LOWERING OF EXHAUST EMISSION IN MODERN TWO-STROKE ENGINE

Władysław Mitianiec, Łukasz Rodak

Cracow University of Technology
Institute of Automobiles and Internal Combustion Engines
Jana Pawła II 37, 31-864 Krakow, Poland
tel.: +48 12 6282692, fax: +48 12 6283690
e-mail: wmitanie@usk.pk.edu.pl, lrodak@pk.edu.pl

Abstract

In the article the results of experimental tests carried out on the modified SI two-stroke experimental combustion engine with direct fuel injection system and the prototype of the oxidizing catalytic converter are presented. Volumetric exhaust emissions of the most important chemical components are many times smaller than standard limits of gaseous emissions given by EU directive for the new stationary engines applied in non-road vehicles and machines Spark ignition two-stroke engine fitted with a catalytic reactor is characterized by high temperature of exhaust gases, which the energy may be used in cogeneration systems. The paper presents the test stand, volumetric concentration of the main components of exhaust gases, results of converted emissions and fuel consumption as a function of air excess coefficient at chosen rotational speeds together with the assessment of the test results. There is decreasing of CO and HC emission during increasing of air excess coefficient and a strong increase of CO_2 behind the catalytic converter. Application of catalytic converter in the outflow system together with direct fuel injection of the tested two-stroke engine enables to achieve values of exhaust emission of main toxic chemical components close to automobile four stroke engines. The paper presents also the comparison of exhaust gas emission of this engine with other engines equipped with different fuelling systems. Presented work is the successor of a wide range of research work in the field of development of modern two-stroke engines carried out in the Cracow University of Technology.

Keywords: *transport, experiments, combustion engines, air pollution*

1. Introduction

Nowadays spark ignition two-stroke engines applied in small motorization as well as agriculture and industrial applications are equipped still in carburetted fuelling system, which causes a considerable emission of injurious exhaust gas components, particularly hydrocarbons and carbon monoxide. Such fuelling system contributes in increasing of specific fuel consumption. Mixing fuelling system does not allow applying catalytic converters, inter alia on account of big amount of unburned lubricating oil in exhaust gases. Big concentration of hydrocarbons exceeds usually 4000 ppm and it does not allow oxidizing them effectively. Symmetry of the piston-port timing system, which is applied in small power SI two-stroke engines, is the reason of the excessive emission of hydrocarbons, as a result of a partial flow of the air-fuel mixture to the exhaust port during scavenges process. In the past the different design methods linked with fuelling system were applied for the purpose of reduction of both hydrocarbons and carbon monoxide as well a decreasing of specific fuel consumption [1]. For such systems one can rate the low-pressure air-assisted direct fuel injection from Orbital [3, 13] described in different technical papers and the system FAST [11] invented by Piaggio. Another solution was the proposal of two-stroke engine invented by IFP and described by P. Durret [4] called as IAPAC. This solution concerned to formation of the air-fuel mixture before a special inlet valve put in the cylinder head as a result of fuel inflow from electronic control injector and the air flow. The inlet valve was controlled by the cam driven from the crankshaft. Such system was like the present multipoint injection systems. All direct injection systems at the beginning of compression process have prevented considerably an escaping of the fuel to the exhaust system. The above mentioned FAST system enabled two times decreasing of hydrocarbons emission in the motor-bicycle from 100 g/kWh to 40 g/kWh. Moreover in the last decade of XX century it was considered an applying of the engine with Orbital fuelling system in the personal car [13] by the company Ford in respect to small weight and volume and also on fulfilling of contemporary exhaust emission requirements.

Applying of electronic control direct fuel injection system enables freely control of fuel dose in dependence on load and rotational engine speed. However, time needed for evaporation of fuel is very short, considerably less than in a direct fuel injection four stroke engine. For this reason the fundamental is beginning of fuel dosing, which takes place usually during closing of the exhaust port. The direct fuel injection system causes multiple decreasing of volumetric ratio of hydrocarbons in exhaust gases in comparison to the carburetted system and enables applying of a catalytic reactor in the exhaust system. Applying of the oxidizing catalytic converter was considered by many researchers [12], also in Poland [10]. The two-stroke engine produces exhaust gases with small volumetric ratio of nitrogen oxides in respect to internal exhaust gas recirculation, which decreases combustion temperature.

The authors in the experimental tests used the two-stroke engine with high pressure direct fuel injection (one of sparse in the world) worked out in the CUT [9]. This engine during experimental investigations was modified by applying of the special small size catalytic converter.

2. Goal and scope of experimental tests

The Goal of the experimental test was to prove possibility further decreasing of contents of hydrocarbons and carbon monoxide in exhaust gases of engine with high pressure direct gasoline injection by means of an oxidizing catalytic converter in comparison to the same engine with the standard exhaust system. The further goal was to check eventual decreasing of engine power or changing of specific fuel consumption. The scope of experimental tests contained determination of adjustable engine performances for several chosen rotational speeds. One tested the change of fuel consumption , the change of engine torque with particular acknowledgment of change of hydrocarbons, carbon monoxide and nitrogen oxides volumetric ratios in exhaust gases before and behind of the catalytic converter. I the paper the chosen results of the experimental work are presented, which show the possibility of further decreasing of contents those chemical species by applying of a simple catalytic system.

3. Experimental object

Adaptation of the catalytic reactor for two-stroke engine with high pressure gasoline direct injection system was carried out on the industrial 1-cylinder air cooled engine Robin EC12 with capacity 115 cm3 in the Chair of Internal Combustion Engine in CUT. Originally this engine was equipped with floatless carburettor and afterwards was modified by applying of electronically controlled direct fuel injection unit with control pressure of dosing fuel. During tests the fuel pressure in the injector was constant and amounted 50 bars. The detailed diagram of experimental stand with hardware and measurement apparatus is shown in Fig. 1.

In the composition of the test stand there entered the eddy current dynamometer Automex and 5-components exhaust gas analyzer Arcon Oliver K-4500 thanks to it there could be possible the measurement of air excess coefficient and the following exhaust gas components: CO, HC, CO2, NO and O2. The engine was lubricated by the oil served to the inlet pipe by using the adjusted needle valve from the tank as a result of pressure below atmospheric in the inlet pipe.

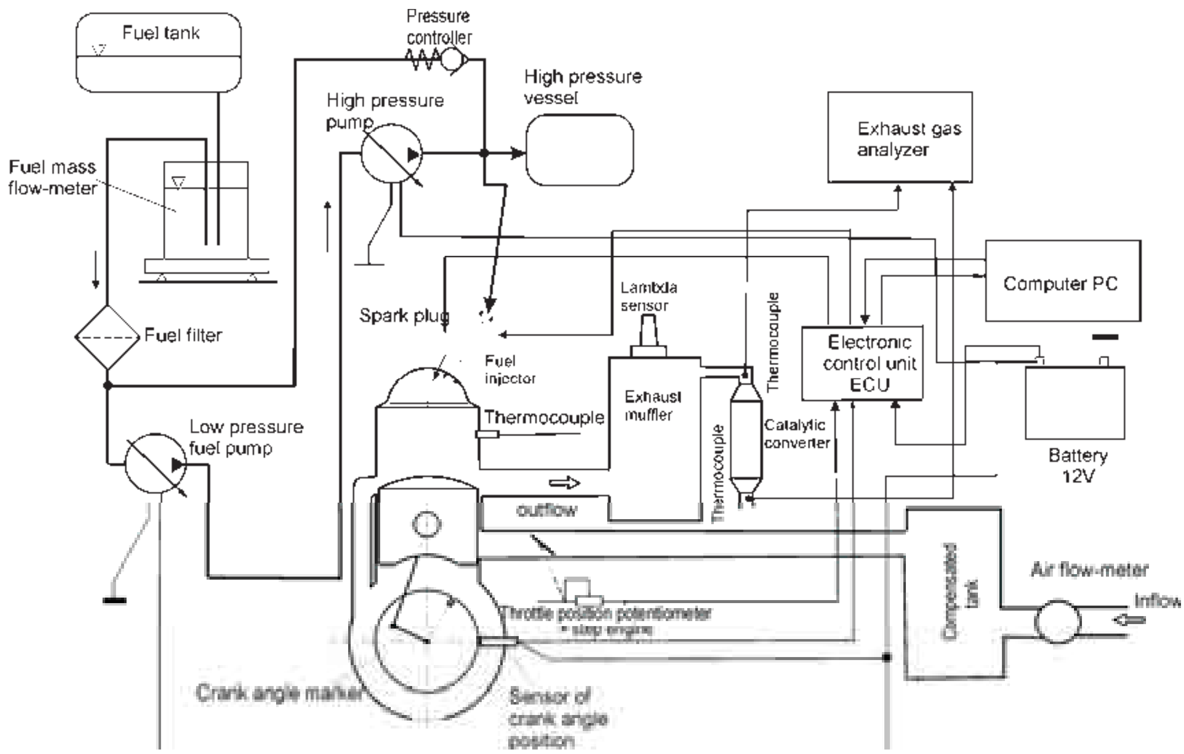

Fig. 1. Diagram of test stand with 2-stroke engine Robin EC12

Exhaust gas input by the gas analyzer was hold continuously by the 3-way valve, which enabled to measure gas composition before and behind the catalytic reactor. In the gas path the special coils were put in order to cool the gas until it entered to the analyzer. The test stand was also equipped with thermocouples for measurement of gas temperature in those two points.

The outflow system behind the muffler was equipped with the small metallic oxidizing catalytic reactor applied in four stroke engines in one-track vehicles. In the catalytic converter unit there were foreseen the outputs for thermocouples and the outputs for exhaust gas probes for analyzer. The reactor was put behind the muffler in order not to disturb the gas flow directly from the cylinder. The design of the muffler did not allow put the lambda sensor in the other place than on the opposite site of the exhaust port. Thanks to the linear characteristic of wide-band lambda sensor and the controller, signal from the sensor had a voltage character and voltage changed from 1 to 5V and reflected the change of air excess coefficient. The control of fuelling system was carried out in LabView environment, while the signal from the lambda sensor was joined with control program of the engine. Thanks to the lambda sensor the program could change the fuel dose on the basis of oxygen amount in exhaust gases. The control computer program enabled to monitor onboard the engine work parameter and change the given value of air excess coefficient.

4. Experimental tests

The successive stage of the work was to carry out the experimental tests on the engine with the catalytic converter. The engine worked at full throttle opening and given rotational speed by the load of dynamometer. The test was carried out for two rotational speeds 3000 and 3500 rpm. The given air excess coefficient was the adjusted parameter in the range 1.0–1.3. The following engine parameters were measured: torque, hour fuel consumption, volumetric ratio of the main exhaust gas species before and behind of the catalytic converter, gas temperature before and behind of the reactor, air mass flow rate and air excess coefficient. This method enabled the comparison of emission of raw exhaust gases and cleaning gases behind the converter. The read value of lambda from the analyzer is not true value for the charge in the combustion chamber, because above 10% of the delivered air to the cylinder is flowing to the exhaust port during scavenge process.

In the Fig. 2-5 the results of the measurements of volumetric concentrations of chosen exhaust gas components are presented at 3000 rpm and full throttle opening. Volumetric ratio of CO (Fig. 2) and hydrocarbons (Fig. 3) in the exhaust gases decrease with the increase of the air excess coefficient both in gas probes taken before and behind the catalytic converter.

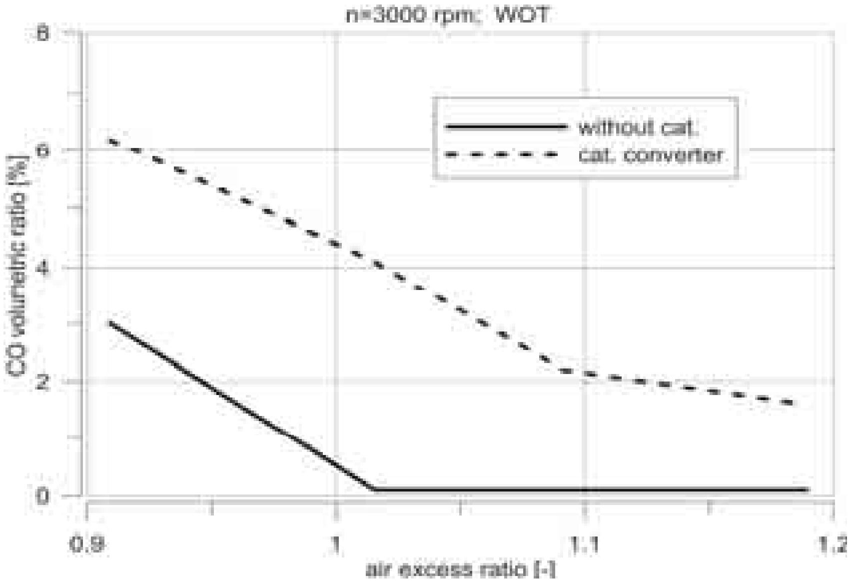

Fig. 2. Volumetric concentration of CO before and after catalytic converter at changeable air excess coefficient in Robin engine at 3000 rpm and WOT

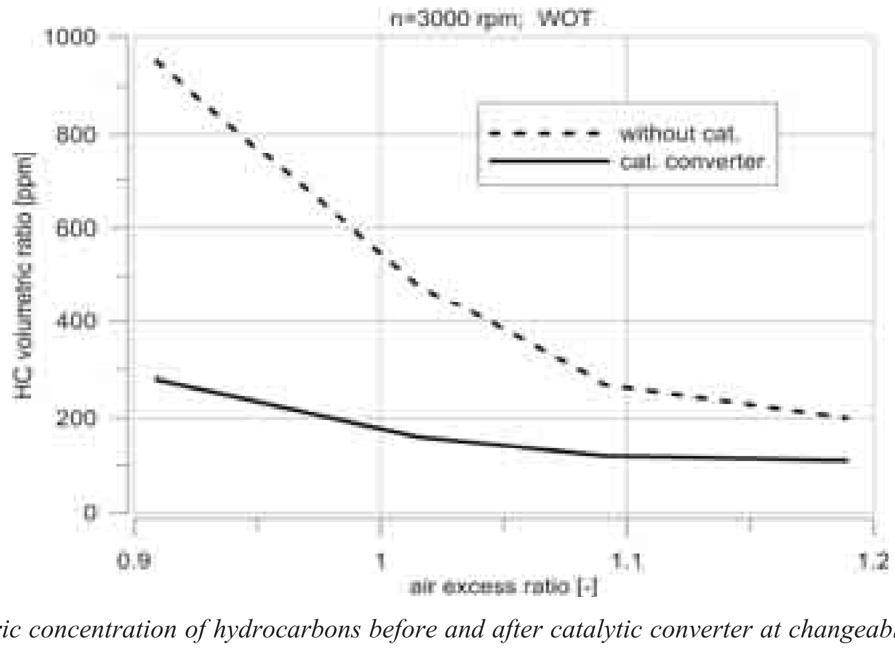

Fig. 3. Volumetric concentration of hydrocarbons before and after catalytic converter at changeable air excess ratio in Robin engine at 3000 rpm and WOT

Volumetric ratio of CO in exhaust gases reaches value below 0.5% and volumetric ratio of hydrocarbons is close to 100 ppm at rotational speed 3000 rpm at leaner mixtures. The tests indicated further lowering of CO and HC contents in the exhaust gases with the increase of rotational speed behind the reactor and at 3500 rpm volumetric ratio of HC amounted below 100 ppm. At expense of the reducing of HC and CO is a slight increase of volumetric ratio of NOx (Fig. 4), where at rich mixture NOx is less before the reactor in comparison to that ratio behind the reactor. This is due the increase of temperature of exhaust gases as a result of oxidation of HC and CO. This phenomenon influences on the increase of carbon dioxide CO_2 in gases behind the catalytic converter. By the way amount of CO_2 in exhaust gases reached maximum value 13.5% at air excess coefficient equalled 1.0 (Fig. 5).

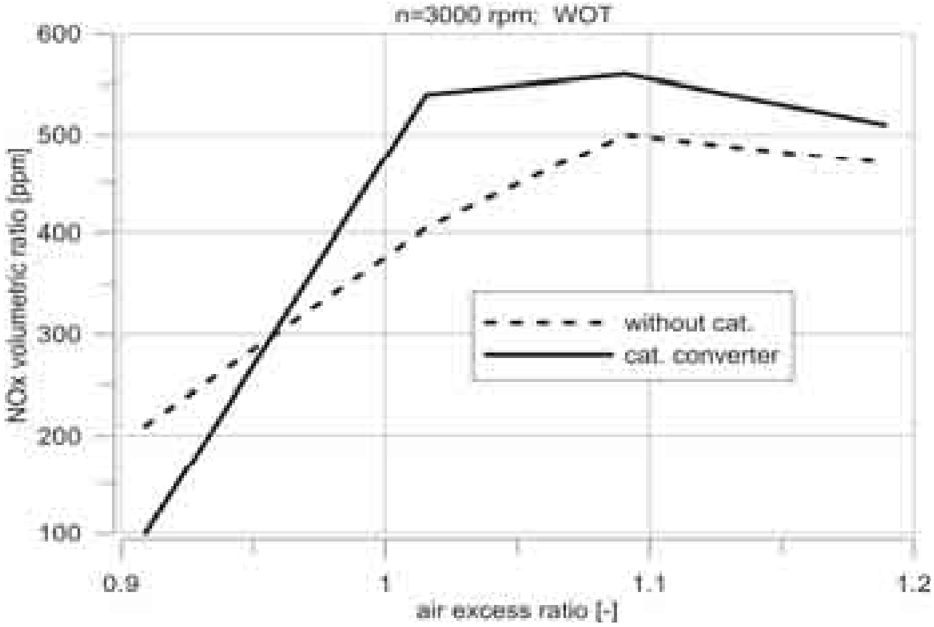

Fig. 4. Volumetric concentration of NOx before and after catalytic converter at changeable air excess ratio in Robin engine at 3000 rpm and WOT

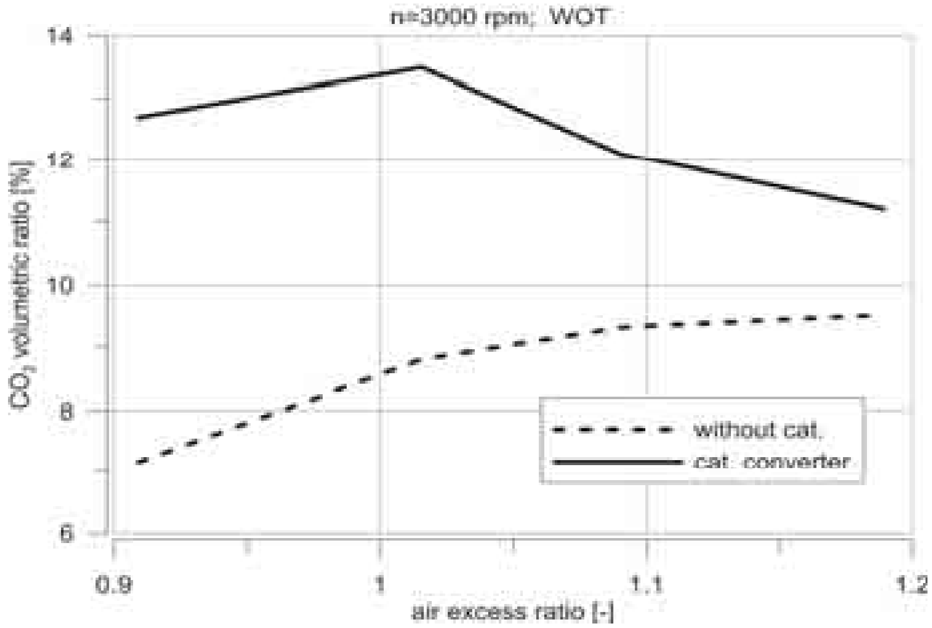

Fig. 5. Volumetric concentration of carbon dioxide before and after catalytic converter at changeable air excess ratio in Robin engine at 3000 rpm and WOT

It should be underlined a significantly less concentration of nitrogen oxides in exhaust gases in comparison to four-stroke engines. In order to decrease content of NOx in exhaust gases it should be applied an additional catalytic converter reducing amount of NOx. Maximal value of volumetric ratio of NOx behind the reactor amounted 550 ppm at air excess coefficient equalled 1.1. Oxidation of HC and CO is easier in two-stroke engines because in exhaust gases there are big amount of oxygen as a result of air inflow to the exhaust system during scavenge process.

5. Emission of exhaust gas species

For SI two-stroke engine there are several class of classification according to EC directive [5] in dependence on engine displacement. This directive concerns to the engines mounted in self-propelled vehicles, which are not moving on the roads. Values of permissible emission of three main toxic species in exhaust gases for new engines mounted in non-road vehicles presents Tab. 1.

Tab. 1. Permissible values of CO, HC and NOx emission for new engines [5]

Class	Carbon monoxide [g/kWh]	Sum of hydrocarbons and nitrogen oxides [g/kWh]
		HC+NOx
SH:1	805	50
SH:2	805	50
SH:3	603	72
SN:1	610	50
SN:2	610	40
SN:3	610	16,1
SN:4	610	12,1
Emission of NOx for all engine classes does not exceed 10 g/kWh		

The tested engine was not destined for driving of vehicles but only for stationary and industry applications. With regard for engine displacement (115 cm^3) the engine Robin can be qualified to the class SH:3 or SN:3. Thanks to obtained results of volumetric ratio of the individual species one can obtain the specific work emission in g/kWh and they can be compared with the limits proposed by European Commission. For example in Fig. 6 and 7 the specific mass emission of carbon monoxide and hydrocarbons are presented [g/kWh] for rotational speed 3000 rpm as a function of air excess coefficient before and behind the reactor at WOT. It is seen small emission of those species behind the reactor amounted 5 g/kWh of CO and 0.5 g/kWh of HC, respectively. In these figures it can be remarked, that this engine fulfils the norm of exhaust gas emission obliged until now since year 2007.

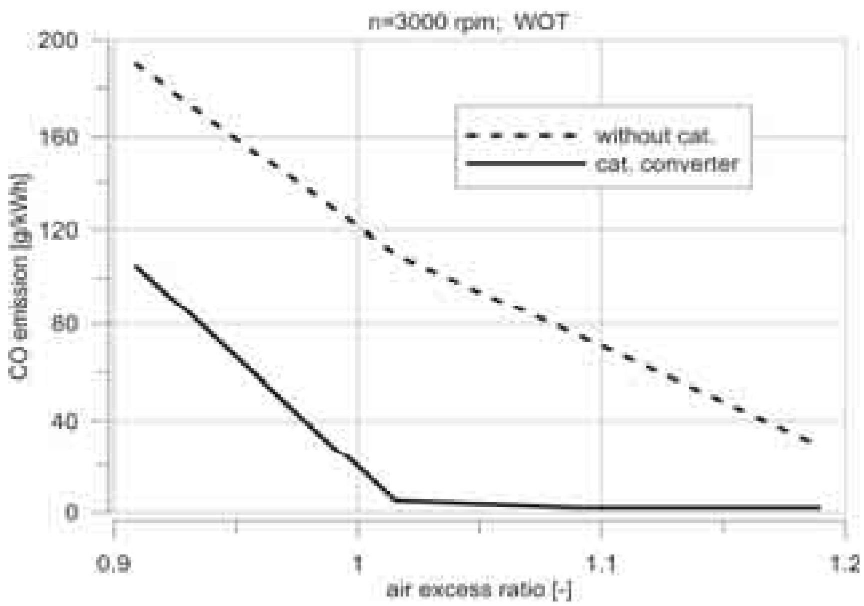

Fig. 6. Mass emission of carbon monoxide before and after catalytic converter at changeable air excess ratio in Robin engine at 3000 rpm and WOT

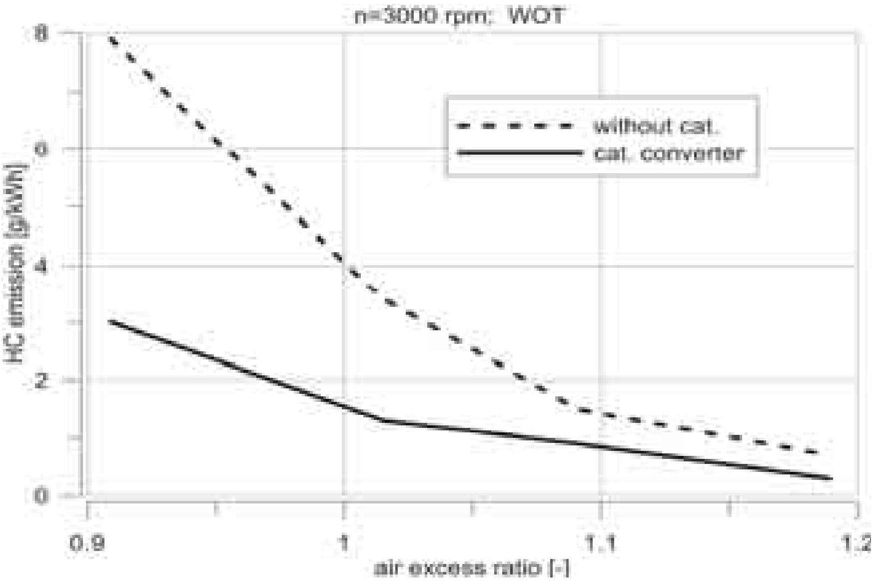

Fig. 7. Mass emission of hydrocarbons after catalytic converter at changeable air excess ratio in Robin engine at 3000 rpm and WOT

Emission of nitrogen oxides is also small for it amounts only 2 g/kWh maximum at tested rotational speed (Fig. 8). Minimal value of emission of this species amounts only 0.5 g/kWh. Working parameters of tested engine (torque, specific fuel consumption) with catalytic converter were the same as in the case with standard muffler. It indicates the feature of modern two-stroke engine fulfilled rigorous requirements of emission without power loss. The tests showed the increase of total efficiency about 30%.

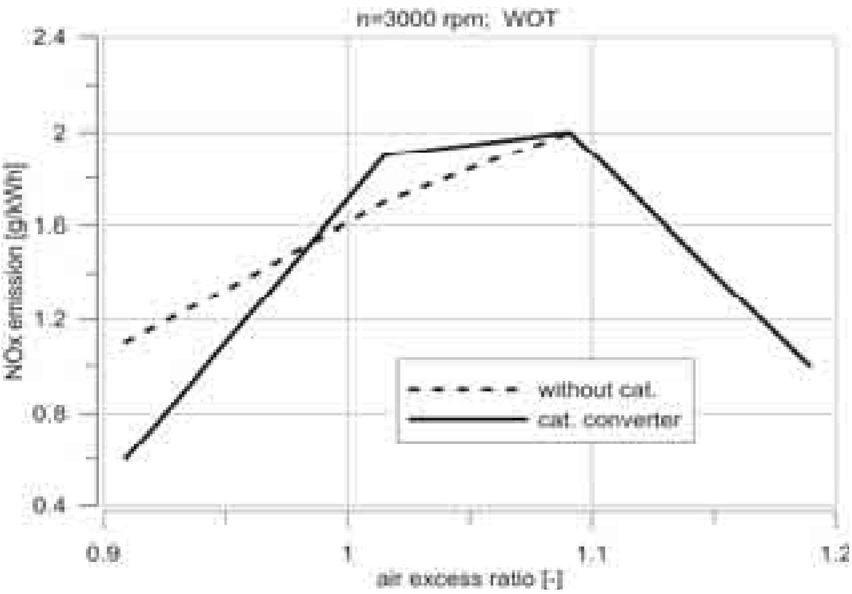

Fig. 8. Mass emission of nitrogen oxides before and after catalytic converter at changeable air excess ratio in Robin engine at 3000 rpm and WOT

The Tab. 2 presents comparison CO, NOx and HC emissions for four two-stroke engines with direct fuel injection systems with the tested engine equipped with high pressure direct injection system supplemented with the catalytic converter. The tested engine indicates significantly lower emission of specified species in comparison to systems RMIS, FAST, IAPAC and DITECH. Inserting of the additional oxidizing catalytic converter is further step in order to decrease the emission of toxic components in the exhaust gases in modern spark ignition two-stroke engines.

Tab. 2. Comparison of exhaust gas emission two-stroke engines with different fuelling systems

Exhaust gas species	Engine RMIS 115 cm^3 [7]	Engine FAST 50 cm^3 [11]	IAPAC SELVA 4,5 kW[4]	Aprilia DITECH 50 cm^3 [14]	Engine Robin with DFI and catalytic converter
CO [g/kWh]	80-140	30-80	100	30-240	5-100
NO_x [g/kWh]	2.5-5	----------	10	5-8	max 2.0
HC [g/kWh]	30-50	10-100	50	24-50	0.5–3.0

6. Summary

Application of the catalytic converter in direct gasoline injection two-stroke engines gives required effect of decreasing of CO and HC emission. Conversion efficiency is very high for these species. Direct fuel injection system together with any catalytic reactor enable fulfilling the emission requirements for such engines. On the basis of experimental test one can be observed that such engine work effectively at air excess ratio near 1.0, however with increasing of air excess coefficient emission of CO and HC rapidly decreases. The tested engine fulfils with an excess the requirements of European directive respectively to CO and (HC+NOx) emissions.

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