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INFLUENCE OF BIOFUELS ON DIESEL ENGINE PERFORMANCE

Abstract

In principle, emission reduction of toxic substances in exhaust gas of IC diesel engines can be achieved at three places: before, in and after the IC engine. The common approach is the introduction of catalytic exhaust systems, valve timing, fuel mixture preparation and combustion modeling, as well as using fuels the chemical composition of which provides the potential for reduction. The latter option seems to be the simplest, but it is not necessarily the first option that would be taken into consideration. Due to the different properties of fuels, it is necessary to optimize individual systems of the internal combustion engine; otherwise, it may happen that the reduction of emissions of toxic substances is absent as a desired effect, or, in the opposite extreme, unacceptable performance of the engine may result.

This paper provides an elaboration on the use of bio fuels in the form of rapeseed methyl esters - bio diesel, in terms of performance and the need for optimization of individual systems on internal combustion engines. That is a precondition for the effective use of bio fuels as the only fuel, and there is also a possibility of optimizing the engine system in order to achieve the best possible relative performance in case both fossil fuel and bio fuel are used.

Introduction

In the age of rising environmental awareness of the general population, obligatory provisions enshrined in the legislation are aimed at reducing the emission of toxic substances from the exhaust of road vehicles to the absolute minimum. However, in doing this, we also want to preserve the comfort stemming from the developed power of road vehicle engines (internal combustion engines). As a matter of fact, with the introduction of so-called auxiliary systems, energy needs are continuously increasing. There is a range of highly sophisticated technological solutions, covering every segment of engine construction, used by constructors in order to continuously decrease the levels of emission of regulated toxic substances from engine exhaust. Exhaust gas treatment is an indispensable technology in all road vehicles. Through the use of various types of catalytic converters, it allows us to decrease almost all emissions of toxic substances subject to regulations.

This technology is relatively easy to apply, by installing it to the exhaust system; however, there are limitations as well, visible in the fact that, due to the shortage of space in road vehicles, it is sometimes very difficult to place such systems appropriately, and their efficiency depends upon the quantity and content of exhaust gases. A very efficient method of decreasing toxic substance emissions from engine exhaust of the IC engine is the so-called combustion process management, which primarily depends on the method of forming the fuel mixture. When it comes to technological solutions of that kind, we need to point out high-pressure fuel injection systems (common rail); charging systems for IC engine (turbo-compressors); systems regulating the method of replacing the working matter (variable timing of opening and closing of inlet and exhaust valves); construction design of inlet and exhaust systems, as well as combustion chambers, with the aim of decreasing the resistance of flow, and focusing the flow of the working fluid, in order to achieve as good a mixture of fuel and air as possible.

Construction solutions, and the application of appropriate oils, can influence the internal resistance in IC engine to a significant degree, thus contributing to the decrease of energy consumption, and, therefore, fuel consumption as well.

The solutions we have just outlined are significantly hampered by certain limitations. That can primarily be seen in the fact that their application on already existing IC engines is technically impossible, or financially unfeasible. The solutions that can be offered for existing IC engines are based on the application of alternative fuels, and on optimizing engine operation for that fuel. However, there are differences between particular types of available alternative fuels, and the potential for decreasing toxic substance emissions from IC engine exhaust depends upon the origin of a fuel (basic raw material used for obtaining the fuel), and upon the properties of that fuel. Particularly interesting are alternative fuels with substances of biological origin as the basic raw material. In principle, the source of such fuels is unlimited, conditionally speaking. Raw material used for the procurement of biofuel can be continuously renewed, and, on top of that, biofuel also has a favorable impact on the emission of unregulated carbon dioxide (CO_2) from the exhaust of road vehicles, among its other properties. That means that the development of technologies for the procurement of biofuels creates preconditions for the development of economy independent of crude oil (new jobs, development of new areas of economy, etc.), and a positive impact on the environment is also achieved.

One common characteristic of all alternative fuels is the fact that IC engine parameters must be adjusted for the use such fuels, in order to be able to properly utilize the fuel potential. In most cases, a mere replacement of conventional fuel by an alternative fuel may even result in the worsening of toxic substance emissions and engine performance, which is unacceptable.

This paper elaborates on the experimental research aimed at determining the performance of IC engine for heavy-duty vehicles, and on optimizing the fundamental parameters of the engine when using biofuel as the basic fuel, or as an addition to fossil fuel.

Experimental part

The research presented in this paper is based on testing the IC engine with basic characteristics outlined in Table 1. The tested engine was a used engine that had been used in a city bus for the period of approximately 15 years prior to the testing. This engine is all the more interesting for testing purposes, given the fact that such engines are still in operation in a considerable number of buses.

Table 1: Basic parameters of the tested engine

Engine	aspirated, 4-stroke, with MAN fuel injection
Number of cylinders	6
Piston bore and stroke	125 mm x 155 mm
Displacement	11.413 dm^3
Compression	18:1
Static injection timing	23°CA before TDC
Nominal power	160 kW / 2200 min^{-1}
Torque	775 Nm / 1400 min^{-1}

The data outlined in Table 1 is the factory data, based on the use of fossil fuel-conventional diesel fuel.

The test itself was conducted on the test bed for internal combustion engine testing, which was placed in an adequate space (testing station), with connectors for all the required energy sources. Engine operation in the course of the testing was managed from the command center, which allowed for optical visibility of the tested engine during the testing procedure. All the equipment and systems for registering the level of measured parameters were located in the command center. The basic data on the test bed for IC engine testing is provided in Table 2.

Table 2: Test bed for IC engine testing

Brand / model	Zöllner / B – 350 AC
Type	Electric
Nominal torque	350 kW
Maximum rotation speed	6000 min^{-1}

On the basis of the goals of IC engine testing, the following parameters and measurements were covered by the testing:

- IC engine rpm
- IC engine torque (power at the brake)
- Fuel consumption per hour
- Fuel temperature, prior to the pump
- Stroke of fuel injector needle of the first cylinder
- Air flow
- Humidity of surrounding air
- CO emission

- Temperature of surrounding air
- Water temperature at engine inlet
- Water temperature in engine block
- Temperature of lubricating oil
- Temperature in exhaust gas collector
- Pressure in the first engine cylinder
- Pressure in air separator right at the entrance to engine, prior to inlet valve
- Pressure drop at air filter
- NO_x emission
- HC emission
- Soot in exhaust gas
- Barometric pressure
- Air temperature in the separator immediately prior to engine inlet
- Pressure in front of the air flow meter
- Pressure in high-pressure pipe of the first cylinder, immediately in front of the injector
- Indication of TDC position

On the basis of selected elements, it is possible to calculate the basic parameters of IC engine, such as power, specific fuel consumption, heat release characteristics, beginning of actual fuel thrust, etc., or their values adjusted for the condition of the standard environment during the testing period [1, 2, 3, 4, 5].

In the course of the testing, the following fuels were used: pure mineral diesel fuel D2, corresponding to the European norm EN 590; and pure biodiesel fuel, corresponding to the requirements of the European norm EN 14214, produced by the company Pinus – tovarna kemičnih izdelkov d.d. Rače. The basic characteristics of used fuels are shown in Table 3.

Table 3: Diesel and bio diesel properties

Fuel	Diesel	Biodiesel
Cinematic viscosity at 30 °C [mm^2/s]	3.34	5.51
Surface tension at 30 °C [N/m]	0.0255	0.028
Calorific value [kJ/kg]	43,800	38,177
Cetane number [-]	45-55	>51

On the basis of clearly different physical properties of fuels used, and on the basis of knowledge on the manner of biodiesel combustion in IC engine, the timing of the fuel injection start was changed as a parameter aimed at the optimization of engine operation depending on whether one or the other type of fuel is used. That is primarily connected with the fact that the combustion timing interval is somewhat lower for biodiesel (which can be linked with somewhat higher cetane number of biodiesel, as compared to diesel fuel) [6], and with the fact that the process of fuel injection is somewhat different (linked to the higher viscosity of biodiesel) [7, 8]. The recommended factory value of 23°CA before TDC was taken as reference value for injection timing. Test bed testing was performed for a relatively wide range of injection timing, which is, in essence, limited by the high-pressure pump itself, or by the possibility of adjusting the pump. For each determined fuel injection timing, the testing was performed first with the conventional diesel fuel, and then, for the same properties, with biodiesel fuel as well.

Upon comparing the obtained results, certain differences were noted, pointing to the need for adjustment of the fuel injection system, depending on the fuel used [9, 10, 11]. Given the fact that the tested IC engine, despite its relatively older design, is still in commercial use, in the continuation of this paper we will provide an overview of results for the injection timing that, based on our conclusions, provides optimal IC engine performance from the point of view of torque, power and fuel consumption, depending on whether fossil or biodiesel fuel is used, without the need to readjust the injection timing at the high-pressure pump when switching from one fuel to the other.

Results and elaboration

As we have already pointed out in the previous chapter, the testing of the IC engine with MAN fuel injection procedure was performed for various injection timing values, using both diesel and biodiesel fuel in a particular regime. Given the fact that power was kept at an approximately equal level when using diesel or biodiesel fuel, with the difference in the effective utilization degree within the tolerable range of 3 %, Figures 1 and 2 clearly show that the advantage in terms of fuel consumption, regardless of the fuel injection timing, is on the side of diesel fuel. The higher consumption of biodiesel fuel, in comparison with diesel fuel, is a consequence of its lower heating value [4, 8, 9], which means that the preservation of IC engine power was achieved by increasing the cyclical delivery of fuel.

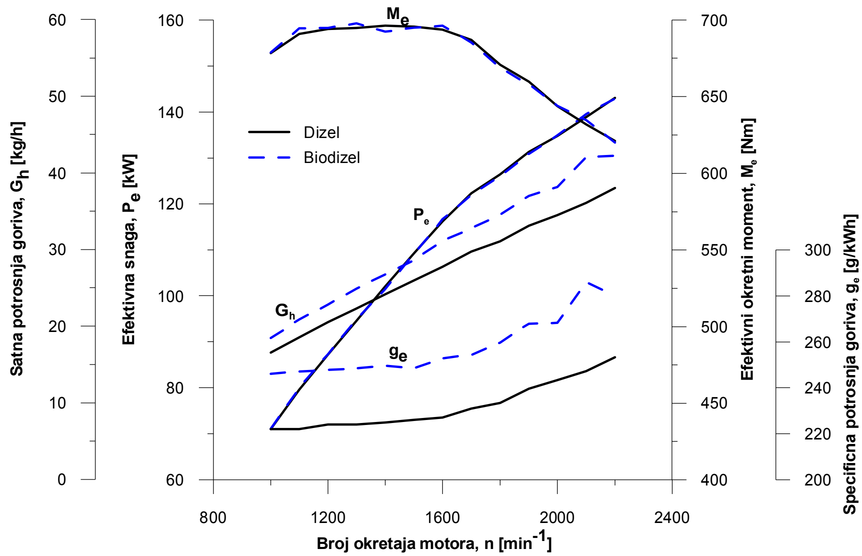

Figure 1: Effective power P_e, effective torque M_e, fuel consumption G_h and specific fuel consumption g_e for use of diesel and bio diesel fuels with injection timing of 23°CA before TDC

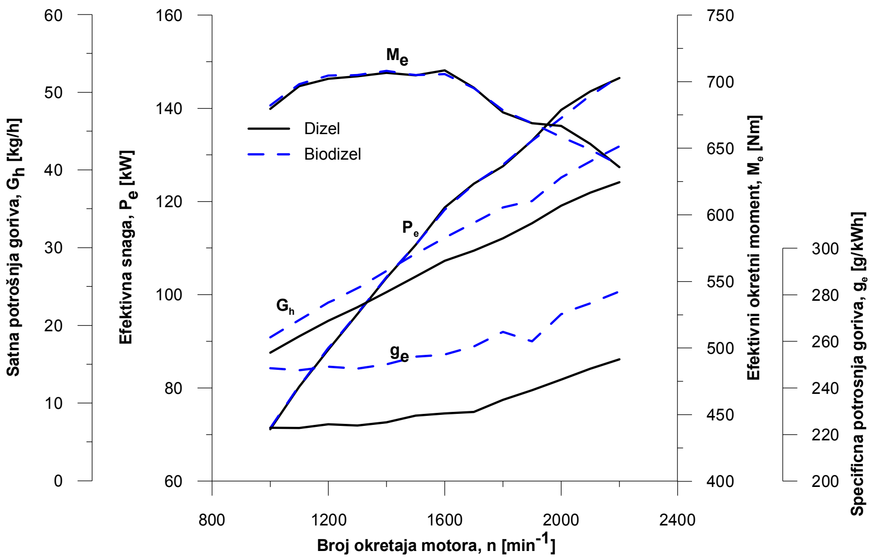

Figure 2: Effective power P_e, effective torque M_e, fuel consumption G_h and specific fuel consumption g_e for use of diesel and bio diesel fuels with injection timing of 21°CA before TDC

If one engages in a comparison of values discussed earlier, depending of fuel injection timing, but this time focusing on one and the same fuel, Figures 3 and 4 lead us to a clear conclusion that the decrease of injection timing from 23 °CA to 21 °CA results in an insignificant change to effective power P_e, or effective torque M_e, both for biodiesel and diesel fuel usage.

The choice of discussed fuel injection timing of 21°CA and 23°CA is a result of comprehensive research series conducted on the tested engine [10, 11, 12] with the aim of determining the optimum value of injection timing, which would result in maximum utilization of the benefits of biodiesel as engine fuel, while at the same time avoiding the worsening of output parameters of the same engine when conventional fossil diesel fuel is used. On the basis of that research [11], which included the measurements of all the relevant parameters, such as the flow of fuel and air, temperature of various fluids, pressure at all characteristic locations, and exhaust gas emissions, the conclusion was that the optimum timing for the use of solely biodiesel fuel is 19°CA before TDC, while the timing of 21°CA provides the best effects when both types of fuel are used.

In addition to this, measurements of the content of exhaust gases were performed as well. The measurements confirmed that, when using biodiesel fuel, CO and HC emissions are lower compared to the use of diesel fuel, while NO_x emission is somewhat higher [13].

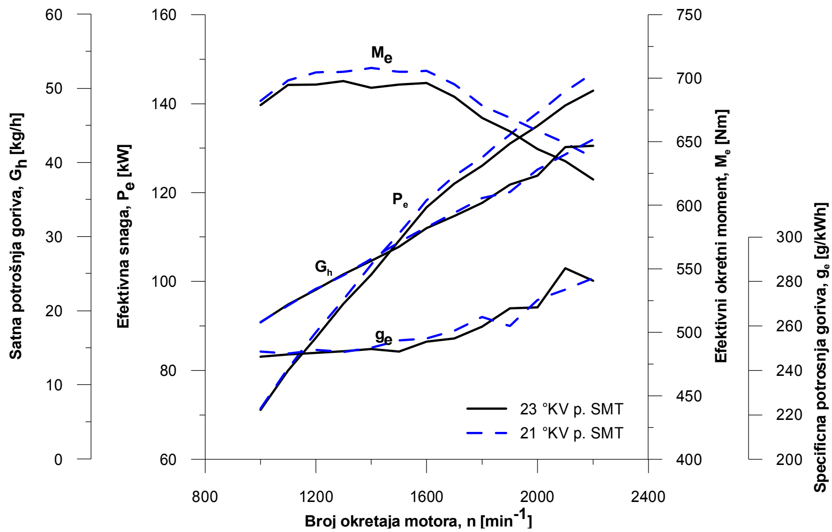

Figure 3: Effective power P_e, effective torque M_e, fuel consumption G_h and specific fuel consumption g_e for use of bio diesel fuel with injection timing of 21°CA and 23°CA before TDC

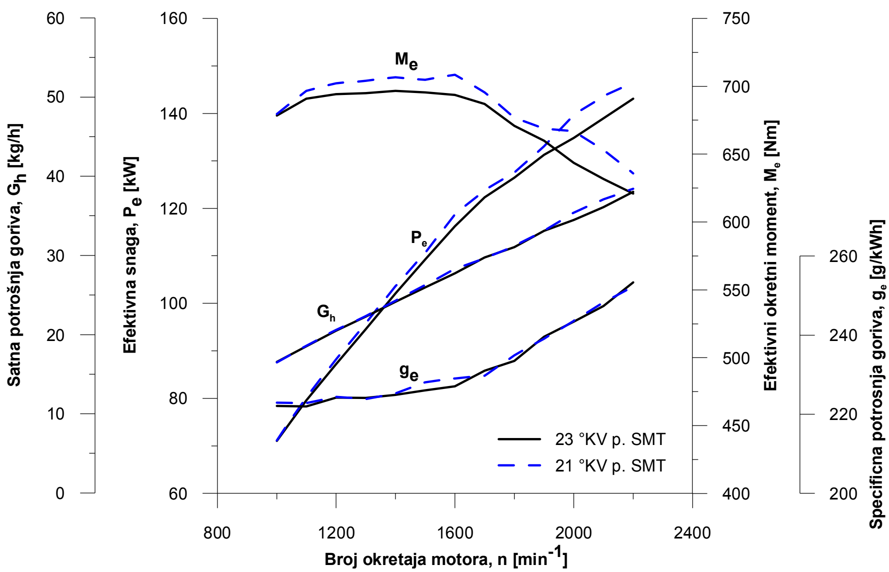

Figure 4: Effective power P_e, effective torque M_e, fuel consumption G_h and specific fuel consumption g_e for use of diesel fuel with injection timing of 21°CA and 23°CA before TDC

Conclusion

This paper has presented the results of testing the influence of basic IC engine parameters on engine performance, primarily from the point of view of power, torque and fuel consumption, when using fossil diesel fuel, and biodiesel fuel as a renewable energy source. We can conclude that the biggest impact is produced by the fuel injection timing, as a parameter that is relatively easy to adjust without direct construction interventions on the IC engine. Due to the evidently different physical properties, there are also phenomenological differences in the process of fuel delivery and fuel consumption; therefore, it is necessary to find an optimum level for the injection timing parameter when using only one fuel type, or both types. By decreasing the factory-recommended fuel injection timing, one can improve IC engine performance when using biodiesel, achieving the level of performance quite similar to the performance achieved by the IC engine operating with the fuel for which it is designed.

Alternative fuels from renewable energy sources undoubtedly possess a potential that makes them able to respond to all the requirements posed by IC engines, end users of road vehicles, as well as the legal provisions related to environmental protection. However, due to the infrastructure that is still poorly developed, and due to the expensive technology of production, it is very difficult to assume that such fuel will turn from an alternative fuel to conventional fuel without national and international incentives.

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621.436.019.8	kut predubrizgavanja dizelovog motora	diesel engine injection advance angle
665.334.94.094.942	biodizelsko gorivo EN14214	biobased diesel fuel EN14214
665.753.4.035	eurodizel gorivo D2, EN 590, aplikativna svojstva	eurodiesel engine fuel D2, EN 590, application properties

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