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The Effect of Selected Compression-Ignition Engine Operating Parameters on the Emission of Toxic Exhaust Gas Components

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Summary. This paper presents an analysis of the effect of two selected engine operating parameters (fuel injection pressure and fuel injection timing on the emission of toxic components in the exhaust gas of compression-ignition engine. Experimental tests were conducted on the Star 359 engine fuelled with biodiesel at different fuel injection pressure values and at different fuel injection timing values.

As a result of engine test bench testing, the characteristic curves of toxic exhaust gas component emissions were made and next analysed.

Key words: internal combustion engine, fuel injection pressure, fuel injection timing, biodiesel.

INTRODUCTION

Fuel injection pressure is an important operational parameter of internal combustion engine because it is responsible for the correct process of fuel pumping through the fuel supply system components, provides appropriate flow rate and indirectly affects the character of fuel jet distribution inside the combustion chamber. Furthermore, it is responsible for the volume of fuel dose injected into to combustion chamber of internal combustion engine [1, 3, 7, 8].

Fuel injection timing refers to the position (rotation angle, inclination angle) of crankshaft in an internal combustion engine between the time when fuel injection starts and the position when the piston reaches the top dead centre (TDC). Fuel injection must always begin just before TDC has been reached by the piston so that the air-fuel mixture has enough time to fully ignite. This angle should be set so as to provide the development of

the maximum power at the least fuel consumption under specific engine operation conditions [2, 6, 9].

At present, apart from traditional fuels (petroleum-derived fuels), there are alternative fuels available on the market that are characterised by improved physical properties, which has a significant effect on the correct operation of an engine. Improved fuel viscosity and density are connected with higher resistance during the flow of fuel through the fuel supply system components, which forces a loss of energy to overcome it, and consequently the engine power drops. This also reduces the range of fuel jet, thus the fuel will ignite close to fuel injector nozzle outlets with small amount of air. This in turn induces incomplete fuel combustion, and this situation may cause a drop in the engine power, reduction of engine efficiency and an increase in the emission of toxic components with exhaust gas [10, 12]. With an increase in the values of these parameters, we receive a mixture which evaporates more slowly due to higher boiling point [11, 13]. When using fuels with improved viscosity and density, it is possible to control the working parameters of engine operation in order to receive better conditions during the air-fuel mixture formation and obtain more controlled combustion process in the working chamber of internal combustion engine [3, 4, 5].

EXPERIMENTAL TEST METHODS

Experimental tests were performed on an engine test bench on the Star 359 engine fuelled with biodiesel (B20). During the experimental tests, the engine operated at different fuel injection pressure values: 22 and 24 MPa, and at different fuel injection timing values: 14, 16 and 18.5° of crankshaft revolutions before TDC. During the tests, engine operation parameters and toxic exhaust gas component emission values were read using an IMR exhaust gas analyser. As a result of engine test bench testing, the characteristic curves of toxic exhaust gas component emissions were made.

Table 1. Technical specification for the Star 359 engine

Arrangement of cylinders	In-line
Number of cylinders	6
Cylinder diameter	110 mm
Piston travel	120 mm
Engine cubic capacity	6840 cm³
Compression ratio	17 (CI)
Maximum power	150 KM
Rotations at maximum power	2800 rpm
Maximum torque	432 Nm
Rotations at maximum torque	1600 rpm
Fuel supply	Direct fuel injection
Type of timing gear	OHV
Firing order	1-5-3-6-2-4
Engine dry weight	510 kg

EXPERIMENTAL TEST RESULTS AND THEIR ANALYSIS

The conducted tests allowed determination of the differences occurring during the emission of toxic exhaust gas components at different settings of fuel injection pressure.

Figure 1 presents the emission of toxic engine exhaust gas components during both fuel injection pressure 22 and 24 MPa in the full range of crankshaft rotational speed. The following exhaust gas components are presented in the diagrams: carbon monoxide (CO), nitrogen oxides (NO_x), carbon dioxide (CO_2), and absorption coefficient “k”.

Figure 2 presents a comparison of the percentages of toxic exhaust gas component emissions assuming that the emission value at the fuel injection pressure of 22 MPa is 100% (black horizontal dashed line) in the function of crankshaft rotational speed. This is intended to show by how much the emission decreases or increases at various ranges of engine rotational speed in relation to the emission at the fuel injection pressure of 22 MPa. It is easy to see that almost all the exhaust gas components have reached significantly lower values, with CO reaching even a 30% lower emission in the initial range of rotational speed to about 1100 rpm, and similarly in the range of higher rotational speeds (2000-2400 rpm) where its emission ranges from 75 to 90% of CO emission at lower fuel injection pressure. The absorption coefficient “k” is also more favourable in relation to the reference point in the whole range of crankshaft rotational speed, particularly at the rotational speed of 2100 rpm where it reaches its minimum and exhaust gas smokiness is at the level of 65% of the reference exhaust smokiness. The CO_2 emission is also decreased although this range is significantly lower in relation to other exhaust gas components. The only small increase of emission was observed for NO_x, which may result from a small increase in fuel temperature as affected by increased fuel injection pressure.

Figure 3 also presents a comparison of the percentages of toxic exhaust gas component emissions at two fuel injection pressure values where the reference point also is the emission at a lower value of fuel injection pressure. Figure 3 differs from the previous one in that it shows the total value of exhaust gas emitted during the engine operation.

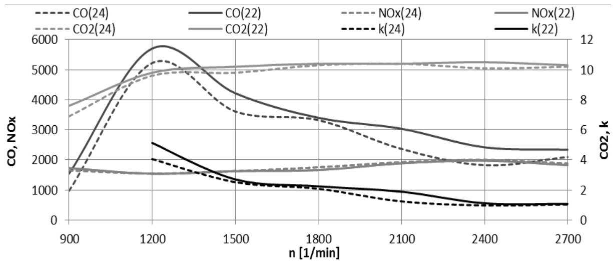

Fig. 1. Emission of toxic exhaust gas components for an engine fuelled with B20 biodiesel at two fuel injection pressure values: 22 and 24 MPa, in the function of crankshaft rotational speed

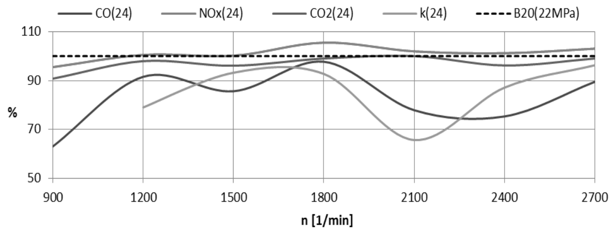

Fig. 2. Comparison of the percentages of toxic exhaust gas component emissions for an engine fuelled with B20 biodiesel at two fuel injection pressure values: 22 and 24 MPa (adopting the value of toxic exhaust gas component emissions at the fuel injection pressure of 22 MPa as a reference value, 100%), in the function of crankshaft rotational speed

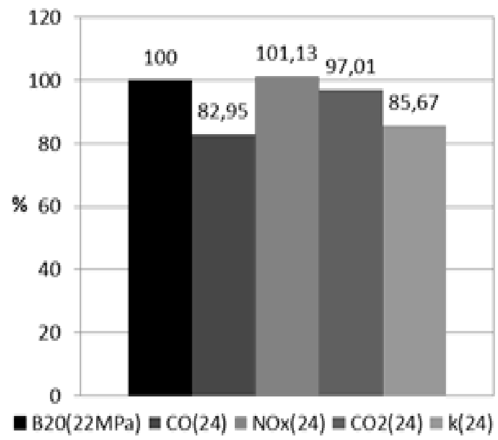

Fig. 3. Percentage presentation of the emission of toxic exhaust gas components for the engine fuelled with B20 biodiesel

Based on this, one can easily conclude what differences have occurred during the emission of exhaust gas at two fuel injection pressure values. The highest decreases have been reported for CO – over 17%, and absorption coefficient – over 14%. The least decrease has occurred for the CO_2 emission – less than 3%, whereas a small increase has occurred for the NO_x emission – slightly more than 1%.

When analysing the effect of fuel injection timing at the constant value of fuel injection pressure 24 MPa (Figs 4 and 5), it can be seen that there is a sharp decrease in the emission of toxic exhaust gas components with a reduction in this engine operating parameter, particularly in the case of the CO and NO_x emission and absorption coefficient “k”

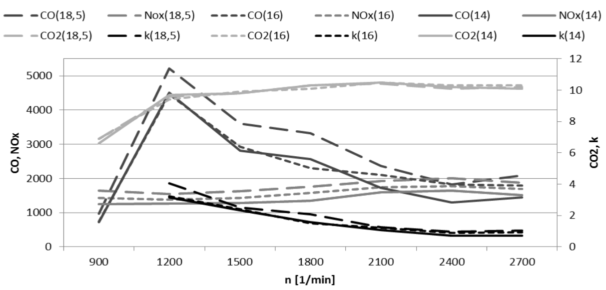

Fig. 4. Emission of toxic exhaust gas components for an engine fuelled with B20 biodiesel at different values of fuel injection timing: 14, 16 and 18,5° of crankshaft revolutions before TDC, in the function of crankshaft rotational speed

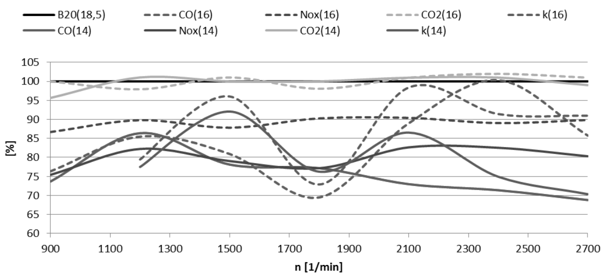

Fig. 5. Comparison of the percentages of toxic exhaust gas component emissions for an engine fuelled with B20 biodiesel at different values of fuel injection timing: 14, 16 and 18,5° of crankshaft revolutions before TDC (adopting the value of toxic exhaust gas component emissions at the ignition timing advance of 18.5° of crankshaft revolutions before TDC as a reference value, 100%), in the function of crankshaft rotational speed

(in relation to the assumed reference values – for the fuel injection timing of 18.5° of crankshaft revolutions before TDC, black horizontal line B20(18.5)). The CO_2 emission at different values of fuel injection timing maintains a similar level in the whole range of engine rotational speed. The highest decreases in the emission of toxic exhaust gas components are observed however for the value of fuel injection timing of 14° of crankshaft revolutions before TDC, which show decreases in all the emitted components in the range from 10 to 30%, except for the CO_2 emission.

CONCLUSIONS

There are possibilities for reducing the emission of toxic exhaust gas components generated by compression-ignition engines without changing their design but through the selection of control parameters, for instance by changing the value of fuel injection pressure or by changing the value of ignition timing advance. It was demonstrated in the conducted tests that an increase in the value of fuel injection pressure has a positive effect on the emission of toxic exhaust gas components. An almost 15% decrease in the value of absorption coefficient during engine operation was observed (instantaneous values reached in some cases even to 40%): almost a 18% decrease in carbon monoxide and a 3% decrease in carbon dioxide. The only reported increase was observed for nitrogen oxides, but at the level of 1% only. It must be remembered, however, that too high an increase in fuel injection pressure may have an adverse effect not only on engine operation but also on the service life of fuel supply system components because they will be exposed to a higher impact of forces occurring inside them.

In the case of lower values of fuel injection timing, significant decreases were observed in the emission of toxic exhaust gas components, particularly CO and NO_x or absorption coefficient "k"; it was only maintained at a similar level at different values of fuel injection timing. The conducted tests confirm the fact that by appropriate selection of engine control parameters we are able to reduce the level of emitted toxic exhaust gas components for a compression-ignition engine fuelled with biodiesel.

The performed analysis referred solely to the exhaust gas emission, not taking into account the differences occurring for engine operation parameters, such as torque, power output, or specific and hourly fuel consumption. By controlling engine operating parameters, they should be selected is such a way that the best possible engine performance is obtained at low fuel consumption in the

whole range of engine crankshaft rotational speeds and while maintaining the level of toxic exhaust gas components emissions as low as possible.

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WPŁYW WYBRANYCH PARAMETRÓW ROBOCZYCH SILNIKA ZS NA EMISJĘ TOKSYCZNYCH SKŁADNIKÓW SPALIN

Summary. W artykule przedstawiono analizę wpływu dwóch wybranych parametrów roboczych pracy silnika, (ciśnienie wtrysku paliwa oraz kąt wyprzedzenia wtrysku) na emisję toksycznych składników spalin silnika z zapłonem samoczynnym. Badania eksperymentalne zostały przeprowadzone na silniku Star 359 zasilanym biodiesel (B20), przy różnych wartościach ciśnienia wtrysku paliwa oraz różnych wartościach kąta wyprzedzenia wtrysku.

W wyniku badań hamownianych zostały wykonane charakterystyki emisji toksycznych składników spalin, które następnie poddano analizie.

Key words: silnik spalinowy, ciśnienie wtrysku paliwa, kąt wyprzedzenia wtrysku, biodiesel.