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PROCEDURES & TREATMENTS LEADING TO REDUCTION OF TOXIC COMPONENTS EMISSION IN DIESEL ENGINE'S EXHAUST GAS

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Abstract

The fight against global warming and Earth atmosphere pollution has been for years one of the most important tasks of governments and national economies of the European Union members. Abandonment of efforts leading to reduction mainly of carbon dioxide emission by heavy industry, electric power generation based on coal, passenger aviation and wheeled passenger transport will inevitably be leading to deterioration of health condition of our citizens.

This article presents an overview of commonly used structural and technological treatments which have impact on reduction of toxic standardized exhaust pollutants in the surface transport, exemplified on SW 400 engine version of L2 / 3 and its turbocharged version 6CT 107 2/L2. The impact of: engine's adjustment parameters, catalytic afterburners, exhaust gas recirculation, modifications of injectors, turbochargers, supercharging air-cooling and particulates filter on carbon monoxide, hydrocarbons, nitrogen oxides and particulates emission was thoroughly examined. The parameters being compared were the results of toxicity tests according to ECE-R49 Regulation and a maximal smoke values on full-load characteristics.

In conclusion, of the paper the limiting allowable values of toxic components emitted in Diesel engines exhaust gases in the following EU Emission Standards are presented.

***Keywords**: Diesel engine, pollution, reduction of emission*

1. Introduction

The subject of presented hereby research work was presentation of influence of commonly used design and technological treatments to reduce the standardized emission of exhaust toxic components. The objects of studies were two polish Diesel engines: atmospheric SW 400 version L2/3 and the turbocharged 6CT 107-version 2/L2. There was subjected to thoroughly evaluation the impact on carbon monoxide, hydrocarbons, nitrogen oxides and particulates emission of following engine parameters and equipment: catalytic afterburners, exhaust gas recirculation, modifications of injectors, turbochargers, supercharging air cooling, particulates filter and basic engine's adjustment parameters.

The results of toxicity tests ECE-R49 and maximum smoke values on external characteristics were engine parameters dedicated to be compared.

2. Input parameters of research engine

The base engine SW 400 L2/3 tested in factory assembly and regulation was characterized for forcing angle 29° CA before TDC by following parameters:

Forcing angle before TDC [° CA]	Ne [kW]	CO [g/kWh]	CH [g/kWh]	NOx [g/kWh]	D_{max} [° B]
29	85.6	28.09	3.44	15.05	6.1

3. Specification of treatments to lower emissions and obtained results

3.1. Optimizing of injection timing

The study began by optimizing the injection timing and the following results were obtained:

Forcing angle before TDC [° CA]	Ne [kW]	CO [g/kWh]	CH [g/kWh]	NOx [g/kWh]	D_{max} [° B]
27	84.2	24.03	2.51	11.70	6.7
25	83.9	19.70	2.09	9.61	6.6
23	81.9	20.03	2.41	8.96	6.7

In the consequence of fixing of injection advance angle to 25° CA before TDC the following change of pollution parameters was obtained:

Ne[kW]	CO [g/kWh]	CH [g/kWh]	NOx [g/kWh]	D_{max} [° B]
-2%	-30%	-39.2%	-36%	+10%

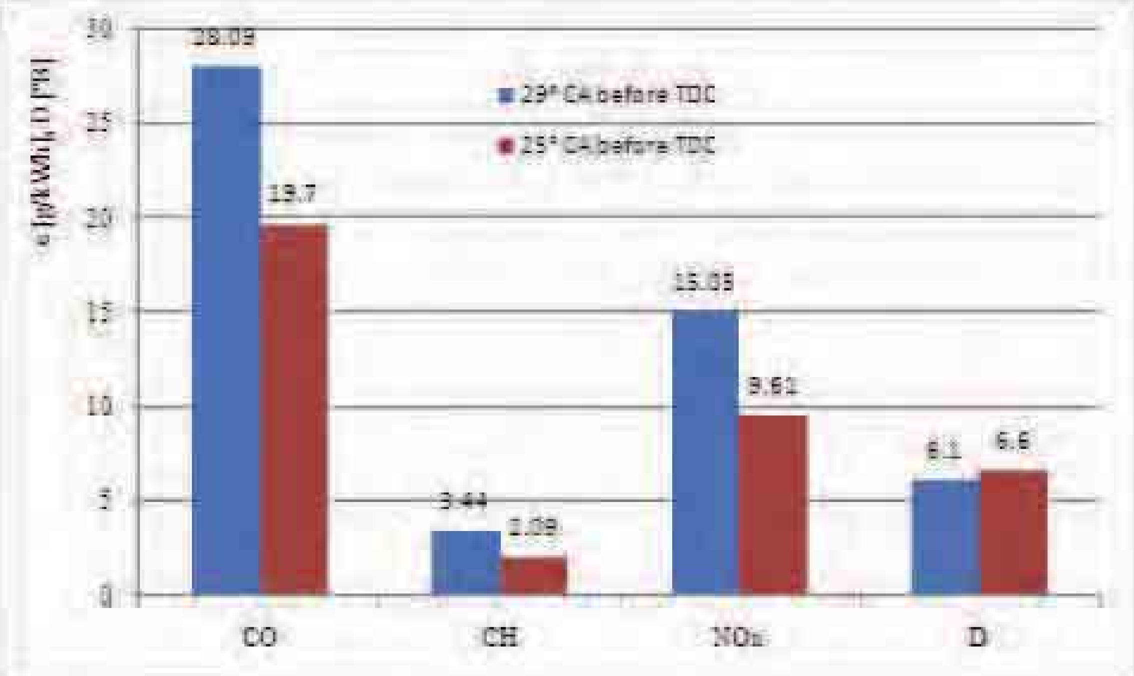


Fig. 1. Effect of injection timing on emission of CO, CH, NOx and smoke value

The unfavourable loss of power by 2% is the amount unnoticeable to the user but the beneficial (of several tens in percent) drop of CO, CH and NOx emission is worth to emphasize. The increase of opacity will be compensated under subsequent treatments.

3.2. Implementation of turbocharging

The next treatment was equipping of 6CT107 engine with a turbocharger 3LD 279/2.17. In this instance, the injection timing was optimized as well and the yielded results are presented in the table below:

Forcing angle before TDC [° CA]	Ne [kW]	CO [g/kWh]	CH [g/kWh]	NOx [g/kWh]	D_{max} [° B]
24	84.24	8.13	2.98	13.81	4.9
22	83.74	6.57	2.63	12.03	5.0
Change in [%]	-0.6	-19.2	-11.7	-12.9	+2

Applying of turbocharging caused the following effects in relation to the base engine:

Engine	Ne [kW]	CO [g/kWh]	CH [g/kWh]	NOx [g/kWh]	D_{max} [° B]
SW400 Forcing angle 29° CA before TDC	85.6	28.09	3.44	15.05	6.1
6CT107 Forcing angle 24° CA before TDC	84.2	8.13	2.98	13.81	4.9
Change in [%]	-1.6	-71.1	-13.4	-11.2	-19.7

Change of parameters in relation to the optimized values came respectively to:

Engine	Ne [kW]	CO [g/kWh]	CH [g/kWh]	NOx [g/kWh]	D_{max} [° B]
SW400 Forcing angle 25° CA before TDC	83.9	19.70	2.09	9.61	6.6
6CT107 Forcing angle 22° CA before TDC	83.7	6.57	2.63	12.03	5.0
Change in [%]	0	-66.7	+25.8	+25.1	-24.2

3.3. Application of catalytic exhaust aftertreatment

In the next step, test engine was equipped with catalytic exhaust aftertreatment unit. A catalytic afterburner Catalytic Exhaust 8SX Type, matched specially for this engine, was put to the study.

The results of exhaust emissions for engine fitted with afterburner are shown below:

Measurement point	Ne [kW]	CO [g/kWh]	CH [g/kWh]	NOx [g/kWh]
Before afterburner	83.74	6.57	2.63	12.03
Behind afterburner		0.87	1.63	11.30
Change in [%]		-86.7	-38	-6

3.4. Application of catalytic exhaust gas recirculation

The next research treatment was implementation of exhaust gas recirculation. Exhaust gases were taken before the turbine and directed to the intake manifold behind compressor. Introducing of this air flow "disturbance" has forced a change of existing turbocharger to 2LD 259/2.17 one, which resulted in a greater pressure difference between the points of collection and the insertion of exhaust gas.

The results of above-mentioned activities are shown in the charts below:

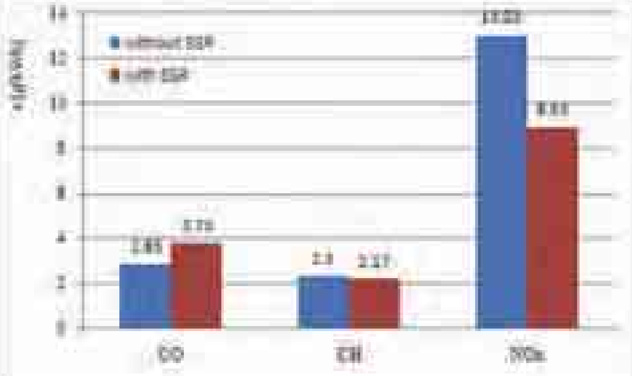


Fig. 2. Effect of exhaust gas recirculation on emission of CO, CH, NOx (measured before catalyst)

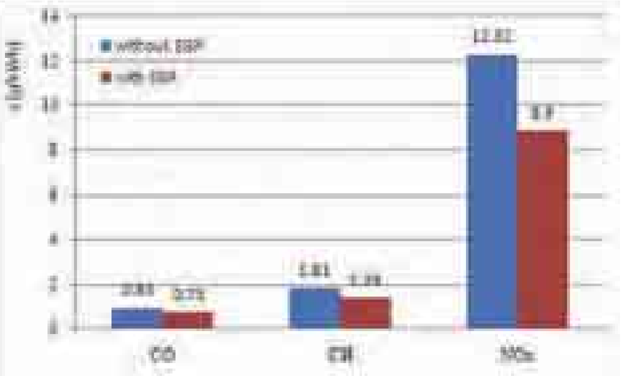


Fig. 3. Effect of exhaust gas recirculation on emission of CO, CH, NOx (measured after catalyst)

Exhaust gas recirculation caused the following change of analyzed parameters (measured behind afterburner).

Forcing angle: 25° CA before TDC	Ne [kW]	CO [g/kWh]	CH [g/kWh]	NOx [g/kWh]
Without EGR	81.9	0.93	1.81	12.32
With EGR		0.73	1.39	8.9
Change in [%]		-21.5	-23.2	-27.7

3.5. Adding in of intercooler

In order to reduce high emission of nitrogen oxides the engine intake system was fitted with a charging air cooler.

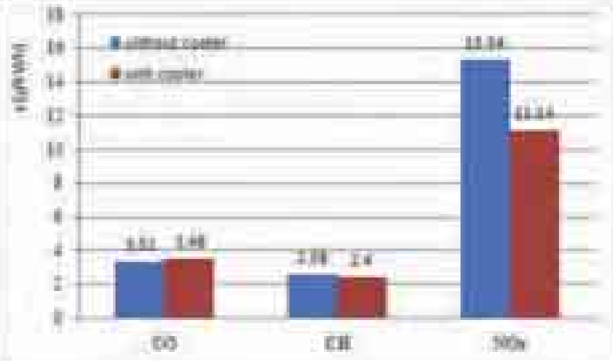


Fig. 4. Effect of charging air cooling on emission of CO, CH, NOx (measured before catalyst)

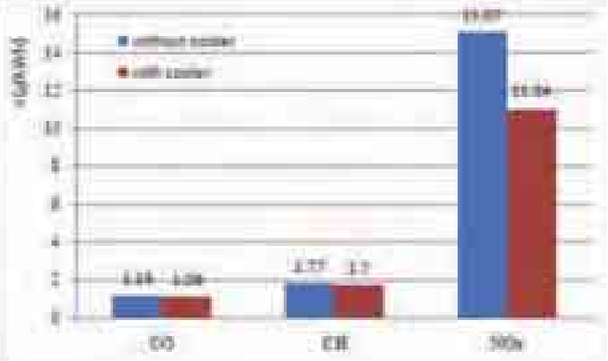


Fig. 5. Effect of charging air cooling on emission of CO, CH, NOx (measured behind catalyst)

3.6. Change of injectors

The next point of research activity was replacing of factory injectors by well-less injectors type VCO.

Forcing angle: 25° CA before TDC	Ne [kW]	CO [g/kWh]	CH [g/kWh]	NOx [g/kWh]
Standard injectors	81.9	1.08	1.7	11.04
Well-less injectors		0.99	0.98	10.48
Change in [%]		-8.3	-42.3	-5.1

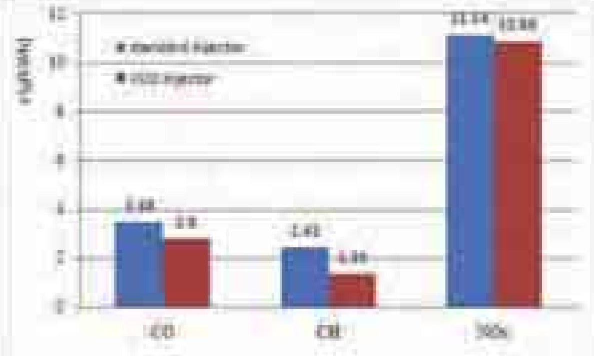


Fig. 6. Effect of injector construction on emission of CO, CH, NOx (measured before catalyst)

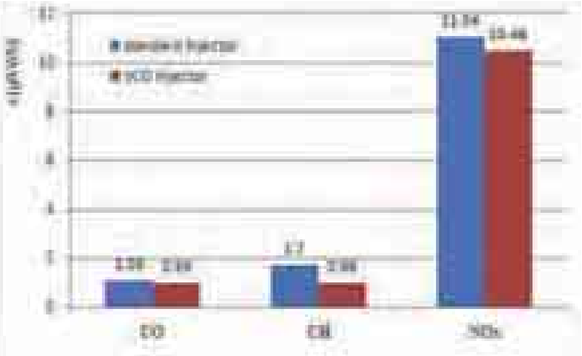


Fig. 7. Effect of injector construction on emission of CO, CH, NOx (measured behind catalyst)

3.7. Installation of soot filter

Afterwards, in place of catalytic afterburner the soot filter 108 SXS was installed.

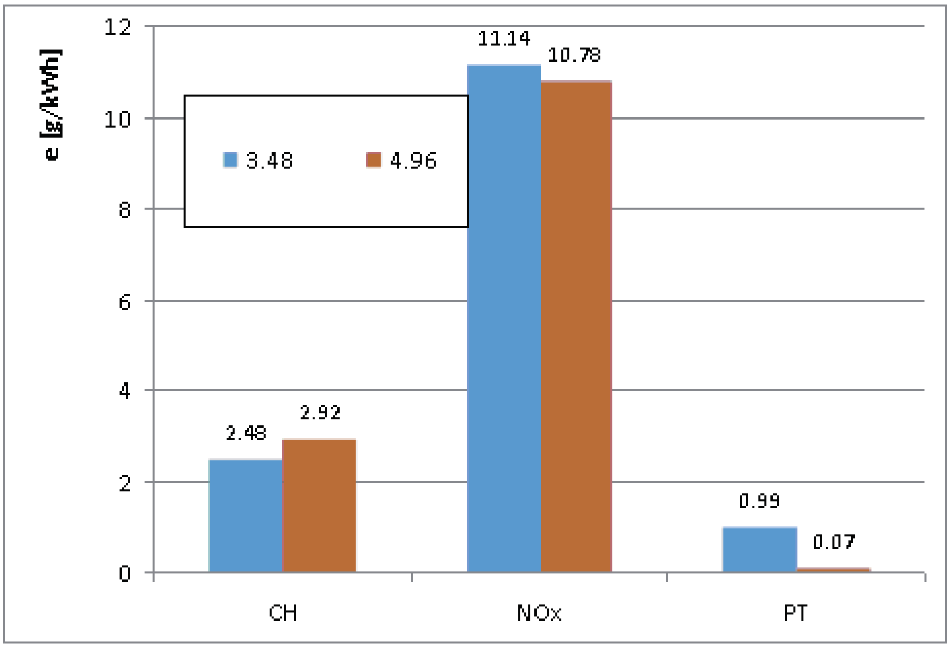


Fig. 8. Effect of soot filter on emission of CO, CH, NOx and particulates PT

Forcing angle: 22° CA before TDC	Ne [kW]	CO [g/kWh]	CH [g/kWh]	NOx [g/kWh]	PT [g/kWh]
Without filter	81.9	3.48	2.48	11.14	0.99
With filter		4.96	2.92	10.78	0.07
Change in [%]		16.1	17.7	-5.1	-92.9

The consecutive point of research works were tests of exhaust aftertreatment system equipped with a soot filter, coated with special catalyst, which played role of catalytic afterburner.

Forcing angle: 22° CA before TDC	Ne [kW]	CO [g/kWh]	CH [g/kWh]	NOx [g/kWh]	PT [g/kWh]
Before filter	81.9	8.75	0.82	6.99	1.42
Behind filter		0.28	0.34	6.95	0.06
Change in [%]		-96.8	-58.5	0	-95.8

3.8. Resultant configuration of test engine

The engine under test - 6CT 107 2/L2 - was finally equipped as follows:

- turbocharger: 3LD 308K/1.8,
- injectors: well-less type NK-3284,
- fuel forcing angle: 22 ° CA before TDC,
- intercooler,
- exhaust Gas Recirculation system,
- soot filter: coated type SXS C 1214.

The final setting-up of the engine allowed obtaining of following effects with reference to the base one:

Engine type	Ne [kW]	CO [g/kWh]	CH [g/kWh]	NOx [g/kWh]	PT [g/kWh]
SW400 ŁT3/2	85.6	28.09	3.44	15.05	1.65
6CT 107 at final setting-up	84.5	0.28	0.34	6.95	0.06
Change in [%]		99.0	90.1	53.8	96.4

3.9. Location of test engine performance against EU Standards

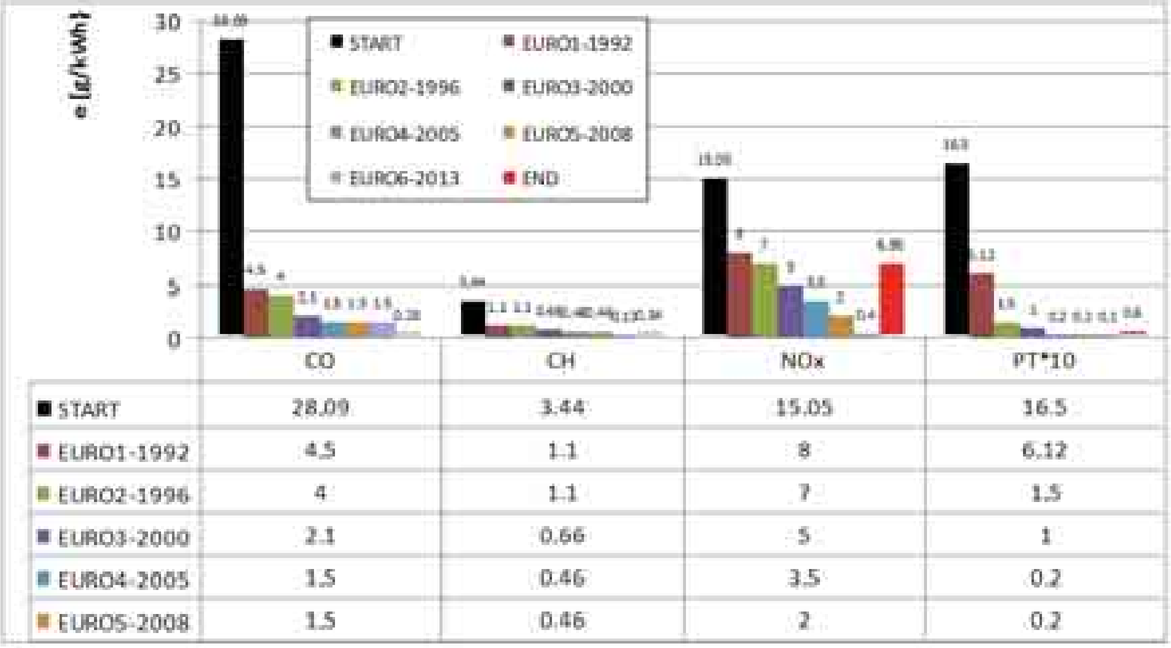
The Tab. 1 presents the EU Emission Standards for Diesel engines, starting from Euro 1 valid in 1992 up to Euro 6 coming into force in January 2013.

Tab. 1. EU Emission Standards for HD Diesel Engines, g/kWh (smoke in m^{-1})

Tier	Date	Test	CO	HC	NOx	PM	Smoke
Euro 1	1992, < 85 kW	ECE R-49	4.5	1.1	8.0	0.612	
	1992, > 85 kW		4.5	1.1	8.0	0.36	
Euro 2	1996.10		4.0	1.1	7.0	0.25	
	1998.10		4.0	1.1	7.0	0.15	
Euro 3	*1999.10, EEVs only*	*ESC & ELR*	*1.5*	*0.25*	*2.0*	*0.02*	*0.15*
	2000.10	ESC & ELR	2.1	0.66	5.0	0.10 0.13[a]	0.8
Euro 4	2005.10		1.5	0.46	3.5	0.02	0.5
Euro 5	2008.10		1.5	0.46	2.0	0.02	0.5
Euro 6	2013.01		1.5	0.13	0.4	0.01	

a - for engines of less than 0.75 dm^3 swept volume per cylinder and a rated power speed of more than 3000 min^{-1}

The figure beneath presents the finally, comparison of tested engine (initial and final version) against the background of EU emission limits:



	CO	CH	NOx	PT*10
■ START	28.09	3.44	15.05	16.5
■ EURO1-1992	4.5	1.1	8	6.12
■ EURO2-1996	4	1.1	7	1.5
■ EURO3-2000	2.1	0.66	5	1
■ EURO4-2005	1.5	0.46	3.5	0.2
■ EURO5-2008	1.5	0.46	2	0.2

Fig. 9. Finally comparison of tested engine (initial and final version) against the background of EU emission limits

4. Summary

The tested engines SW 400 as well as 6CT107 were extremely “dirty” with respect to the toxicity of their exhaust gases. Their emission performances exceeded repeatedly the emissions standards, which were obligatory, even a quarter century ago. Applying of above described treatment helped to reduce their exhaust emission to EURO3 - standard requirements. It is worth to observe an advantageous impact of injection acceleration on all toxic components of exhaust gas. Minor changes of injection forcing angle yielded a large emission values improvement of CO, CH and NOx. Applying of soot filter at such a big smoke values and particulates PT will affect negative the filter life or reduce the time between its successive regenerations.

It is necessary to assume that application of above-mentioned procedures to “cleaner” engine would result in emission of CO and CH meeting even EURO 5 levels. Achieving the established for Euro 6 NOx emission level at 0.4 g/kWh, requires probably applying of SCR technology (Selective Catalytic Reduction). Long-term personnel experience of accredited Diesel Engines Testing Laboratory at Aviation Institute in Warsaw, Poland indicates problems with enough accurate measurement of particulate emissions with precision of 0.01 g/kWh by means of gravimetric method. The required precision is namely on level of “background” in the dilution tunnel of PM measurement apparatus. Computational simulations show, that to obtain test result of 0.01 g/kWh with uncertainty of ± 0.004 g/kWh (40%!) for engine of 70 kW, the mass of particles deposited on the filter should be less than 0.12 mg.

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