IMPACT OF LOW-TEMPERATURE CORONA DISCHARGES ON GASEOUS POLLUTANTS LEVEL IN DIESEL ENGINE'S EXHAUST GAS

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Abstract

This publication presents the results of research on level changes of gaseous pollutants contained in the exhaust gas in the consequence of applying of equipment taking advantage of low-temperature corona discharges. Not only influence of different plasma reactor configurations on the emission of toxins have been evaluated, but also on the main parameters of the engine under test and exhaust gas cleaning efficiency as well. The device supplied by DC voltage of 10-15 kV the operating value generated a low-temperature corona discharge in the especially formed electrostatic field. The devices were located behind the exhaust manifold of Diesel engine then operated in the high temperature zone of exhaust.

The survey was realized in parallel with on-going research program at Institute of Aviation which has related to purification of Diesel engine's exhaust gas from particulates. The test results of emission of toxins obtained using the flat-arrangement and the axial-symmetric reactor systems were compared and discussed. The multi-variant designs of axial-symmetric device allowed the purposeful formation of favourable shape and intensity of electrostatic field and values of current, which induced the corona discharge. This activity has created better research capabilities for different geometric configurations of the reactors, namely linear and angular location and size of deflecting electrodes, structure of blade assembly generating a corona discharge, matching of proper distance between deflecting electrodes and blades.

Keywords: *exhaust gas, plasma reactor, emissions of gaseous toxins, experimental study*

1. Introduction

Institute of Aviation carried out research works on designs and models of flat and axially symmetrical arrangements of plasma reactor systems, primarily for the maximum reduction of particulates contained in engine fumes. Generation in flowing exhaust gas the corona discharge allowed the particulates to be charged homonymous and after deflecting of the their paths in a fixed electrostatic field to be agglomerated to greater clusters and separated. During the process of agglomeration the particulates do not alter their total weight, but convert into different form only. Particularly important is the agglomeration of the most harmful nanoparticles into larger structures, which can easier be removed from the exhaust and destroyed. Reactors making use of low-temperature corona discharges, obtained by putting thin wires or blades in a strong permanent electrostatic field, induced the uniform charging of particulates and their subsequent agglomeration and acceleration in order to separate them from the exhaust stream by capturing through the cyclones. An additional effect of changes in pollution levels of toxic exhaust components was also observed, although the most frequently systems used while studying the impact of the toxic components of combustion gases, particularly of NOx, are reactors powered by alternating current, primarily based on the phenomenon of corona discharge induced through the layer of dielectric or the layer of granules. These reactors, however, does not allow homonymous charging of particulates but may act as particulates pick-up device or as a NOx converter.

2. Study of toxins emission in the case of flat configuration of reactor

The study was carried out on the test bed using a 4-cylinder naturally aspirated Diesel engine Ursus. Measurements were made on warmed up engine in steady states according to Directive 97/68/EC. Both the engine and its completion have not been changed. Measurement of gaseous toxins emissions was performed using a set of Signal analyzers.

In case of flat configuration design of the reactor, which construction was presented in the study published in "Journal of KONES 2006" [6], the tests were carried out for voltage of values above 10 kV DC. This voltage level assured the existence of fully developed corona discharges, which intensity increased with increasing of voltage, causing higher agglomeration and stronger deflection of charged particulates. In case of configuration described above one of the most difficult problems connected with the functionality of purifying device turned out the phenomenon of carbon black deposition on electrode's insulators. The conduction of current between electrodes and their shields via the soot contained in exhaust gas limited maximum value of voltage to 12 kV.

The diagrams beneath (Fig. 1-3) show the variation of emission values of toxic exhaust components when working with inactive reactor (without power supply - 0 kV) and with the active reactor powered by a DC voltage by values respectively 10, 11 and 12 kV. The characteristics are presented depending on exhaust gas velocity, that is rotational speed and braking load of engine, as well as geometrically optimized device structure for the best effectiveness of particulate capturing.

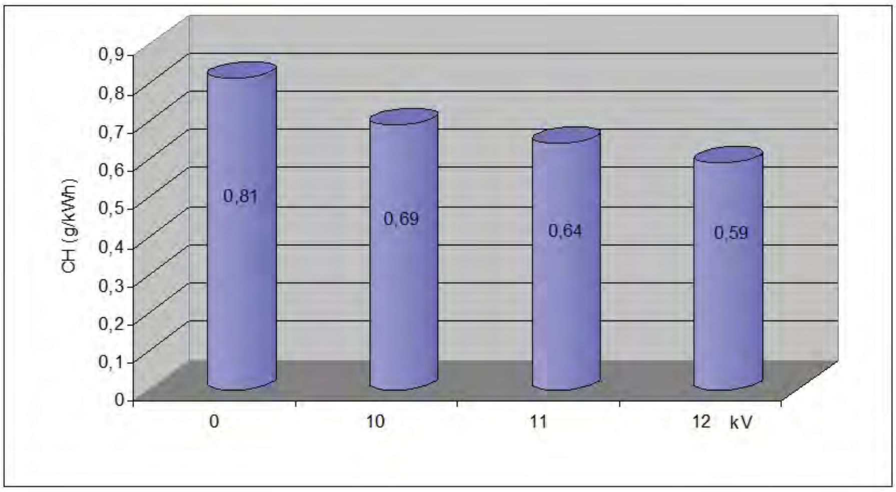

Fig. 1. Emission CH in [g/kWh] in acc. with 97/68/EC Directive at 10 - 12 kV DC supply and without voltage

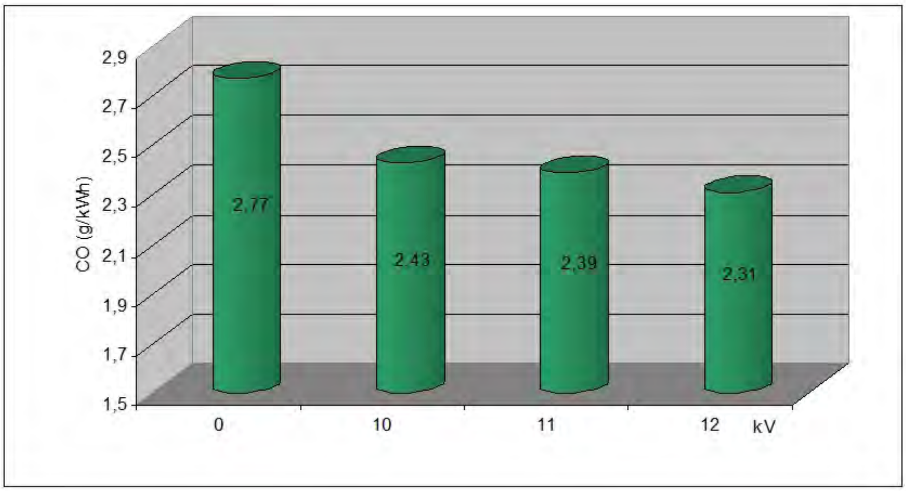

Fig. 2. Emission CO in [g/kWh] in acc. with 97/68/EC Directive at 10 - 12 kV DC supply and without voltage

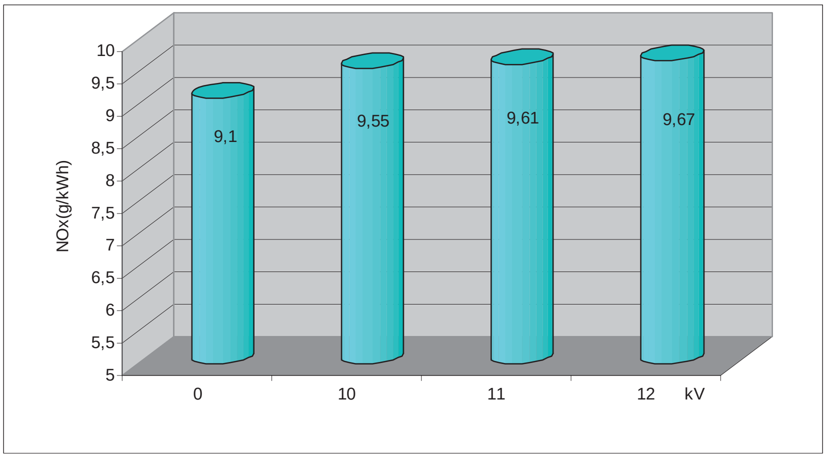

Fig. 3. Emission NOx in [g/kWh] in acc. with 97/68/EC Directive at 10 - 12 kV DC supply and without voltage

As a result of applying of flat configuration reactor powered by 12 kV DC voltage the highest drop of hydrocarbons emission of about 32% and carbon monoxide of about 17% were achieved. In addition an increase of nitric oxides of 17% was observed. It might be useful to mention, that the 40% effectiveness of particulates separation was gained as well.

The diagrams of gaseous toxins emission and chosen engine parameters for both cases: inactive and active reactor supplied by 12 kV DC voltage are presented below. Measuring points for maximum torque speed (1.500 rpm) correspond to 50%, 75% and 100% of maximum torque (Mmax) respectively, whereas measuring points for rated speed graphs (2.000 rpm) correspond to 10%, 50%, 75% and 100% of rated power (Ne).

a) Case of inactive installation.

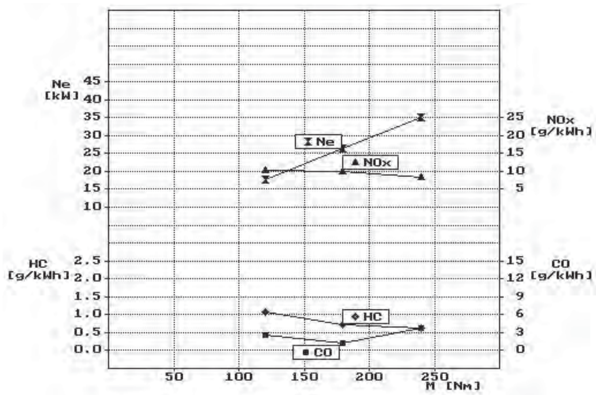

Fig. 4. Curves of gaseous toxins for maximal torque speed

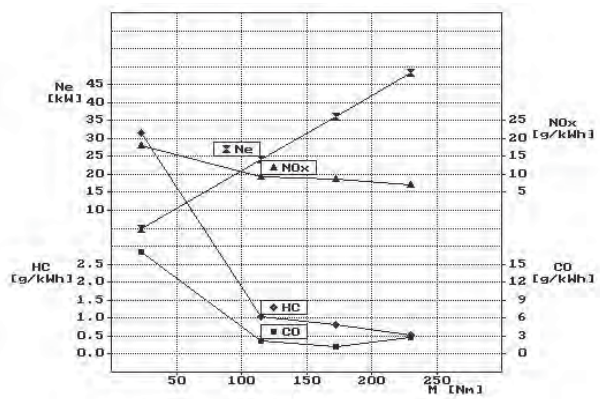

Fig. 5. Curves of gaseous toxins for rated speed

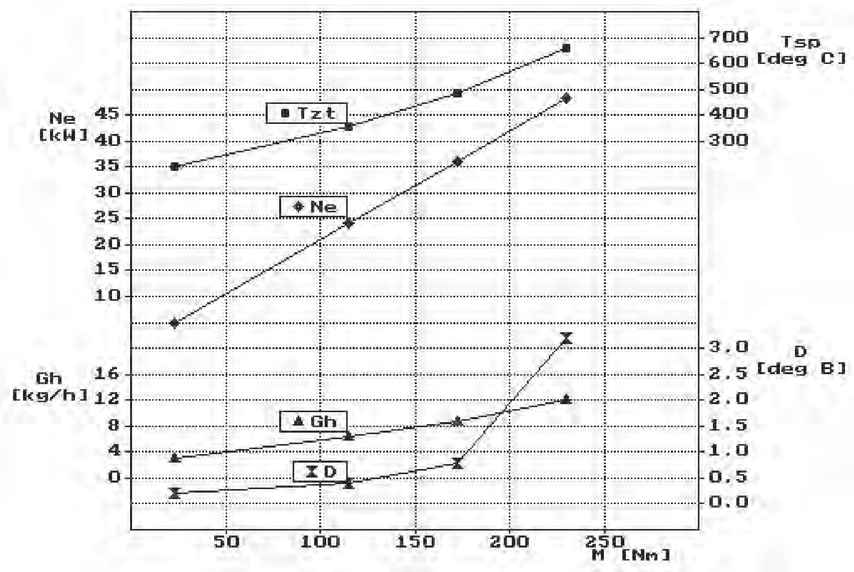

Fig. 6. Curves of chosen engine parameters for rated speed

b) Case of active installation

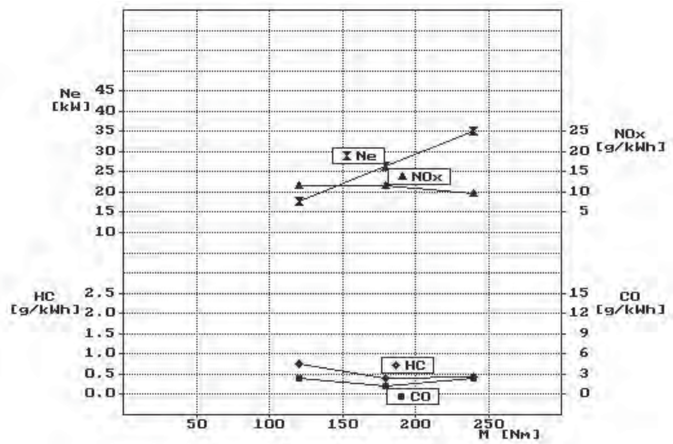

Fig. 7. Curves of gaseous toxins for maximal torque speed

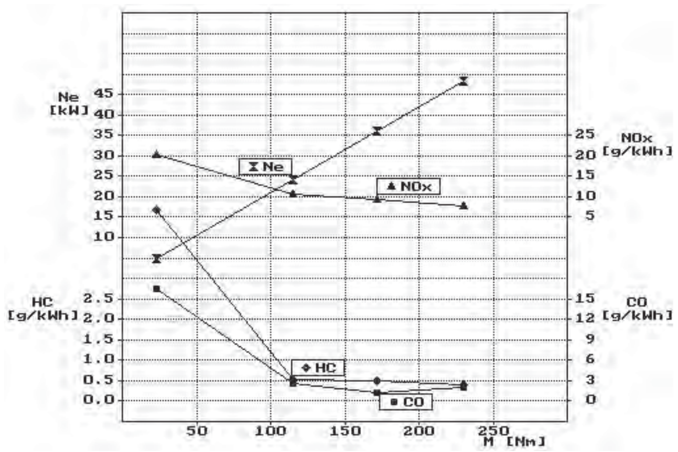

Fig. 8. Curves of gaseous toxins for rated speed

The courses of toxins emissions as a function of time are similar in cases of maximum torque speed and rated speed, but a slight decrease of power Ne [kW], smoke D [deg B] and slight increase fuel consumption Gh [kg/h] can be observed.

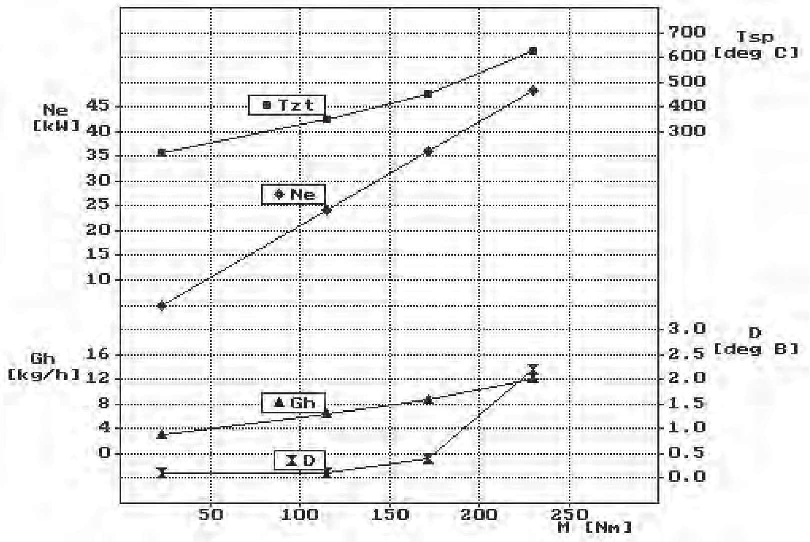

Fig. 9. Curves of chosen engine parameters for rated speed

3. Study of toxins emission for the case of axially symmetrical configuration of reactor

In the course of researches of emission a modified variant of axially symmetrical installation was used, where the number of electrodes was limited to one, surrounded by insulator playing the role of main supporting unit of blades assembly, which generates corona discharges and diverting electrode. The specification of axially symmetrical configured reactor was presented in "Journal of KONES 2007" [7]. The studies were performed using the experimental engine URSUS 4390 and the acquired results are shown on Fig. 10-12.

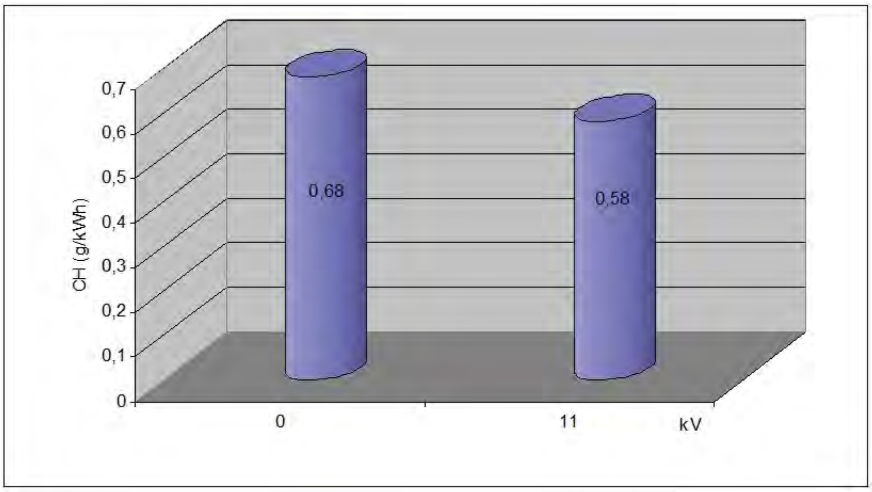

Fig. 10. Emission CH in [g/kWh] in acc. with 97/68/EC Directive in the inactive (0 kV) and an active reactor

Applying of axially symmetrical reactor supplied by voltage of 11 kV DC allowed the researchers for reduction of hydrocarbon emissions by about 15%, carbon monoxide emissions by about 4% and nitrogen oxide emissions by around 6%. For the discussed reactor configuration, the effectiveness of particulates separation was on the level of only 12%.

Thoroughly examining a number of variants and modification not only geometry of equipment but also location and size of blades, length of corona discharge area, area of strong deflecting field and module of particulates separator resulted in the final version of reactor. Details of the construction were published in the "Journal of KONES 2009" [9]. A new design of ceramic

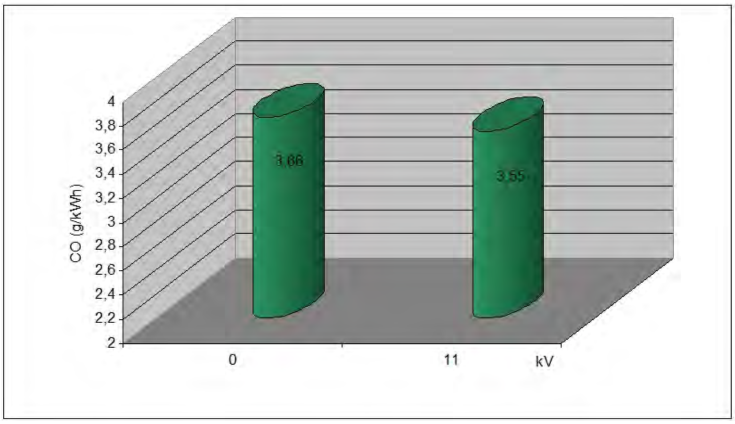

Fig. 11. Emission CO in [g/kWh] in acc. with 97/68/EC Directive in the inactive (0 kV) and an active reactor

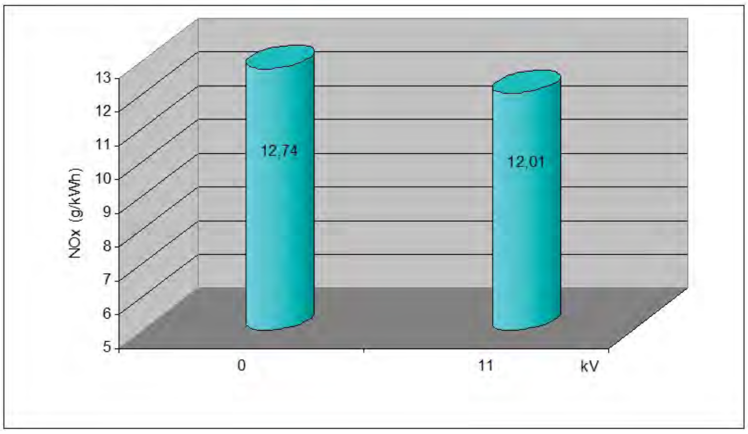

Fig. 12. Emission NOx in [g/kWh] in acc. with 97/68/EC Directive in the inactive (0 kV) and an active reactor

insulator was blown round with the air which proved to be essential and necessary to prevent the deposition of soot on it. The stream of exhaust gas inside the device was divided into two zones - the inner zone where the cleaner part of fumes were driven and the outer one, containing positively charged, deflected in the electrostatic field particulates. It caused the considerably elongation of reactor’s work time. Of course, studies on these changes were aimed at obtaining the possible best result of exhaust treatment primarily from the particulates. It has been found, that the engine speed or time period when the exhaust gas flowed through the device at different engine load affects the value of toxins emission.

The achieved results of pollution levels are shown in Fig. 13 to 15.

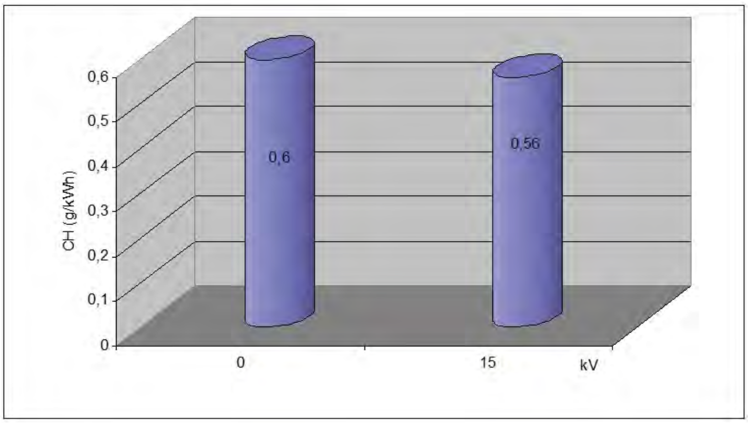

Fig. 13. Emission CH in [g/kWh] in acc. with 97/68/EC Directive in the inactive (0 kV) and an active reactor

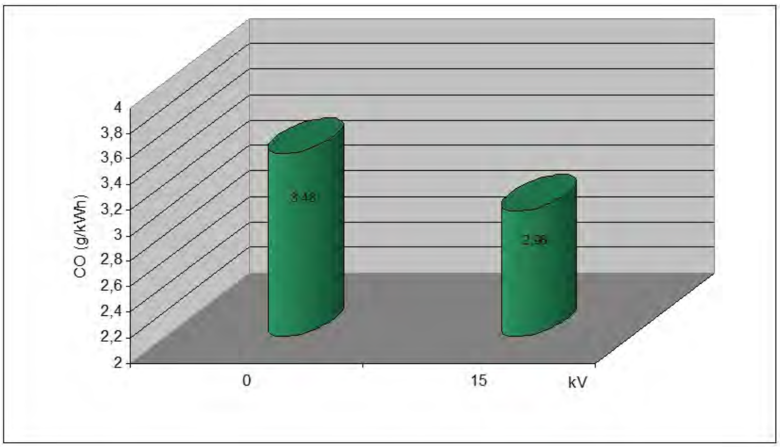

Fig. 14. Emission CO in [g/kWh] in acc. with 97/68/EC Directive in the inactive (0 kV) and an active reactor

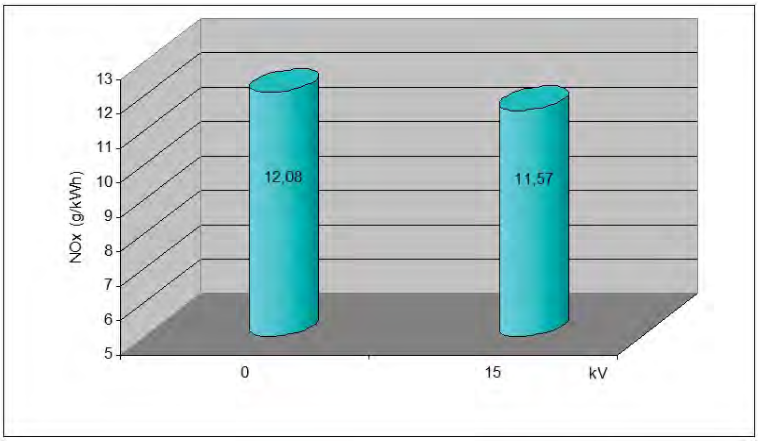

Fig. 15. Emission NOx in [g/kWh] in acc. with 97/68/EC Directive in the inactive (0 kV) and an active reactor

The impact of structural changes of device's final version on toxins emission and other engine parameters appeared to be rather slight. Emission of hydrocarbon was decreased by about 7%, carbon monoxide by about 13% and nitrogen oxide by about 4%. The optimization of reactor's structure gave the effect of aftertreatment of particulates at 66%.

4. Summary

- Using low-temperature corona discharge the biggest changes of the emission of toxins were obtained for the flat configuration of reactor when running at a voltage of 12 kV DC. Significantly reduction of hydrocarbon emission (by about 32%) and carbon monoxide emissions (by about 17%) was achieved but nitrogen oxides emission increased by about 9%.
- On the other hand the axially symmetrical version of device gave a slight reduction of the emission levels of all toxic components contained in the exhaust.
- Changes of engine's parameters: power, fuel consumption and smoke seemed to be rather small. Variation of smoke followed the changes of hydrocarbon's emission value.
- A model prototype of axially symmetrical plasma reactor designed for removing particulates from exhaust gas did not reduce significantly the emission of gaseous toxins.
- At present, the simultaneous reduction of toxins and particulates in the exhaust is a major question in the course of design and optimization activity, not only by Diesel engine combustion system but also by beyond-engine systems based on the use of plasma reactors for the catalytic reduction of nitrogen oxides in the presence of plasma.

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