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ECOLOGICAL INDICATORS OF THE PERKINS 1104D-E44TA ENGINE AFTER ITS ADAPTATION FOR BEING POWERED WITH NATURAL GAS AND DIESEL FUEL

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Abstract

The contemporary progress of automotive industry and transportation is determined to a large extent by the increasing environmental requirements, aimed at limiting the harmful impact of vehicles upon human life and people's health. A crucial issue linked with operating vehicles is the exhaust gases generated by internal combustion engines. In order to reduce this hazardous impact upon the natural environment, the construction of the engines is continuously improved, electronic controlling is being developed for managing the course of working processes taking place in cylinders and auxiliary systems, exhaust gases cleaning systems are being developed, alternative fuels are being sought for and the possibilities of their optimal use are being examined. Natural gas is the fuel that is highly expected and hoped to be used more widely for powering internal combustion engines in vehicles. This article presents the values of selected ecological indicators of the Perkins 1104D-E44TA Diesel engine, powered by compressed natural gas and Diesel fuel (CNG + ON). For comparison reasons, the engine was powered with both fuels at the same time and then only by Diesel fuel (ON) in the same working conditions. Before the tests, the powering system control unit had been calibrated so as to enable obtaining similar values of torque while the engine was powered with the Diesel fuel only and with both CNG and ON while working with external speed characteristics; the calibration was also set up to allow for the maximum share of the natural gas in the total fuel amount supplied into the engine cylinders without engine knocking. When powering the engine with both CNG and Diesel fuel, the concentration levels of nitric oxides and carbon dioxide in exhaust gases were lower. However, the total content of hydrocarbons in the exhaust gases grew multiple times, and the content of the carbon monoxide was significantly increased. In addition, the obtained measurement results of the smokiness of the exhaust gases and the content of the soot with the engine powered with two fuels were not satisfactory.

Keywords: *piston combustion engines, engine fuels, harmful exhaust gases components, bi-fuelling, natural gas, experimental tests*

1. Introduction

The fuels for powering piston combustion Diesel engines should have good self-ignition properties. The fuel supplied to the cylinders, mixed with air during the compression process, must self-ignite before the piston reaches the top dead centre (TDC). Diesel fuels have such properties; obtained from oil, they are mixtures of hydrocarbons, with boiling temperature range between 180 and 360°C. These properties have been determining the development course of Diesel engines nearly since their invention. The alternative fuels to be used in Diesel engines should also have self-ignition properties, and vegetable oil esters demonstrate such characteristics [1, 6, 8]. Their chemical composition includes carbon, hydrogen and oxygen. The cetane number of the esters meets the requirements for Diesel fuels; the properties of vegetable oil esters make them suitable for powering Diesel engines in clear form or as an additive for Diesel fuels. The popular and available alternative fuels for piston internal combustion engines are hydrocarbon gas fuels, such as natural gas and the mixture of propane and butane, commonly known as LPG [4, 10].

2. Possibilities of powering Diesel engines with hydrocarbon gas fuels

The hydrocarbon gas fuels may be easily used for powering petrol engines. They are more resistant to engine knocking than conventional petrol. They have high ignition temperature, they mix easily with air, and the resulting mixture is uniform. The mixtures of hydrocarbon gas fuels and air have a broad range of ignition, which allows for combustion of lean mixtures. They have a lower calorific value of stoichiometric values when compared to conventional liquid fuels. Moreover, they are more difficult to store due to their properties arising from their state of matter in ambient conditions. They require an auxiliary feeding system to be installed, which generates additional costs. The hydrocarbon gas fuels are much more difficult to use for powering Diesel engines, as the fuels are very resistant to self-ignition. Since these fuels are usually much more affordable and available, in particular the LPG, the feeding systems have been developed which allow for using them in Diesel engines. There are two methods of using the hydrocarbon gas fuels, i.e. LPG and natural gas, for powering Diesel engines. The first one is adopting the engine for such fuels. The compression ratio is lowered and the ignition system is installed. After that, the engine cannot be powered with Diesel fuel, and the engine itself demonstrates the properties of petrol engines. Another method of using the gas fuels for powering is bi-fuelling with both gas fuel and Diesel fuel at the same time [2, 9, 11]. Then, the gas-air mixture is supplied into the cylinders, and its ignition is triggered by a liquid fuel with good self-ignition properties, injected into cylinders at the end of the compression stroke. The amount of the injected fuel is adequately decreased, depending on the amount of the supplied gas fuel. This is a universal solution, as it allows for fuelling the engine with the conventional fuel when the gas fuel is not available. When setting the proportions between the gas and liquid fuels supplied into the cylinders, one has to take note of the possible engine knocking, which may result in the engine damage.

3. Tested item

The tested item was the PERKINS 1104D-E44TA piston internal combustion Diesel engine, with a direct injection system. The engine is equipped with a broadly used Common Rail injection system, with electronically controlled electromagnetic injectors [2]. On the basis of the information from the sensors, specifying the ongoing engine operation parameters, such as engine load and crankshaft rotational speed, the electronic control unit determines the amount of the injected fuel, controlling the value of the pressure in the fuel tank as well as the injection time. The amount of the injected fuel per one work cycle of the engine is divided into two parts. First, a small amount of fuel (so called pre-injection) is injected. It evaporates quickly, transforming into the fuel-air mixture, which self-ignites. This creates the conditions for the injection of the main dose, which allows for quicker ignition and combustion. This helps smoothen the pressure course in the cylinder, as well as to influence the course of the combustion process. A turbocharger is installed in the engine's intake system, controlled electronically by the control unit. It allows for providing more air into the cylinders in the broad range of the crankshaft's rotational speed. The solutions used in the fuel feeding system and in the engine's intake systems enabled to increase the engine's power obtained from the engine's cubic capacity. In addition, the engine meets the Tier 3 exhaust gases emission requirements for non-road use engines. The PERKINS 1104D-E44TA engine at the engine-testing bench has been equipped with the OSCAR-N DIESEL CNG feeding system. It enables interchangeable feeding of either ON only or bi-fuelling with CNG and ON. The essential technical data of the tested engine are found in Tab. 1.

4. Test stand

The test was conducted at the engine testing station, installed in the Laboratory of Thermal Engines of the Kielce University of Technology. The test stand comprised the PERKINS 1104D-

E44TA Diesel engine, which can be powered either with Diesel fuel only or with both Diesel fuel and natural gas (CNG + ON). The engine at the testing station included the eddy current brake AMX – 200/6000, manufactured by ELEKTROMEX CENTRUM, with 200 kW power. The testing station was equipped with the computer workstation, AUTOMEX software for controlling, checking and visualising testing processes. Also installed is the Automex inertial fuel dosimeter, which allows for precise measurements of the engine's ON consumption. The hourly use of natural gas is measured at the testing station by means of the Emerson gas flow meter, operating on the basis of the Coriolis effect. Changes of working parameters are made by means of the control module, installed in the testing station control room. The analysis of the engine's exhaust gases was carried out by means of the Horiba analysers: MEXA-1600DEGR [12], MEXA-1230 PM [3, 7] and AVL DiCom 4000 PL [5]. Fig. 1 presents the flowchart of the testing station with the PERKINS 1104D-E44TA engine.

Tab. 1. Basic technical data of the Perkins 1104D-E44TA Diesel engine [2]

Parameter	Unit	Value
Cylinder arrangement	–	straight
No of cylinders	–	4
Injection type	–	direct
Type of fuel system	–	Common Rail
Max. engine power	kW	96.5
Engine speed at maximum power	rpm	2200
Max. torque	Nm	516.0
Engine speed at max. torque	rpm	1400
Engine cubic capacity	m^3	$4.4 \cdot 10^{-3}$
Cylinder diameter	mm	105
Piston stroke	mm	127
Compression ratio	–	16.2
Air supply system	–	turbocharger, intercooler

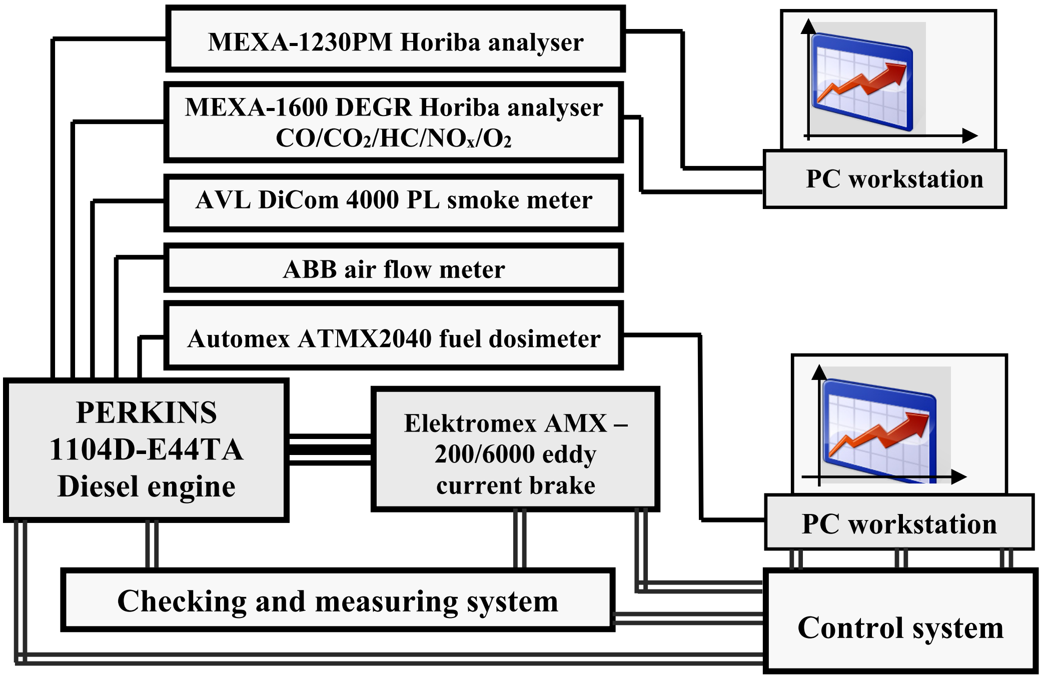

Fig. 1. Testing station flowchart

5. Test results

Before the tests, the system of powering the Perkins 1104D-E44TA engine with compressed natural gas and Diesel fuel was calibrated with the aim of determining proportions between the amount of supplied natural gas (CNG) and the amount of the Diesel fuel (ON). The optimisation criterion was to obtain the comparable values of the torque while the engine is bi-fuelled and when it is powered by Diesel fuel only as well as preventing engine knocking and temperature increase with engine operating under external work characteristics. Having measured the hourly Diesel fuel consumption and hourly natural gas consumption, it was possible to calculate the total hourly consumption of the bi-fuelled engine (CNG+ON). Fig. 2 presents the comparison of the hourly and specific fuel consumption of the tested engine, bi-fuelled with natural gas and Diesel fuel as well as with Diesel fuel only as it worked under the load characteristics for crankshaft rotational speed of n = 1400 and 2200 rpm. When powering the engine with CNG and ON, the hourly and specific fuel consumption values were higher than with the ON only. The mass fraction of the CNG was calculated in the total mass of fuel supplied into the bi-fuelled (CNG+ON) engine. Also calculated was the amount of supplied energy, contained in the gas as well as the liquid fuel. On that basis, it was possible to calculate the share of energy supplied into the engine by the CNG in the total amount of energy supplied into the engine powered with both fuels (CNG+ON). These portions are presented on Fig. 3. As the engine load increases, the amount of natural gas supplied into the cylinder decreases considerably. Such proportions result from the possible occurrence of engine knocking and temperature growth of exhaust gases with the increasing engine load.

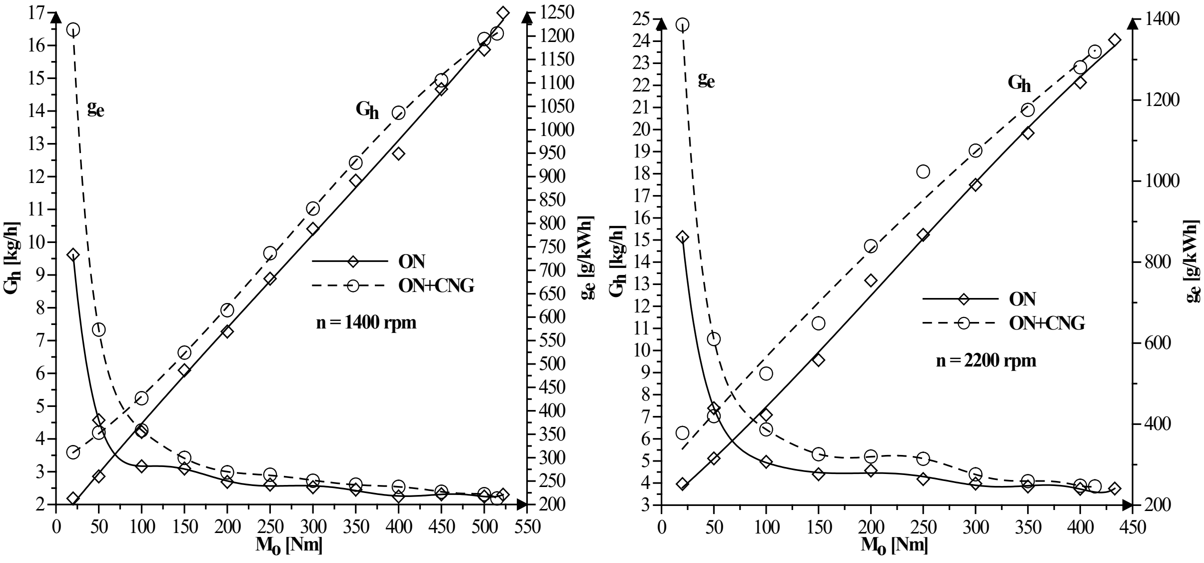

Fig. 2. Load characteristics of the Perkins 1104D-E44TA engine bi-fuelled with CNG and ON as well as with the ON only; at crankshaft rotational speed of n = 1400 and 2200 rpm

Figure 4 presents the comparison of the concentration values of the carbon oxide in the Perkins 1104D-E44TA engine exhaust gases, bi-fuelled with CNG and ON as well as with the ON only, operating under the load characteristics. With the engine fuelled with the ON only, the concentration level of the carbon oxide was considerably lower in the exhaust gases. An opposite result was obtained when measuring the concentration level of the carbon dioxide CO_2 in the exhaust gases of the tested engine. When it was bi-fuelled with CNG and ON, the concentration levels of carbon dioxide was lower than with engine being fuelled with the ON only. Fig. 5 presents the comparison of the carbon dioxide concentration levels in the Perkins 1104D-E44TA engine as it is bi-fuelled with CNG and ON as well as with the ON only.

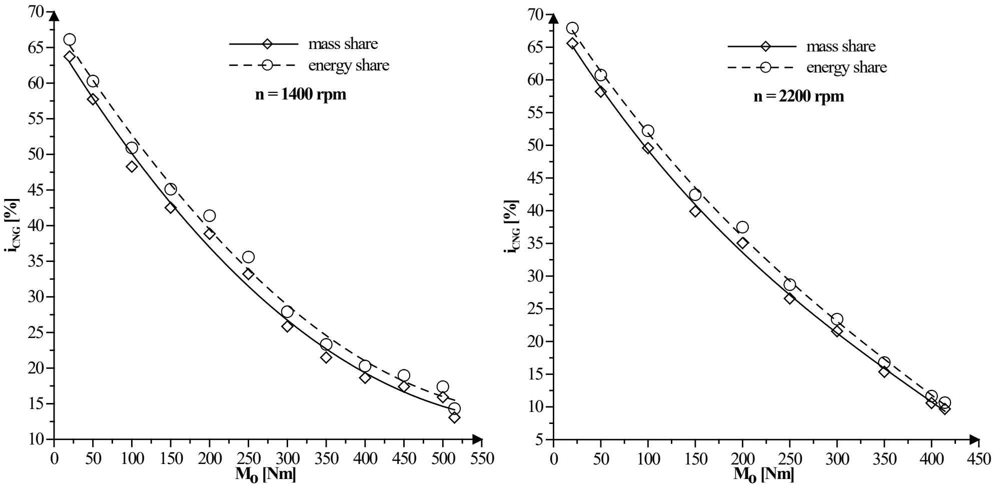

Fig. 3. Mass and energy share of the compressed natural gas in total amount of fuel supplied into the cylinders of the Perkins 1104D-E44TA engine, bi-fuelled with CNG and ON, operating under the load characteristics for the crankshaft rotational speed of n = 1400 and 2200 rpm

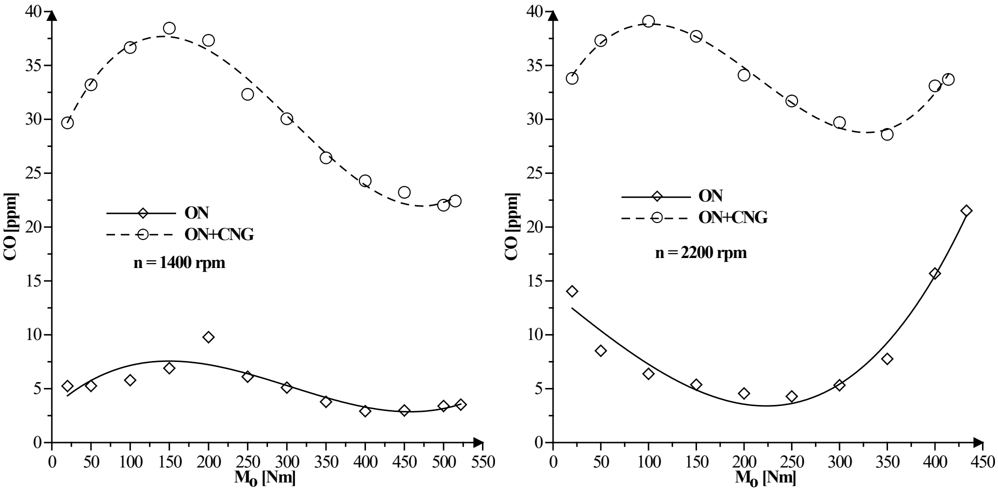

Fig. 4. Comparison of the concentration levels of the carbon monoxide CO in the exhaust gases of the Perkins 1104D-E44TA engine, operating under the load characteristics for the crankshaft rotational speed of n = 1400 and 2200 rpm, and bi-fuelled with CNG and ON as well as with the ON only

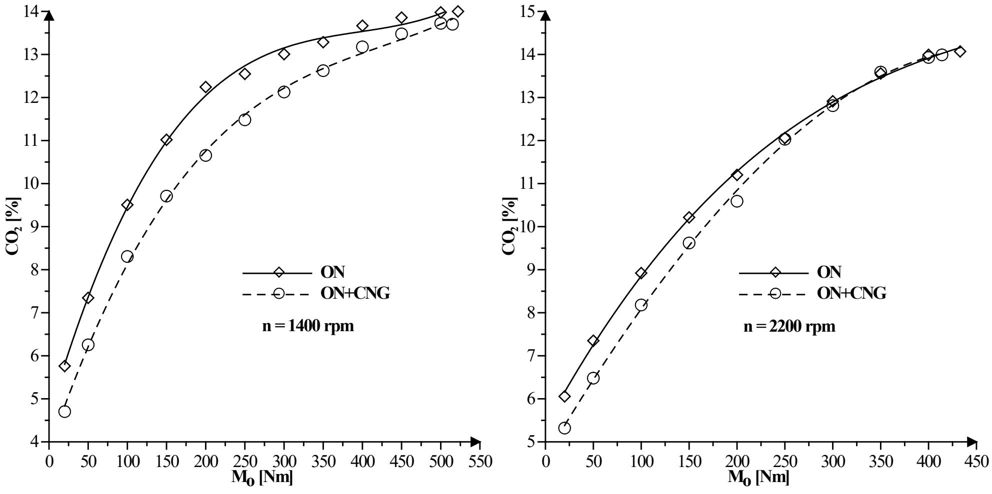

Fig. 5. Comparison of the concentration levels of the carbon dioxide CO_2 in the exhaust gases of the Perkins 1104D-E44TA engine, operating under the load characteristics for the crankshaft rotational speed of n = 1400 and 2200 rpm, and bi-fuelled with CNG and ON as well as with the ON only

A positive outcome of using natural gas for powering the Diesel engine as it is bi-fuelled with CNG and ON is the reduction of concentration levels of nitric oxides NO_x in the exhaust gases. Fig. 6 presents the comparison of the concentration levels of nitric oxides in the exhaust gases of the Perkins 1104D-E44TA engine as it is bi-fuelled with CNG and ON and with the ON only. As regards the total concentration level of hydrocarbons in the exhaust gases, it increased multiple times when compared to the exhaust gases of the engine powered with the ON only. The concentration of the THC hydrocarbons in the exhaust gases of the bi-fuelled engine decreases with the lower engine load. It is mainly contributed by the fact that the share of the gas fuel supplied to the engine declines with the increasing engine load, and the combustion process temperature increases. Fig. 7 presents the concentration measurement results of total content of the unburned THC hydrocarbons in the exhaust gases of the Perkins 1104D-E44TA engine, bi-fuelled with CNG and ON and with the ON only. During the tests, the smokiness of the Perkins 1104D-E44TA engine exhaust gases was measured. With both CNG and ON supplied and the engine's operation under the load characteristics with the crankshaft rotational speed of n = 1400 and 2000 rpm, the smokiness of exhaust gases was larger than when the engine was powered with the ON only. Fig. 8 demonstrates the measurement results of the exhaust gases smokiness.

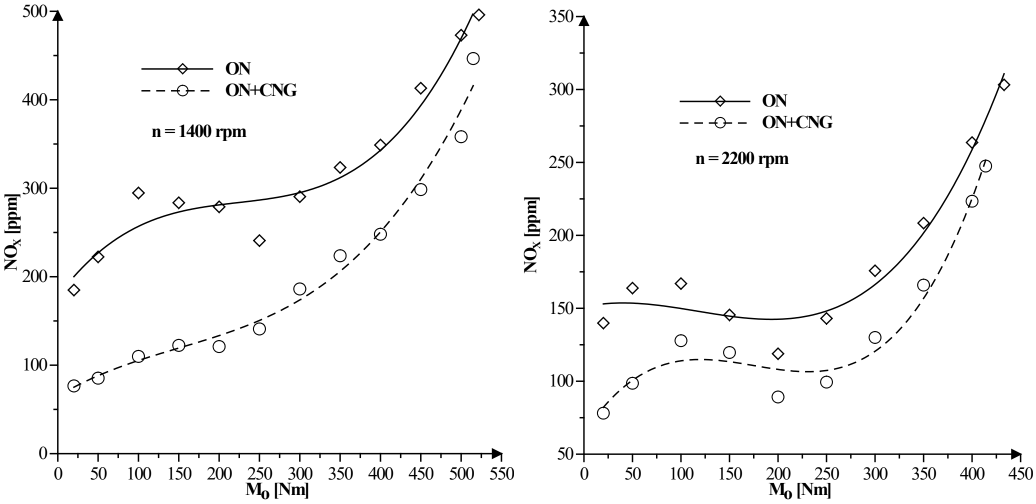

Fig. 6. Comparison of the nitric oxides NO_x concentration levels in the exhaust gases of the Perkins 1104D-E44TA operating under load characteristics for the crankshaft rotation speed of n = 1400 and 2200 rpm, and bi-fuelled with CNG and ON as well as with the ON only

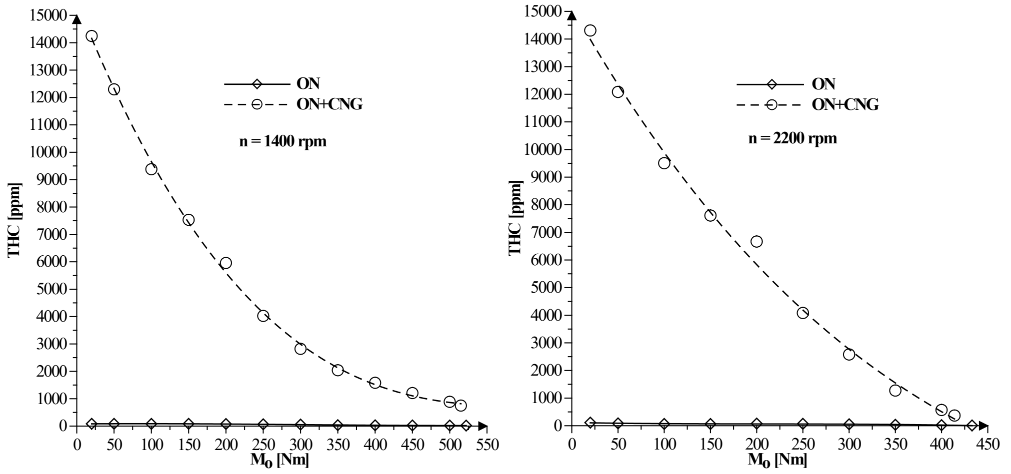

Fig. 7. Comparison of the concentration of total hydrocarbons THC in the exhaust gases of the Perkins 1104D-E44TA engine, operating under the load characteristics for the crankshaft rotational speed of n = 1400 and 2200 rpm, bi-fuelled with CNG and ON and with the ON only

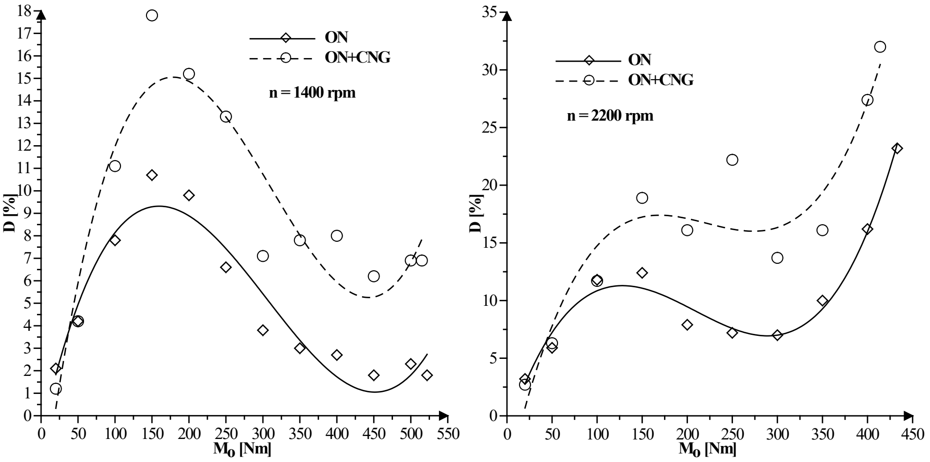

Fig. 8. Comparison of the smokiness of the exhaust gases of the Perkins 1104D-E44TA engine, operating under the load characteristics for the crankshaft rotational speed of n = 1400 and 2200 rpm, and bi-fuelled with CNG and ON as well as with the ON only

During the tests, the content of soot in the exhaust gases was measured by means of the Horiba's MEXA-1230PM analyser. The results are presented on Fig. 9. With the engine operating under the load characteristics for the crankshaft rotational speed of n = 1400 rpm, and when supplying both CNG and ON, the concentration levels of soot in the exhaust gases for the majority of measurement points were lower than those when the engine was powered with the ON only. The soot concentration levels for this load characteristics and with the engine powered with the ON were lower only at the highest engine loads. With the engine operating under the load characteristics for the crankshaft rotational speed of n = 2200 rpm and with supplying both CNG and ON, the soot concentration levels in majority of the measurement points were higher than with the engine being fuelled with the ON only.

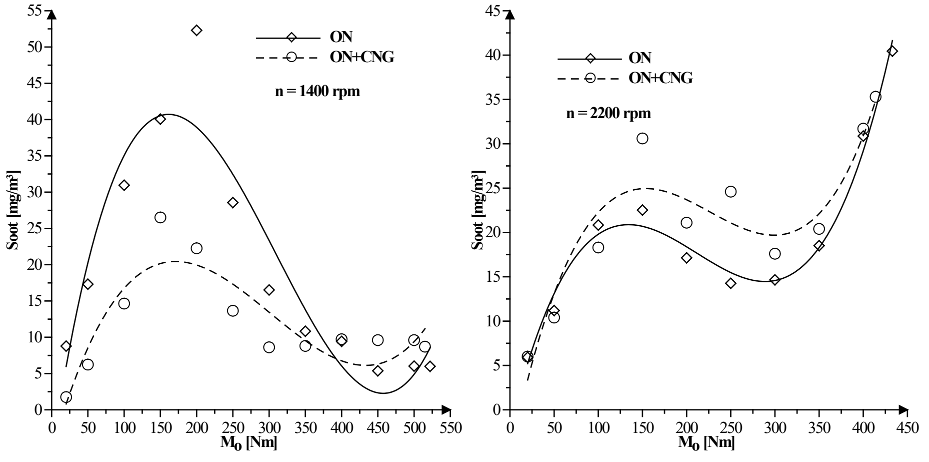

Fig. 9. Comparison of the soot content in the exhaust gases of the Perkins 1104D-E44TA engine, operating under the load characteristics for the crankshaft rotational speed of n = 1400 and 2200 rpm, and bi-fuelled with CNG and ON as well as with the ON only

6. Summary

The Perkins 1104D-E44TA engine has been adopted for bi-fuelling with the compressed natural gas and Diesel fuel (CNG+ON). Before the tests, the control unit of the bi-fuelling system was calibrated in such a way to obtain the highest possible share of the gas fuel in the total amount of fuel supplied into the engine cylinders. The gas fuel dose was limited by the possible occurrence of the engine knocking as well as by the temperature of the exhaust gases, which was not to exceed the temperature of the exhaust gases of the engine being fuelled with the ON only. With the engine bi-fuelled with CNG and ON, the concentration levels of nitric oxides and carbon dioxide in the exhaust gases were lower when compared to the engine being powered with the ON only. Other ecological parameters of the bi-fuelled engine were worse than when the engine was powered with the ON only. First of all, when the Perkins 1104D-E44TA engine is bi-fuelled with CNG and ON, the concentration levels of total hydrocarbons in exhaust gases are significantly higher than with the engine being powered with the ON only. This is likely caused by the increased content of methane in the exhaust gases, which does not burn completely. Natural gas is a greenhouse gas with a higher global warming potential than the carbon dioxide. In order to reduce the methane content level in the engine's exhaust gases, it would be necessary to modify the process of injecting Diesel fuel, which initiates the combustion process, as well as the composition of the fuel-air mixture. When the engine was bi-fuelled, the emission of the carbon monoxide was considerably higher, as was the smokiness of the exhaust gases. It suggests poorer conditions for the combustion process in the engine's cylinders, the outcome of which is higher incomplete combustion.

The Perkins 1104D-E44TA engine, fitted with the Common Rail fuelling system has been adopted for effective combustion of the Diesel fuel. Its adoption for bi-fuelling has resulted in worsening of the ecological indicators of the engine work indicated above, when compared to the engine fuelled with the ON only. This suggests that further research is required, aimed at improving the conditions for the combustion process for the modern Diesel engines powered with two fuels.

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