doi: 10.17221/72/2015-RAE

Monitoring of selected emissions of internal combustion engine

M. Králik[1], J. Jablonický[2], Z. Tkáč[2], Ľ. Hujo[2], D. Uhrinová[2], J. Kosiba[2], J. Tulik[2], R. Záhorská[2]

[1]*S-EKA s.r.o., Technical Services of Emission Control of motor vehicles. Department of Technical Support, Nitra, Slovak Republic*

[2]*Department of Transport and Handling, Faculty of Engineering, Slovak University of Agriculture in Nitra, Nitra, Slovak Republic*

Abstract

Králik M., Jablonický J., Tkáč Z., Hujo Ľ., Uhrinová D., Kosiba J., Tulik J., Záhorská R. (2016): **Monitoring of selected emissions of internal combustion engine**. Res. Agr. Eng., 62 (Special Issue): S66–S70.

The paper deals with the possibility of appropriate measurement and evaluation of emissions of nitrogen oxides. Development of exhaust systems which captures the solid particles emitted from engine, lost an objective assessment of the emission status of the diesel engine of agricultural tractor. Therefore, it is necessary to find a new method of measuring and quantifying the emission state of the diesel engine by measuring emissions, which should be economic and time-saving, but especially universal and sufficiently precise. The selected method should also provide sufficient information on such emissions that are subject to approval but they are not controlled during periodic checks.

Keywords: nitrogen oxides; diesel engines; measuring of emission of diesel engine

The combustion of hydrocarbon fuels (diesel) emissions result of various kinds. The gaseous pollutants from diesel engines mainly comprise carbon monoxide (CO), nitrogen oxides (NO_x), sulphur oxides (SO_x) and hydrocarbons (HC) (Colbeck et al. 2011; Ma et al. 2011). Nitrogen oxides are usually generated during combustion at high temperature, and its concentration increases with the engine combustion efficiency (Yanowitz et al. 2000). Combustion products are dependent on engine design, engine power and its load. It is therefore necessary to provide careful precision fuel injection, and perfectly attuned air – fuel, as well as optimum mixing of the premix. Perfect oxidation of carbon and hydrogen contained in the fuel produces carbon dioxide CO_2 and water H_2O. The incomplete oxidation of these elements is present in the flue gas carbon monoxide CO and hydrogen H_2. When using air as the oxidant, it is always the most significant component of the content of nitrogen N_2. The oxygen O_2 occurs in the exhaust gas when the entire contents does not apply for the oxidation of fuel, because it was the fresh mixture in excess, or has not been used for other reasons (closing in fuel beam, etc.). At high temperatures in the combustion chamber, there are formed by oxidation of the nitrogen of the air of NO_x mainly composed of NO and smaller amount of nitric oxide NO_2. At very adverse local or global conditions for oxidation of fuels, exhaust gases contain unburned hydrocarbons HC (may be referred to CH, CH_x, HC, etc.) of different composition. The utter exclusion of air (inside the drop of liquid fuel) occurs at high

Supported by European Community, Project No. 26220220180.

doi: 10.17221/72/2015-RAE

temperature decomposition (cracking, cleavage) of the hydrocarbon molecules, resulting in unreacted carbon and the formation of solid carbon particles (soot) in the exhaust gas. These particles along with solid carbon (soot) emissions constitute monitored diesel engines that are jointly assessed to smoke emission engine (Robert Bosch 1993; Takáts et al. 1997; Brožová et al. 2009).

Composition of exhaust gases and the proportion of the components of diesel engine are relatively balanced. During the service life of the engine, there is a gradual change in the differences of fractions of the individual components by all modes of engine operation. Changing the technical condition of the engine affecting the quality of the preparation of the mixture or the conditions of the combustion process causes an increase in the production of CO, respectively. HC, which is on the one hand, mean a decrease in the effective pressure P_e, and thus improving the conditions for reduction of the nitrogen oxides NOx. Second, the change in the temperature balance of the effect of increasing the production of solid particles. It is clear that the deterioration of the technical condition of the engine while maintaining the traffic characteristics of the injection pump is a decrease in torque M_k hour while maintaining the fuel economy and M_p thus increase specific fuel consumption M_{Pe}. This situation is reflected by changing the proportion of the various pollutants in exhaust emissions and to decrease the proportion of NOx and increase shares CO and HC while growth smoke of engine *d*. The relationship between the quality of the preparation of a mixture and technical condition of the engine on the one hand and increasing the proportion of various pollutants of smoke in the exhaust gas with the a significant change in the technical condition of the engine on the other hand, has a great diagnostic meaning (Lenďák et al. 2007; Tomic et al. 2008, Ogunmola et al. 2013; Jukl et al. 2014).

MATERIAL AND METHODS

For emission measurements, was used parent engine Lombardini LDW 502 M3 (Lombardini Group, Reggio Emillia, Italy) (Fig. 1). The parent engine is water-cooled, inline twin cylinder four strokes, with indirect injection and pump – nozzle injection system. Type of engine timing is OHV, and to one cylinder belongs to two valves. Motor control is provided by centrifugal governor and automatic cold start fuel enrichment. The engine is equipped with a venting system of the crankcase, which fulfils the emission standards EURO 2. Basic technical parameters of the engine are given in Table 1.

Emissions measurement and sampling was secured by five gas analyser MAHA MGT 5 (MAHA Maschinenbau Haldenwang GmbH & Co. KG, Haldenwang, Germany). The analyser measures the content (CO, CO_2 and HC) by non-dispersive infra-

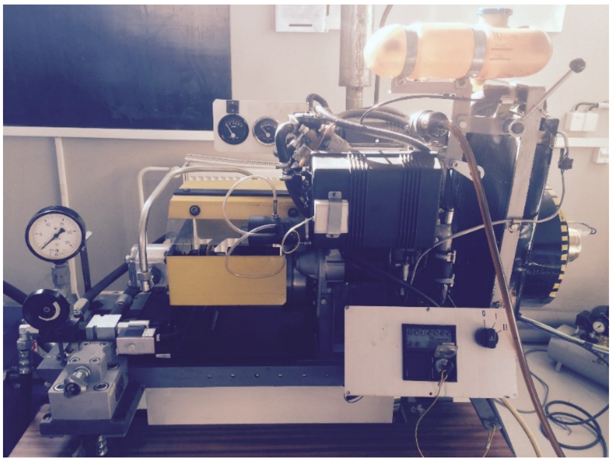

Fig. 1. Engine Lombardini LDW 502 M3 mounted on test bed

Table 1. Basic technical parameters of the engine Lombardini LDW 502 M3

Basic technical parameters Lombardini LDW 502 M3	
Number of cylinder	2
Displacement (cm^3)	505
Bore (mm)	72
Stroke (mm)	62
Compression ratio (–)	22.8:1
Combustion timing (°)	360
Engine power (according to 80/1269/CEE), ISO 1585 (kW/HP)	9.3/12.6
Max. torque (N·m)	26
Max. torque speed (rpm)	2,200
Idle speed (rpm)	1,100
Max. power speed (rpm)	3,750
Max. speed (rpm)	3,820
Max. water pump flow at speed 3,600 rpm (dm^3)	40
Oil consumption (kg/h)	0.007
Oil level in engine (dm^3)	1.4
Air consumption at speed 3,600 rpm (dm^3)	910

Source: www.lombardini.it

doi: 10.17221/72/2015-RAE

red absorption, and the proportion (O_2 and NO_x) is measured by means of electrochemical cells. Analysed gas was taken with a probe of a vehicle exhaust. Subsequently, the measured gas separates water and flue gas flow into the measuring chamber.

For NO_x measurement, the galvanometric sensor uses the principle of a galvanic cell where the electrode system is separate from the analysis medium permeable membrane made, for example was used: Teflon, polypropylene or silicone rubber. The membrane was permeable only to gas, not for electrolytes and water. During measurement, there were two concentrations of nitrogen oxides NO_x, concentration in the measured gas and the reference gases which was mostly air, were compared.

Engine speed was measured with an external RPM sensor AVL DiSpeed 492 (AVL DiTEST; Fahrzeugdiagnose GmbH, Graz, Austria) and is intended to measure the speed of two and four-stroke engines. Sampling speed was based on sensing signal to vibrations of the engine, or recording sound vibrations that are detected by the sensor, which was attached to the motor vehicle inspected by a permanent magnet. When placing magnetic sensors, it has to be ensured that the sensor was placed downstream of the controlled piston engine. During the measurement, the reference engine was mounted on the test bench, the dry atmospheric pressure of 102.61 kPa and temperature of 24.12°C, which is a temperature of 297.27 K were measured. Before the measurement, we conducted leak test of analyser that has been done clogging the sample probe with plug. The plug was for this purpose intended by the manufacturer and the other side of hose was connected to the analyser. Subsequently the analyser pump created vacuum across the entire measurement chain and we counted decrease vacuum for 20 s. In our case, was a leak 16 hPa, what was minimal leakage, because the manufacturer allows the leak 230 hPa for 20 seconds. After we let the analyser set to zero through the ambient air, which can be regarded as zero, because it is taken in through an active carbon filter which absorbs all the gases that may affect the measurement. After the leak and resetting the analyser, we heated the reference engine to 70°C at the increased speed (1,800 to 2,000 rpm).

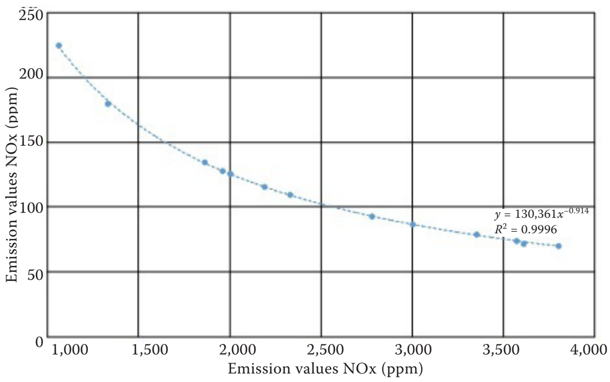

Fig. 2. Average measured values for NO_x emissions at variable speeds

Samples of measured gas were taken off by one straight sampling probe of stainless steel with many holes which are formed in different radial planes, which has been installed in the exhaust pipe to a depth of 0.52 m in the exhaust gas upstream. Location of probe ensured taking enough hot exhaust gases and the total length of the inlet hose sampling probe was 1.8 m.

During the measurement, at first the NO_x emissions at variable speeds in ten points were sampled. Measuring speed were chosen arbitrarily, but had to be chosen to provide complete coverage of the speed range of the engine from idle to max. engine speed. We repeated measurements ten times in succession at the same speed, in order to obtain higher file properties of the present notice. From the measured values, were calculated average values listed in the Table 2. On the basis of measured values listed in the Table 2 was set out depending between NO_x emissions and engine speed (Fig. 2). The curve depending between NO_x emissions and engine speed was offset by trend line and was discovered, that the conduct of NO_x at the parent engine has power function. To confirm our assumption reliability equation is used wherein R^2 coefficient reached 0.9996 (Fig. 2).

RESULTS AND DISCUSSION

Analyses of the functional dependence in the form of power type function Eq. (1):

Table 2. Average values for NOx emissions at variable speeds

Speed (rpm)	1,060	1,330	1,860	1,960	2,000	2,190	2,330	2,780	3,000	3,350	3,570	3,610	3,800
NO_x (ppm)	223	180	135	128	126	116	110	93	87	79	74	72	64

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Table 3. Calculated values of NOx based on power type of boundary function from max. and min. engine speed

Speed (rpm)	Values NO_x (ppm)		Difference (%)???
	calculated	measured	
1,060	225.00	223	–0.9
1,330	173.44	172	–0.8
1,860	118.05	120	1.6
1,960	111.17	111	–0.2
2,000	108.62	108	–0.6
2,190	97.89	97	–0.9
2,330	91.17	90	–1.3
2,780	74.45	74	–0.6
3,000	68.23	69	1.1
3,350	60.11	61	1.5
3,570	55.89	55	–1.6
3,610	55.18	55	–0.3
3,800	52.02	53	1.9

$$NO_{x_{max}} \times n^k_{min} = NO_{x_{min}} \times n^k_{max} \quad (1)$$

$$NO_{x_{max}} = NO_{x_{min}} \left(\frac{n_{max}}{n_{min}}\right)^k$$

where: $NO_{x_{max}}$ – max. value of NO_x (ppm); $NO_{x_{min}}$ – min. value of NO_x (ppm); n_{max} – maximum engine speed (rpm); n_{min} – minimum engine speed (rpm); k – exponent (1.147)

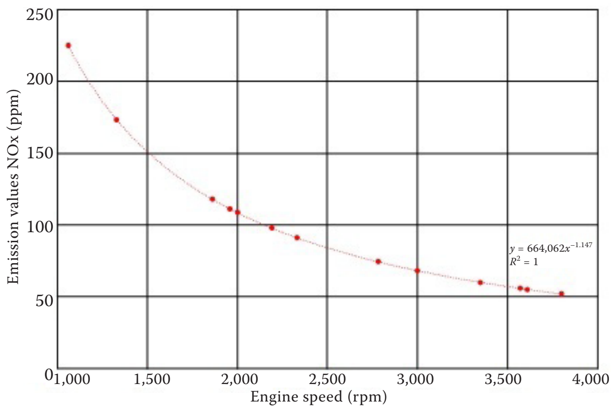

Fig. 3. Calculated theoretical values of NO_x based on power type function from min. and max. engine speed

Using Eq. (1), the progressions emissions of nitrogen oxides NO_x, were calculated and verified depending on the speed of used engine. Result values are shown in Table 3 and Fig. 3. When we compared each measured and calculated values, have found a mutual tolerance (%). Our highest observed tolerance was 1.9% and the lowest tolerance was 0.9%. Tolerance values may be affected by analyzer MAHA MGT 5 (producer, town, state), because it measures only on integer values and not decimal numbers that we calculate out using Eq. (1).

Lately the nitrogen oxides were measured with free acceleration method. During measuring with

Table 4. Measured and evaluated values of NO_x during regeneration test

Measurement No.	Repetition	NO_x measured before NO_x measurement (ppm)	Stable NO_x after measurement (ppm)	Tolerance (%) –1	Regeneration time* (s)
1	1	210	209	–0.48	20.48
	2	216	216	0.00	20.63
	3	217	217	0.00	18.60
2	4	210	209	–0.48	24.92
	5	210	210	0.00	15.00
	6	216	214	–0.93	22.99
3	7	214	214	0.00	15.20
	8	214	213	–0.47	22.14
	9	211	210	–0.47	20.48
4	10	214	212	–0.93	25.00
	11	213	212	–0.47	17.39
	12	215	213	–0.93	21.00
5	13	205	203	–0.98	24.85
	14	214	213	–0.47	20.61
	15	211	210	–0.47	21.48

*all the values were within the range of the 25 s

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free acceleration method the reference engine was burdened only its own inertia force. During the implementation of free acceleration method, the accelerator pedal has been depressed during one second to achieve the max. amount of fuel. With method of free acceleration the 50 measurements from idle to maximum speed, was performed. The min. number of measurements was determined by mathematic-statistical methods based on the measured sample. For idle speed, the min. number of repetitions was counted to 1, and at the max. speed, it was the number of repetitions counted to 2. From the experience and existing methodological guidelines for measuring the values of smoke, was determined the min. number of repetitions of the NO_x measurements to 3 (Table 4).

CONCLUSION

Method of monitoring the emission state in terms of NO_x formation can move in two directions. One way is loading the engine free acceleration, or the use of theoretical calculations in combination with practical exercises. Scoring of both methods are simple, time-saving and do not damage the controlled engine.

When measuring with free acceleration results, it was evaluated based on the recovery time to baseline NO_x max. 25 s while we were waiting for stability NOx emissions to baseline with a tolerance of – 1% ppm of baseline. When measuring method based on measurements at randomly selected speed, the results were compared with theoretically calculated values of NO_x and the test result is satisfactory if the measured value will be equal to the theoretically calculated value, or the NO_x measured value has dropped below 1% of the calculated values. Measurements of the two methods were carried out on the reference engine at the engine temperature 70°C.

The theoretically calculated values were calculated by using formula, which is exploitable for the engine we used.

For the further verification of the methods of measurement and their potential applications in a wide range of diesel engines and their exhaust systems, it is necessary to carry out further measurements and evaluate the results to other combustion engines that can form the basis for development of database systems.

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Received for publication October 28, 2015
Accepted after corrections March 23, 2016

Corresponding author:

Ing. Ján Kosiba, Slovak University of Agriculture in Nitra, Faculty of Engineering, Department of Transport and Handling, Trieda A. Hlinku 2, 949 76 Nitra, Slovak Republic; e-mail: jan.kosiba@gmail.com