25%. The torque values recorded by the sensor placed on PTO are converted to the engine torque by means of appropriate gear ratio (3.543). The losses in the gearbox have no effect on the comparative measuring of the influence of fuel on the external speed characteristics of the engine and therefore they are not taken into consideration. The fuel consumption was recorded by means of the flowmeter AIC VERITAS 4004 with measurement error 1%. Data were saved on the hard disk of the measuring computer (netbook), with the use of A/D converter LabJack U6 with frequency 2 Hz, in the form of text file. The programmes MS Excel and Mathcad were used for data evaluation.

The fuels used for testing are diesel which meets the regulation EN 14 214 (RME) and hydrotreated vegetable oil (HVO). The table presents parameters for these basic fuels such as: density, viscosity, cetane number and calorific value.

Tab. 1. – Basic parameters of the fuels (ATMANLI ET AL., 2015; QI ET AL., 2014; MURALI KRISHNA ET AL., 2014; AATOLA ET AL., 2008; TZIOURTZIOUMIS, 2012; KIBUGE ET AL., 2015)

Fuel	Density at 15°C (kg m^{-3})	Calorific value (MJ kg^{-1})	Viscosity at 40°C (mm^2 s^{-1})	Cetane number
HVO	780	44	2.5–3.5	80–99
RME	880	37.5	4.5	51
diesel – EN 590	825	43.3	2.5	50

The external speed characteristics of the engine were measured for all tested fuels. Then the measuring points of the eight-point NRSC (Non-Road Steady Cycle) test were determined according to ISO 8178-4 (type C1) (Fig. 1). The points of the test are defined by rotation speed (idle, at max. torque and rated) and load in percentage (0, 10, 50, 75 and 100%). The test was used for measuring the specific fuel consumption. Specific fuel consumption for the whole NRSC test was calculated according to the equation (1). In every predetermined measurement point the measured parameters were stabilized.

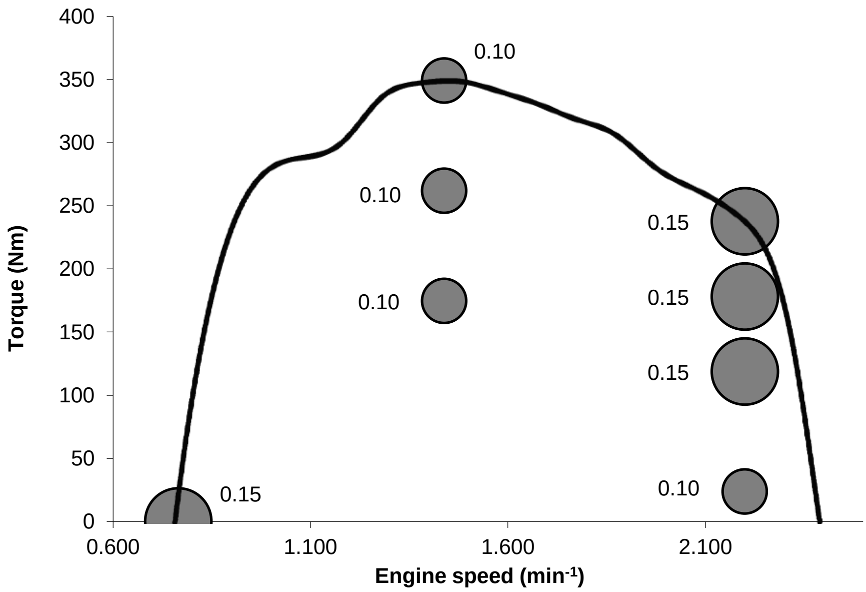

Fig. 1. – Measurements points for the NRSC test for HVO with weight factors

$$m_{NRSC} = \frac{\sum_{i=1}^{8}\left(M_{Pi} \cdot WF_i\right)}{\sum_{i=1}^{8}\left(P_{PTO,i} \cdot WF_i\right)} \qquad (1)$$

where: m_{NRSC} – Specific fuel consumption for the whole NRSC test (g kWh^{-1}); $M_{P,i}$ – hourly fuel consumption (g h^{-1}); WF_i – weight factor (–); $P_{PTO,i}$ – power on the PTO (kW)

RESULTS AND DISCUSSION

The results are resumed in the Tab. 2 (diesel – EN 590), No. 3 (RME) and No. 4 (HVO). The values marked by light grey colour show the best value from tested fuels. The values marked by dark grey colour show the worst value from tested fuels.

Tab. 2. – NRSC cycle – Zetor Forterra 8641 – diesel (EN 590)

Speed	**Torque**	**Power - PTO**	**Fuel consumption**	**CO**	**CO_2**	**HC**	**NO_x**	**Smoke**
(rpm)	(Nm)	(kW)	(kg h^{-1})	(g h^{-1})	(g h^{-1})	(g h^{-1})	(g h^{-1})	(g h^{-1})
2,199	770.1	50.05	15.12	105.30	57.077	2.12	578.49	16.44
2,199	590.6	38.39	11.95	52.13	49.967	1.54	478.80	5.00
2,202	402.9	26.22	10.17	66.75	41.954	1.44	314.36	5.70
2,195	69.4	4.50	5.84	80.23	25.213	1.26	103.95	5.69
1,440	1,038.5	44.21	11.75	347.26	49.925	1.18	591.84	36.19
1,440	822.6	35.02	9.23	129.11	40.572	0.89	525.12	14.23
1,439	536.0	22.81	6.53	23.58	28.527	0.70	375.49	4.47
725	0.0	0.00	0.99	36.88	4.636	0.61	69.96	0.21
Weighted value		**27.85**	**9.07**	**97.18**	**37.469**	**1.26**	**375.88**	**10,16**
NRSC (g.kWh^{-1})			**325.61**	**3.49**	**1.345**	**0.045**	**13.50**	**0.365**

Tab. 3. – NRSC cycle – Zetor Forterra 8641 – RME

Speed	**Torque**	**Power - PTO**	**Fuel consumption**	**CO**	**CO_2**	**HC**	**NO_x**	**Smoke**
(rpm)	(Nm)	(kW)	(kg h^{-1})	(g h^{-1})	(g h^{-1})	(g h^{-1})	(g h^{-1})	(g h^{-1})
2,202	758.2	49.36	16.51	53.98	58.519	1.65	719.70	2.38
2,201	596.9	38.84	13.85	49.85	48.564	1.43	560.05	1.92
2,196	383.1	24.87	11.01	45.21	39.067	1.34	317.33	1.27
2,197	85.6	5.56	6.95	78.16	24.562	1.16	119.22	0.85
1,496	1,020.7	45.14	12.90	113.64	47.763	0.70	690.05	2.04
1,496	803.9	35.55	10.58	52.35	38.658	0.67	602.68	1.16
1,495	520.3	22.99	7.65	24.02	27.247	0.67	419.90	0.63
730	0.0	0.00	1.40	23.16	4.731	0.24	10.41	0.25
Weighted value		**27.89**	**10.22**	**52.65**	**36.455**	**1.02**	**424.31**	**1,34**
NRSC (g.kWh^{-1})			**366.61**	**1.89**	**1.307**	**0.037**	**15.22**	**0.048**

Number of evaluated points is 48 (8 point NRSC cycle and 6 evaluated components). From the 48 points the diesel fuel – EN 590 achieved the best values in 10.4 % of points and the worst results in 58.3 % of points.

From 48 points the RME fuel achieved the best values in 39.6 % of points and the worst results in 39.6 % of points.

From the 48 points the HVO fuel achieved the best values in 50.0 % of points and the worst results in 2.1 % of points.

Tab. 4. – NRSC cycle – Zetor Forterra 8641 –HVO

Speed	Torque	Power - PTO	Fuel consumption	CO	CO_2	HC	NO_x	Smoke
(rpm)	(Nm)	(kW)	(kg h^{-1})	(g h^{-1})	(g h^{-1})	(g h^{-1})	(g h^{-1})	(g h^{-1})
2,196	721.0	46.80	14.75	104.29	57.078	2.02	468.37	4.67
2,200	543.0	35.32	12.16	50.52	46.041	1.24	343.03	2.04
2,198	358.0	23.26	10.01	46.66	37.392	1.48	205.86	1.31
2,196	79.6	5.17	6.51	39.64	24.289	0.21	86.46	1.11
1,506	1,021.6	45.49	11.61	117.40	45.192	0.75	496.26	5.11
1,506	778.3	34.64	9.24	52.84	36.114	0.81	412.05	2.02
1,506	521.9	23.23	6.93	23.40	25.741	0.24	282.50	0.86
715	0.0	0.00	0.99	31.50	3.630	0.52	35.99	0.18
Weighted value		**26.66**	**9.11**	**58.27**	**34.755**	**0.99**	**285.71**	**2.14**
NRSC (g.kWh^{-1})			**341.85**	**2.19**	**1.304**	**0.037**	**10.72**	**0.080**

Generally, in relation to the NRSC test, the HVO fuel achieved the best results for production of HC, CO_2 and above all NO_x. The RME fuel achieved the best results in case of CO and mainly smoke emissions. The diesel fuel achieved the best results only in fuel consumption.

Similar results with slightly higher fuel consumption were obtained by BEATRICE ET AL. (2010). Authors AATOLA ET AL. (2008) and RANTANEN ET AL. (2005) reached the reduction of fuel consumption. The fuel consumption is affected by the design of the engine and properties of the fuel. The engines with mechanically controlled injection pump and injectors reaches higher fuel consumption while running on HVO since it has lower density. RANTANEN ET AL. (2005) and BEATRICE ET AL. (2010) reached reduce of the emissions of CO while using HVO fuel. On the contrary, KRAHL ET AL. (2009) stated the slight increase of the emissions of CO. AATOLA ET AL. (2008), RANTANEN ET AL. (2005) and Beatrice et al. (2010) reached positive results of the emissions of HC with HVO fuel. The reduction was up to 50 % in comparison with diesel. AATOLA ET AL. (2008), RANTANEN ET AL. (2005), KRAHL ET AL. (2009) and BEATRICE ET AL. (2010) confirms the positive impact of the HVO fuel on the emissions of NO_X. Because of the better ratio of carbon and hydrogen the HVO fuel also slightly reduces the production of CO_2 according to RANTANEN ET AL. (2005) and BEATRICE ET AL. (2010). In the case of smoke or production of particulate matter the other authors (AATOLA ET AL., 2008; KRAHL ET AL., 2009; NYLUND & KOPONEN, 2012; RANTANEN ET AL., 2005; BEATRICE ET AL., 2010) also confirms the reduction of smoke in connection with the HVO fuel. The similar results were also obtained by other authors (MAGNO ET AL., 2016; MAGNO ET AL., 2015; MANCARUSO & VAGLIECO, 2012; LEBEDEVAS ET AL., 2010) with RME fuel. The RME fuel causes mainly the increase of the fuel consumption and NO_X production and the reduction of smoke, hydrocarbon and carbon monoxide production.

CONCLUSIONS

Comparison by means of the NRSC test when using three kinds of fuels (diesel fuel - EN 590, RME, HVO) at a supercharged engine of Zetor Forterra 8641 resulted in the following conclusions:
- in production of HC, CO_2 and NO_x the best results have been achieved in case of HVO fuel,
- in production of CO and smoke emissions the best results were recorded in case of RME fuel
- in fuel consumption the best results were achieved in case of diesel fuel - EN 590,
- from 48 measured points the HVO fuel achieved the best results at 50 % of points, RME at 39.6 % of points and diesel fuel – EN 590 at 10.4 % of points,
- from 48 measured points the HVO fuel achieved the worst results at 2.1 % of points, RME fuel at 39.6 % of points and diesel fuel – EN 590 at 59.3 % of points,

From the measured results obtained during the NRSC test it is obvious, that the biofuels can have a considerable share in reduction of production of harmful emissions from combustion engines. It is entirely clear, that it was achieved considerable reduction of smoke emissions even by more than 80 %, CO production till by 40 % and NO_x production by use of HVO fuel by 20 %. It seems, that the HVO fuel could be the biofuel of the future for compression ignition engines.

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Corresponding author:
doc. Ing. Martin Pexa, Ph.D., Department for Quality and Dependability of Machines, Faculty of Engineering, Czech University of Life Sciences Prague, Kamýcká 129, Praha 6, Prague, 16521, Czech Republic, phone: +420 22438 3278, e-mail: pexa@tf.czu.cz