MODERN DIESEL ENGINES NO_X PARTICLES EMISSION

Konrad Krakowian, Andrzej Kaźmierczak

Technical University of Wrocław
Department of Motor Vehicles and Internal Combustion Engines
Braci Gierymskich Street 164, Wrocław, Poland
tel.: +48 71 3477918, fax: +48 71 3477926
e-mail: konrad.krakowian@pwr.wroc.pl, andrzej.kazmierczak@pwr.wroc.pl

Agata Wdowikowska

Wrocław University of Environmental and Life Sciences
Institute of Agricultural Engineering
Grunwaldzki Square 24A, 50-363 Wrocław, Poland
tel.: +48 71 3205105, fax:+48 71 3282868
e-mail: wdowikowskaa@gmail.com

Abstract

Exhaust gases recirculation systems (EGR), together with catalytic reactors, are commonly installed in modern piston combustion engines. Their purpose is to reduce the amount of nitrogen oxides (NO_X) emitted in fumes. The need for this reduction takes its source from introducing more rigorous EURO standards, which are treating about maximum levels of NOx, HC and particulates produced, as a side effect of engine's operation. Applied exhausts recirculation circuits can be roughly characterized by a principle, that a part of exhaust gases is redirected (through a cooler) and reaches a special valve. This valve, respectively to engine's current load and speed, drives more or less exhaust to suction manifold. The position of the valve determines the system's overall efficiency, but also differentiates the amount of toxic gases and smoke produced by each of the engines cylinders. Recent research have focused only on the overall efficiency of recirculation systems, representing it by measuring the total amount of NO_x particles emission from exhaust pipe. However, the quantity of exhaust gases that is reaching each cylinder can be negatively dependant on EGR valve's physical position in the circuit. This happens due to the fact that combusted loads have different proportions of charged air and fuel. For estimating the difference among each of the loads, and in the same time, indirectly, in equal emission of NO_x from corresponding cylinders, a research was carried out on a model VW 2.0 TDI engine, equipped with standard, factory mounted, exhausts gases recirculation circuit. Measurements of toxic emissions were executed with regards to thirteen-point ESC (European Stationary Cycle) test.

Keywords: *air pollution, combustion engines, EGR valve, exhaust emission & ecology, vehicles*

1. Introduction

The article describes the impact of using a single EGR (Exhaust Gas Recirculation) on the emission of toxic compounds from each engine cylinder. The study object is Volkswagen 2.0 TDI engine (diesel engine with direct injection). This engine is factory equipped with a vacuum EGR valve. The research has been divided into several stages. First of all, the objective was to determine the border characteristics of the engine. ESC (Emission Stationary Cycle) was carried out. The next step was to assay at which speeds and loads the exhaust gas recirculation valve is opened. The final step was to measure toxic compounds by each cylinder separately.

2. Determination of parameters of the research unit

Toxic emissions were measured using a standard test, which is used to certify ESC for diesel engines. The development of the test requires knowledge of the external characteristics of the test engine. For this purpose, a dyno-test was conducted, relating torque characteristics with rotational speed (Fig. 1).

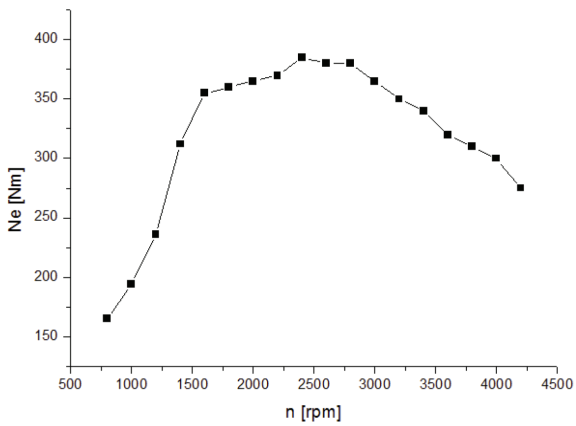

Fig. 1. The physical characteristics of engine 2.0 TDI (Ne_{max} = 385 Nm by 2400 rpm)

ESC test is based on thirteen points at which the motor works at a determined speed and load. Speed and load are determined by the characteristics of full power. Consequently, the following parameters need to be determined:

– N_{max} – maximum speed, which beyond the maximum power corresponds to 70% Ne_{max}
– N_{min} – the minimum speed, which corresponds to 50% Ne_{max}

Determination of the maximum and minimum rotation speed is calculated to define the speed of the individual *A*, *B* and *C* phases of testing:

$$A = n_{\min} + 0.25 \cdot (n_{\max} - n_{\min}),$$
$$B = n_{\min} + 0.50 \cdot (n_{\max} - n_{\min}), \qquad (1)$$
$$C = n_{\min} + 0.75 \cdot (n_{\max} - n_{\min}),$$

where:
n_{min} – minimum speed,
n_{max} – maximum speed,
A, *B*, *C* – following speeds: *A* = 1785 rpm, *B* = 2590 rpm, *C* = 3395 rpm.

Tab. 1. Modes of operation for VW 2.0 TDI ESC test

Measuring Point No.	Duration [min]	Engine speed, *n* [rpm]	Load, *Ne* [%]	Load, *Ne* [Nm]
1.	4	idling running	0	0
2.	2	1785	100	360
3.	2	2590	50	190
4.	2	2590	75	285
5.	2	1785	50	180
6.	2	1785	75	270
7.	2	1785	25	90
8.	2	2590	100	380
9.	2	2590	25	95
10.	2	3395	100	340
11.	2	3395	25	85
12.	2	3395	75	255
13.	2	3395	50	170

3. Determination of the operating states of the exhaust gas recirculation

The test engine is equipped with a vacuum exhaust gas recirculation valve. Recirculation is regulated by a vacuum solenoid, which is controlled by the ECU (Electronic Control Unit). Pulse width modulation voltage (PWM) is the control signal for the solenoid. Fig. 2 and Fig. 3 shows the oscilloscope waveforms for a closed and fully open valve.

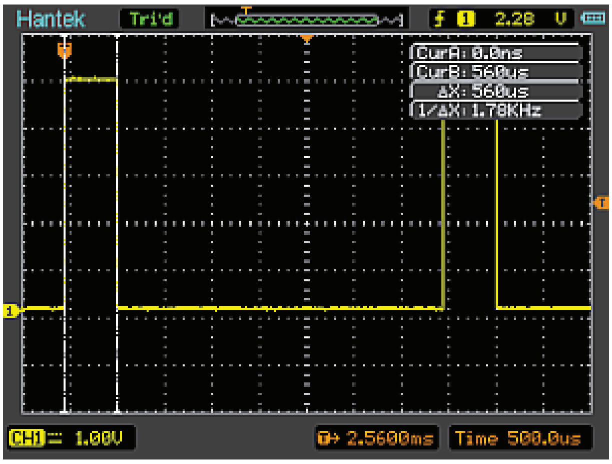

Fig. 2. Fully closed EGR valve

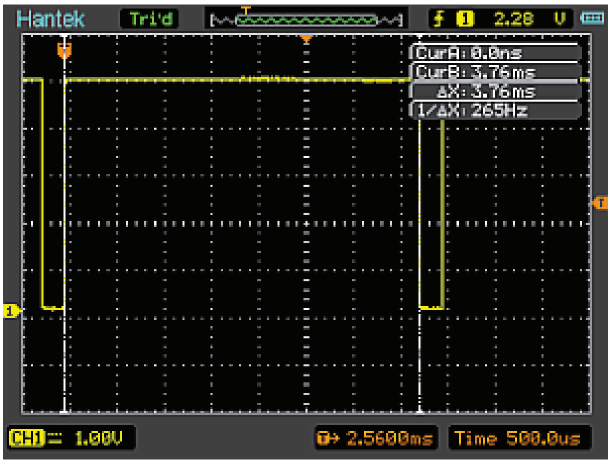

Fig. 3. Fully open EGR valve

On the basis of observation, however, it was found out that the valve is fully closed when the width of the pulse is equal to 840 µs, while it is fully open for 3176 µs pulse width.

4. The test results

The study was performed in two stages. The aim of the first step was to check at what speeds and engine loads for ESC test the EGR valve is opened by the control unit. For this purpose, the oscilloscope was connected to the output K13 of the control unit, which is responsible for controlling the EGR valve. Then, in the different phases of the ESC test, the PWM pulses' width were measured (Tab. 2.).

Tab. 2. Research EGR valve on the basis of the measurement points of the ESC test

Measuring Point No.	Engine speed, *n* [rpm]	Load, *Ne* [Nm]	The duration of the control pulse PWM [µs]	opening the EGR valve [%]
1.	idling running	0	1440-2040	22
2.	1785	360	800	0
3.	2590	190	800	0
4.	2590	285	800	0
5.	1785	180	800	0
6.	1785	270	800	0
7.	1785	90	1640–2120	27
8.	2590	380	800	0
9.	2590	95	1680–2200	33
10.	3395	340	800	0
11.	3395	85	800	0
12.	3395	255	800	0
13.	3395	170	800	0

Table 2 shows that only for three measuring points the EGR valve is opened. Knowing the times of pulses for which the exhaust gas recirculation valve is fully closed and fully opened, its opening percentage was calculated. It follows that the EGR valve is opened only at medium and low speed at low loads. The aim of the next stage of the research was to measure the emissions of toxic compounds for each cylinder at measuring points at which participation of recirculated exhaust gas was observed (points 1, 7 and 9 of Tab. 2). Probes were placed in the exhaust manifold so that the sampling point was located directly above each of the exhaust valves. During the tests, three measurements were made for each of the cylinders and the individual data points. The results were averaged and are presented in Tab. 3.

The following devices were used so as to carry out the measurements:

– Infralyt 4000 production JUNKALOR – measurement of CO_2 and O_2,
– Hartmann & Braun Uras 10 E – measurement of NO and CO,
– AVL Smoke Meter Software AVL Device Control Software.

Tab. 3. The results of measurements of emissions of toxic compounds from 1, 2, 3, 4 cylinder

Measuring Point No.	Cylinder 1					Cylinder 2				
	CO_2 [%vol]	O_2 [%vol]	CO [%vol]	NO [%vol]	FSN	CO_2 [%vol]	O_2 [%vol]	CO [%vol]	NO [%vol]	FSN
1	2.37	18.30	0.010	0.0074	0.298	2.58	18.14	0.0117	0.0087	0.234
7	4.49	14.67	0.027	0.0040	0.630	4.40	14.30	0.0217	0.0020	0.480
9	4.32	15.50	0.015	0.0040	0.448	4.38	15.20	0.0134	0.0047	0.274
Measuring Point No.	Cylinder 3					Cylinder 4				
	CO_2 [%vol]	O_2 [%vol]	CO [%vol]	NO [%vol]	FSN	CO_2 [%vol]	O_2 [%vol]	CO [%vol]	NO [%vol]	FSN
1	2.60	18.18	0.010	0.0093	0.216	2.29	18.17	0.010	0.0087	0.205
7	4.42	14.42	0.025	0.0020	0.379	4.43	14.63	0.027	0.0013	0.325
9	4.07	15.48	0.015	0.0053	0.229	3.66	15.80	0.018	0.0060	0.251

5. Conclusion

The study on emissions of toxic compounds in the exhaust gas was carried out by means of ESC test. It enabled us to conclude that:

– emissions of carbon dioxide (CO_2) and oxygen (O_2) for all cylinders are on the same level (Fig. 4 and Fig. 5),
– emission of carbon monoxide (CO) at idle is stable while at higher speeds it increases for the first and fourth cylinder (Fig. 6).
— emissions of nitrogen oxide (NO_x) are different for each cylinder (Fig. 7).
– opacity (FSN) is different for each cylinder (Fig. 8).

Comparing Fig. 4 and Fig. 5 it can be seen that with the increase in nitric oxide the opacity decreases. It is related to the dependency which implies that the exponential growth of the number of nitrogen oxide particles decreases. Thus, when the exponential decrease in nitrogen oxides takes place. the number of solid particles increase (Fig. 9).

The above studies show that the use of a single EGR valve affects the different distribution of the exhaust gases for individual combustion chambers. Consequently, it influences the emission of nitrogen oxides which varies for individual cylinders.

References

[1] Krakowian, K., Kaźmierczak, A., Górniak, A., Włostowski, R., Błasiński, T., *Exhaust Gas Uniformity in Modern Diesel Engines*. Journal of KONES Powertrain and Transport, Vol. 19, No. 2, pp. 259-262, 2012.

[2] Sobieszczański, M., Pietras, D., Knefel, T., *Dobór zaworu sterowania recyrkulacją spalin w silniku ZI z zasilaniem MPI*, Journal of KONES, Combustion Engines, Vol. 8, No. 3-4, 2001.
[3] Wdowikowska, A., *Optimizing the Amount of Exhaust Gases in EGR System for Diesel Engine*, Master thesis, Wrocław 2013.

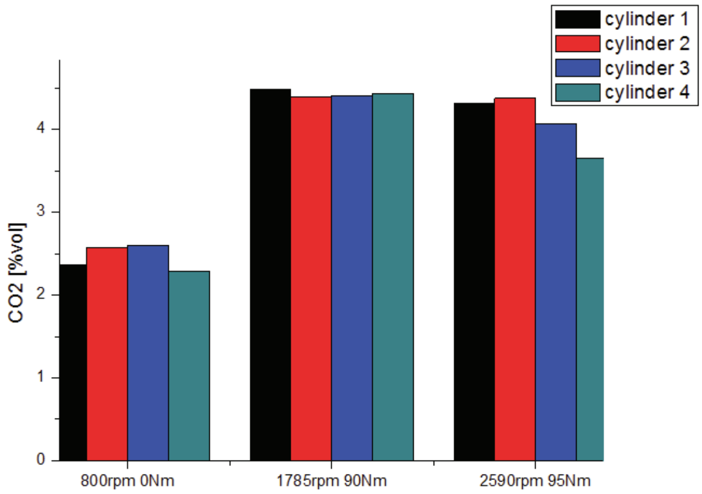

Fig. 4. CO_2 emissions for a particular cylinder at different speeds (800, 1785, 2590 rpm) and loads (0, 90, 95 Nm)

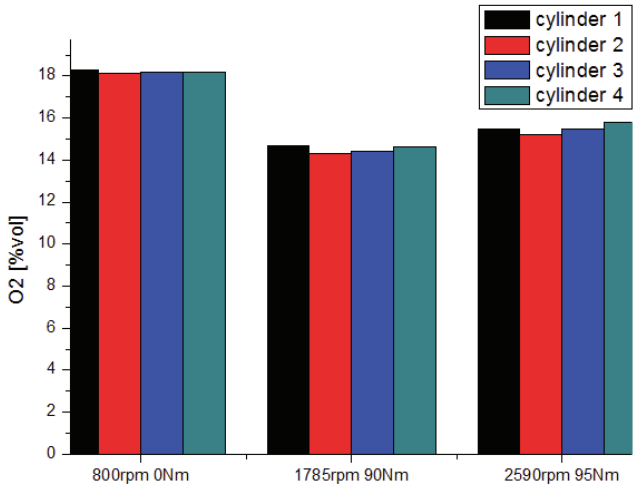

Fig. 5. O_2 emissions for a particular cylinder at different speeds (800, 1785, 2590 rpm) and loads (0, 90, 95 Nm)

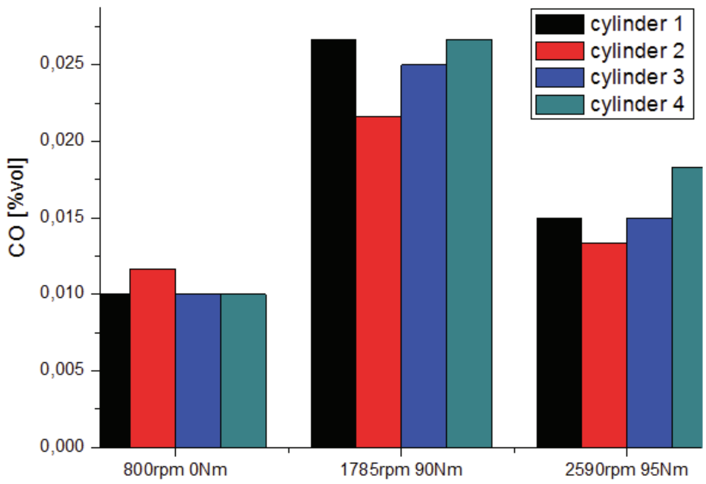

Fig. 6. CO emissions for a particular cylinder at different speeds (800, 1785, 2590 rpm) and loads (0, 90, 95 Nm)

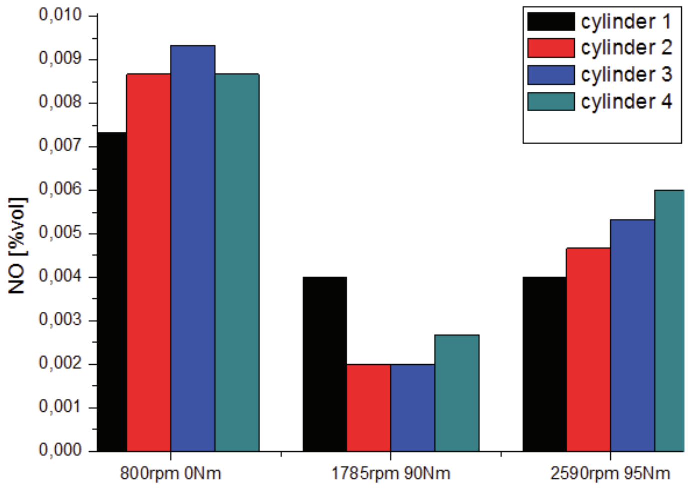

Fig. 7. NO emissions for a particular cylinder at different speeds (800, 1785, 2590 rpm) and loads (0, 90, 95 Nm)

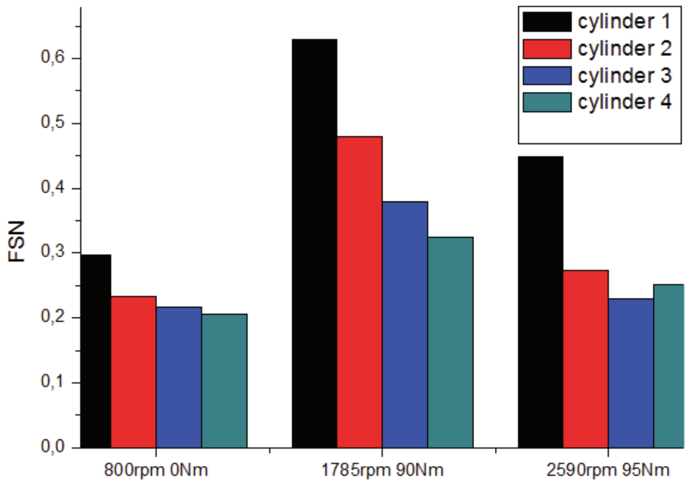

Fig. 8. FSN emissions for each cylinder at different speeds (800, 1785, 2590 rpm) and loads (0, 90, 95 Nm)

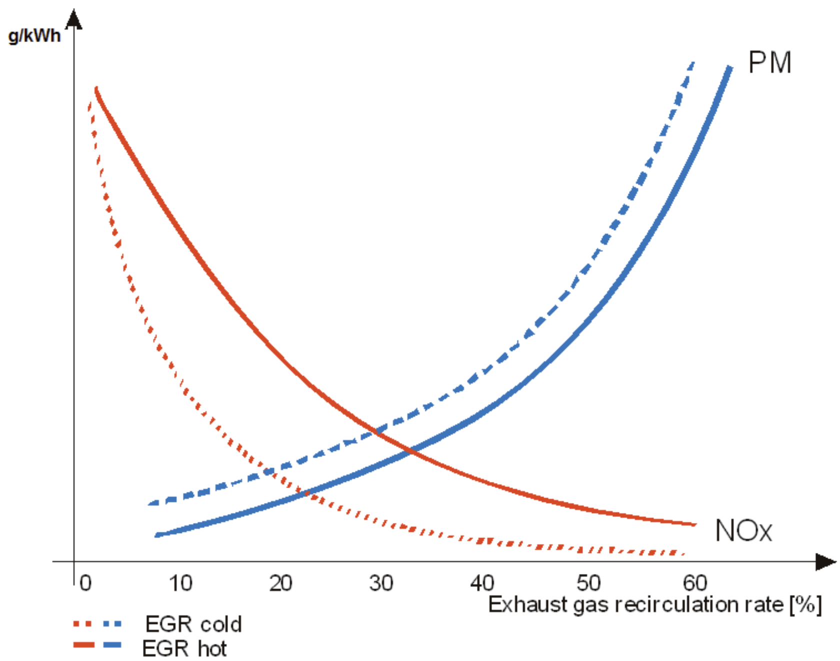

Fig. 9. The relationship between nitrogen oxide and particulate matter[1]