NITROGEN OXIDES CONCENTRATIONS AND HEAT RELEASE CHARACTERISTICS OF THE PERKINS 1104D-E44TA DUAL-FUEL ENGINE RUNNING WITH NATURAL GAS AND DIESEL

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Abstract

In the near future, natural gas may become a fuel, which will see increased use in powering internal combustion engines. Due to its properties, it can be used to power spark-ignition engines without major obstacles. Yet using natural gas to power compression-ignition engines proves to be more difficult. One of the possibilities are the dual-fuel compression-ignition engines running with gas fuel and diesel fuel, enabling ignition through compression and combustion of gas fuel. The article presents the heat release characteristics of the Perkins 1104D-E44TA engine powered by compressed natural gas and diesel fuel. Characteristics of heat release are an image of the combustion process. They affect the engine performance indicators. The determined heat release characteristics for a dual-fuel-powered engine were compared with the heat release characteristics for a diesel engine under the same operating conditions. An analysis of heat release characteristics was carried in the scope of their influence on the concentration of nitrogen oxides in the exhaust of the tested engine. The effect of the relative amount of heat released and the heat release rate during the combustion process in the Perkins 1104D-E44TA engine cylinder running dual-fuel with CNG+diesel on the concentration of nitrogen oxides in the exhaust, as compared to the values measured when running with diesel fuel only, was demonstrated. Higher share of natural gas in the total amount of energy supplied to the engine cylinders results in greater differences in the course of the combustion process and result in a greater reduction in the concentration of nitrogen oxides in the exhaust of the tested engine.

Keywords: engine fuels, dual-fuel engine, natural gas, nitrogen oxides, heat release characteristics

1. Introduction

Compression-ignition engines are widely used for propulsion of heavy vehicles in road transport. Their advantageous features, such as higher efficiency, lower fuel consumption and lower operating costs, have also led to a very broad application for

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the propulsion of passenger cars. The main problem of modern compression-ignition engines is the emission of nitrogen oxides and particulate matter. Due to ecological requirements, the compression-ignition engines currently in use have been equipped with modern fuel injection systems, turbocharging systems and complex exhaust filtering systems. This has made these engines very dependent on fuel quality and operating conditions, and the cost of possible repairs is high. Some postulates are made on the withdrawal of compression-ignition engines from production and use. According to the authors, this is unlikely to happen in the coming years, especially in the case of lorries, buses, motorised machinery and other vehicles with off-road applications.

There is a need for further development of diesel technology. We could strive to create conditions for combustion delivered to fuel cylinders where emissions of particulate matter and other harmful components of exhaust gases and fuel consumption will be further reduced. Modern day compression-ignition engines have been adapted for running diesel fuels obtained from crude oil. The fuels are mixtures of many different hydrocarbons boiling at temperatures ranging from 150°C to 280°C [9]. From the point of view of the capability of a compression-ignition engine, the most important feature of fuel is its ability to form a fuel-air mixture and its self-ignition through compression. When looking for alternative fuels to power these engines, one should certainly consider the compression-ignition capabilities after mixing them with air and compressing the resulting mixture in the cylinder.

Fatty acid esters of vegetable oils are an alternative fuel, which can be used to power diesel engines without any major obstacles. Their physical and chemical properties are similar to those of diesel fuels. They are characterized by a high cetane number. After application of appropriate additives, they can be used in various climatic conditions to power the engines. In order to ensure their proper use, they must meet the standards [32]. Their use does not require any structural changes in the engine and its fuel injection system. Depending on the latitude, esters are obtained from various vegetable oils [8, 25, 27, 34, 35, 36, 45]. Waste fats from catering and food processing industry can also be used for their production [5, 10, 16, 20, 21]. Esters can also be obtained from animal fats [2, 17, 23, 41]. Raw materials for obtaining esters other than those originally intended for food production are also sought [11, 15, 19]. Esters obtained from various raw materials are the subject to a wide array of research and analyses aimed at testing their capabilities of powering compression-ignition engines, which are used [14, 28, 29, 37, 33].

Vegetable fuels, due to their availability, will not replace diesel fuel. They can only be used, to a limited extent, to supplement it. Recently there has been an increasing interest in natural gas as a fuel for supplying piston combustion engines used in transport [18, 22, 24, 38, 42]. It can be used without any major problems to power spark-ignition engines. More complications occur in case of compression-ignition engines. Natural gas has a high octane number. Its mixture with compressed air in the cylinder does not self-ignite upon compression. An ignition source is required. One of the possibilities of igniting the compressed natural gas-air mixture is an injection of diesel fuel. It self-ignites and initiates the process of combustion of gas fuel. Engines in which two fuels are combusted simultaneously within cylinders are referred to as dual-fuel engines in literature. Dual-fuel engines running natural gas and diesel are currently the subject of numerous studies. The efficient and ecological indicators of compression-ignition engines adapted to run simultaneously on gas fuel and conventional diesel fuel are determined and analysed [4, 13, 31, 30, 39]. In these studies, attention is also drawn to the course of the combustion process presented in the form of graphs of heat release rate [1, 12, 40, 44, 46]. It has a significant impact on the pressure of the working medium in the cylinder, and thus on the engine operation indicators. The heat release process and the pressure in the engine cylinder can be shaped by controlling the fuel injection process [3, 43].

2. Object of the study

The object of the study was a compression-ignition internal combustion engine with direct fuel injection – PERKINS 1104D-E44TA. This engine is equipped with a widely used Common Rail fuel injection system with electromagnetic injectors. On the basis of information provided by the sensors determining the current engine operating conditions, the electronic control unit calculates the injected fuel dose by controlling the value of pressure in the fuel accumulator and the opening time of injectors. The injected fuel dose per engine combustion cycle is divided into two parts. First, a small amount of fuel is injected, the so-called pre-injection, followed by the main dose. There is an electronically controlled turbocharger in the engine's intake system. Table 1 shows the basic technical data of the tested engine.

The PERKINS 1104D-E44TA engine on an engine test stand was equipped with the OSCAR-N DIESEL compressed natural gas supply system. It provides the means of running the engine in dual-fuel mode, i.e. compressed natural gas and diesel fuel at the same time. The tested engine still has all the characteristics of a compression-ignition engine and may only be powered with the diesel fuel for which it has been factory-fitted. Gas fuel is injected into the engine intake system after the turbocharger, and before the intercooler, by means of four injectors mounted on a common rail. After passing through the intercooler, the mixture of natural gas and air is supplied to the engine cylinders. Its ignition in the cylinder is possible due to the injection of diesel fuel at the end of the compression process. The amount of injected diesel fuel depends on the amount of gas fuel supplied and on engine operating conditions.

Tab. 1. Basic technical data of the Perkins 1104D-E44TA diesel engine

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

Tab. 1. Basic technical data of the Perkins 1104D-E44TA diesel engine; cont.

Parameter	Unit	Value
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

3. Engine test stand

The tests were carried out on an engine test stand located in the Heat Engine Laboratory (Laboratorium Silników Cieplnych) at the Kielce University of Technology. The station consisted of the tested PERKINS 1104D-E44TA compression-ignition internal combustion engine, which can be powered by diesel fuel or diesel and natural gas simultaneously in the dual-fuel operation mode. The basic elements of the station, such as: engine and brake with complete control, as well as systems enabling engine operation, are placed on a common frame. Electro-mechanical brake type AMX – 200/6000, manufactured by ELEKTROMEX CENTRUM can receive 200 kW of power from the engine and transmit 700 Nm of torque. The engine test stand is equipped with a desktop computer running Automex software to control, inspect and visualize the course of tests. The measurement of diesel fuel consumption of the tested engine is carried out with the use of the ATMX2040 mass fuel gauge manufactured by Automex. Hourly consumption of natural gas is measured at the stand using the Emerson gas flow meter, the operation of which is based on the Coriolis effect. Accurate measurement of the mass of air supplied to the cylinders is carried out using an ABB flow meter. Pressure in the engine cylinder was measured using the AVL IndiSmart 612 indicating system. Concentrations of basic components of exhaust gases were determined with the use of the MEXA-1600DEGR research exhaust analyser. It enables continuous, real-time measurement of the basic components of the exhaust. In addition to the original system, the engine control room is equipped with NIRA research controller for compression-ignition engines. This controller provides access to the configuration of engine control parameters selected during engine's ECU tuning: injection system control, injection times and phases, fuel injection pressure, turbocharging system control, exhaust gas recirculation and other elements of engine operation. Parameters can be changed by means of the PC located in the control room of the test stand. The block diagram of the engine test stand with PERKINS 1104D-E44TA engine is shown in Figure 1.

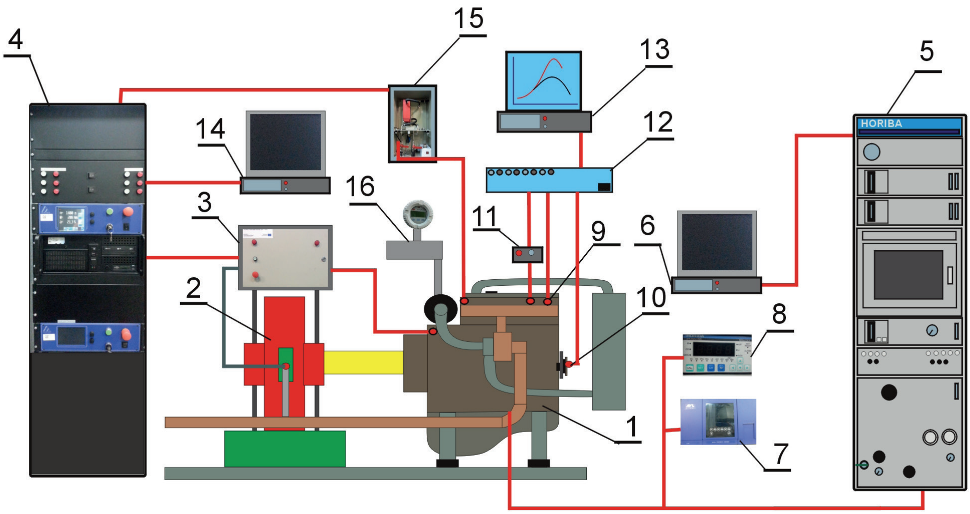

Fig. 1. Test stand flowchart: 1- Perkins 1104D-E44TA engine, 2 – Automex AMX 200/6000 brake, 3 – measurement module, 4 – measurement cabinet with test stand control system, 5 – Mexa-1600DEGR exhaust analyser (manufactured by Horiba), 6 – computer that records the exhaust gases analysis results, 7 –AVL Dicom 4000 smoke meter, 8 –AFR Analyzer Mexa-730 l AFR (air-fuel gauge) (Horiba), 9 – cylinder pressure sensor AVL, 10 – AVL 365C crankshaft rotation angle encoder, 11 - system for measuring the current controlling the operation of the injector, 12 – AVL IndiSmart 612 system for indicating quick-changing values, 13 – computer for the quick-changing values measurement system, 14 – computer for controlling the parameters of the test stand and for storing test results, 15 – Automex ATMX2040 inertial fuel dosimeter, 16 – ABB inertial air flow meter

4. Research methodology

The aim of this article is to show the relationship between the concentration of nitrogen oxides in the exhaust of the Perkins 1104D-E44TA engine and the heat release characteristics of the engine when running compressed natural gas and diesel fuel simultaneously and diesel fuel only. During the experimental tests, the tested engine operated according to its external speed characteristics, i.e. at the maximum possible load, at different crankshaft speeds. These conditions are conducive to a significant emission of nitrogen oxides, which are intensively formed at high temperatures and the presence of excess oxygen. In addition, the tests were carried out with the engine running according to the load characteristics for crankshaft speed at $n = 1800$ rpm. During the tests under the same operating conditions, the engine was powered by diesel fuel only and by compressed natural gas and diesel fuel – dual-fuel operation. During the tests on the engine test stand the following values were measured: hourly consumption of diesel fuel, hourly consumption of natural gas, torque, nominal power, concentrations of basic components in the exhaust, including nitrogen oxides. Moreover, the pressures in the cylinder of the tested engine were recorded for fifty consecutive cycles under the set operating conditions. For further analysis, index charts averaged over fifty cycles were used.

5. Heat release characteristics

The working medium in the engine cylinder, before the start of the combustion process is a mixture of fuel and air. During the fuel combustion process, heat is released, which causes changes in pressure and temperature of the working medium inside the engine cylinder. The course of heat release has an impact on, among other things: speed of pressure build-up during combustion, maximum values of pressure and temperature inside the cylinder, mechanical and thermal loads of engine components and energy, economic and ecological indicators of the engine's operation. Heat release characteristics in publication [6] are defined as the quotient of heat released until the present moment of time and the total amount of heat delivered to the cylinder with fuel in the analysed work cycle. The above relation can be presented in a mathematical form:

$$x = \frac{Q(\alpha)}{g_c \cdot W_u} \tag{1}$$

where: $Q(\alpha)$ – the amount of heat released until the present, g_c – the dose of fuel supplied in one engine work cycle, W_u – the calorific value of fuel.

With the hourly fuel consumption measured during the experimental tests, the amount of fuel burned during one engine work cycle is calculated using the equation:

$$g_c = \frac{G_h}{30 \cdot n \cdot c} \tag{2}$$

where: G_h – hourly fuel consumption, n – engine crankshaft speed, c – number of engine cylinders.

The heat release characteristics shall be determined on the basis of indicator charts. The most frequently used for this purpose are averaged indicator charts from successive cycles, measured under the specified engine operating conditions. In the paper the heat release characteristics were determined assuming that the combustion process ended with the opening of the exhaust valve and that the total value of the relative amount of heat released during the combustion process is equal to unity [6, 7]. The equation of the First Law of Thermodynamics for processes taking place in the engine cylinder can be written in the following form:

$$dQ_x = dU + pdV + dQ_{str} \tag{3}$$

where: dQ_x – amount of heat released in the cylinder until the present, dU – change of internal energy of the working medium in the cylinder, pdV – work performed in the cylinder by the working medium, dQ_{str} – heat lost, among others, to the cylinder walls as a result of incomplete combustion and as a result of the dissociation phenomena.

The amount of heat released in the cylinder until the current time can be calculated from the equation:

$$dQ_x = g_c \cdot W_u \cdot dx \tag{4}$$

The total amount of heat that can be released during the combustion process in the cylinder can be calculated with the equation:

$$Q = g_c \cdot W_u \tag{5}$$

Dividing the equation (3) by $g_c W_u$ provides a relationship allowing to determine the relative characteristics of the indicated amount of net heat released during the combustion process [26]:

$$dx = dx_i + dx_{str} \tag{6}$$

The above equation can be written in the following form:

$$x_i = x - x_{str} \tag{7}$$

In equation 7, the value of x_i is the indicated characteristic of the relative release of heat consumed for the conversion of internal energy of the working medium and the execution of the absolute work [6]. The relative amount of heat released during the combustion process in the engine cylinder is calculated from the equation:

$$x_i = \frac{U_i - U_{ps} + \int_{V_{\alpha ps}}^{V_i} pdV}{g_c \cdot W_u} \tag{8}$$

where: U_i – current value of internal energy of the working medium, U_{ps} – internal energy of the working medium at the beginning of the combustion process, V_i – current volume of the cylinder, $V_{\alpha ps}$ – volume of the cylinder at the beginning of the combustion process.

The internal energies of the working medium at the beginning of the combustion process are determined from the dependence [7]:

$$U_{ps} = M_{ps} \bar{c}_{vps} T_{ps} \tag{9}$$

where: M_{ps} – molar mass of the working medium at the beginning of the combustion process, $\bar{c}_{vps}$ – molar specific heat of the working medium at the beginning of the combustion process, T_{ps} – temperature of the working medium at the beginning of the combustion process.

The current value of internal energy of the working medium is calculated with the equation [26]:

$$U_i = M_i \bar{c}_{vi} T_i \tag{10}$$

where: M_i – the current kmol value of the working medium inside the engine cylinder during the combustion process, c_{vi} – the current value of the molar specific heat of the working medium during the combustion process, T_i – the current value of the temperature calculated from the state equation.

A detailed methodology for calculating the internal energy of the working medium at the beginning of the combustion process and the current value of the internal energy of the working medium during the combustion process is presented in the literature [6, 7].

Knowing the characteristics of x,i relative amount of net heat released during the combustion process, the rate of relative amount of heat released during the combustion process is calculated [26]:

$$\dot{x}_i = \frac{x_i - x_{i-1}}{\alpha_i - \alpha_{i-1}} \tag{11}$$

where: x_i – relative amount of heat at point i, x_{i-1} – relative amount of heat at point i-1, α – engine's crankshaft rotation angle at point i, α_{i-1} – engine's crankshaft rotation angle at point i-1.

6. Tests results

Heat release characteristics were determined with Perkins 1104D-E44TA engine operation according to external speed characteristics and load characteristics for crankshaft speed n = 1800 rpm. Figure 2 presents a comparison of the values of nominal power, torque, hourly and brake specific fuel consumption of the tested engine operating according to external speed characteristics and running in dual-fuel mode and on diesel fuel only. The dual-fuel operation resulted in slightly lower nominal power and torque values, slightly higher hourly fuel consumption values and significantly higher brake specific fuel consumption values compared to the diesel only operation. A comparison of the hourly and brake specific fuel consumption of the Perkins 1104D-E44TA engine running according to the load characteristics for crankshaft speed n = 1800 rpm and running in dual-fuel operation as well as powered by diesel fuel only is shown in Figure 3. By powering the engine with two types fuels simultaneously, higher values of indicators assessing fuel consumption were obtained in comparison to its powering with diesel only.

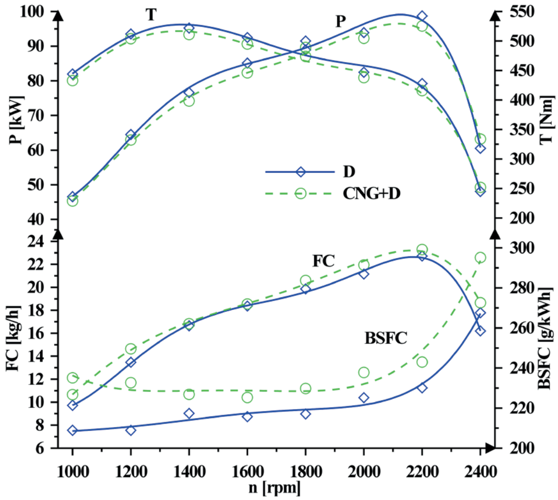

Fig 2. External speed characteristics of Perkins 1104D-E44TA engine running on compressed natural gas and diesel fuel (CNG+D) in dual-fuel operation and on diesel fuel (D) only

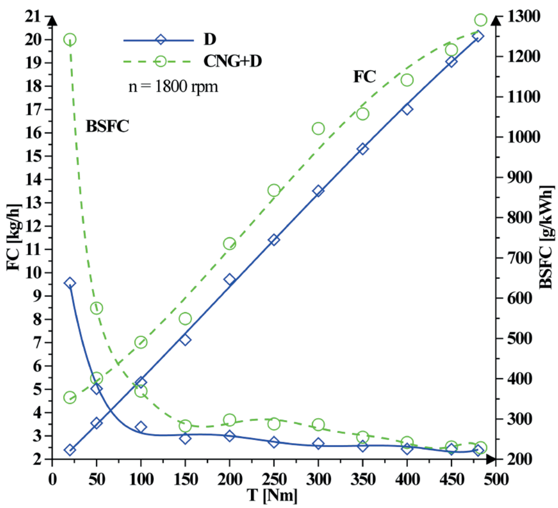

Fig. 3. Load characteristics of Perkins 1104D-E44TA engine determined for crankshaft speed n =1800 rpm, powered by compressed natural gas and diesel (CNG+D) in dual-fuel operation and by diesel fuel (D) only

Before commencing the tests, a calibration of the Perkins 1104D-E44TA dual-fuel injection system for supplying compressed natural gas and diesel was carried out. The aim of the study was to determine the amount of natural gas that can be delivered to the cylinders of the engine under various operating conditions, while maintaining the correct course of the combustion process. With dual-fuel operation, detonation combustion and excessive temperature rise of the exhaust must be avoided, which can result in engine damage. Figure 4 shows the energy share of natural gas in the total energy input to the cylinders of a dual-fuel engine operating according to external speed characteristics and load characteristics for crankshaft speed n = 1800 rpm. The energy share of natural gas in the operation of the engine according to external speed characteristics is small, ranging from about 11% to about 16% and 21.1% for a speed of 2400 rpm. When the engine is running according to the load characteristics, the energy share of gas decreases with an increase in load from 71.3% to 14.9%. At high engine loads, the proportion of natural gas supplied to the engine cylinders was limited by the possibility of occurrence detonation combustion.

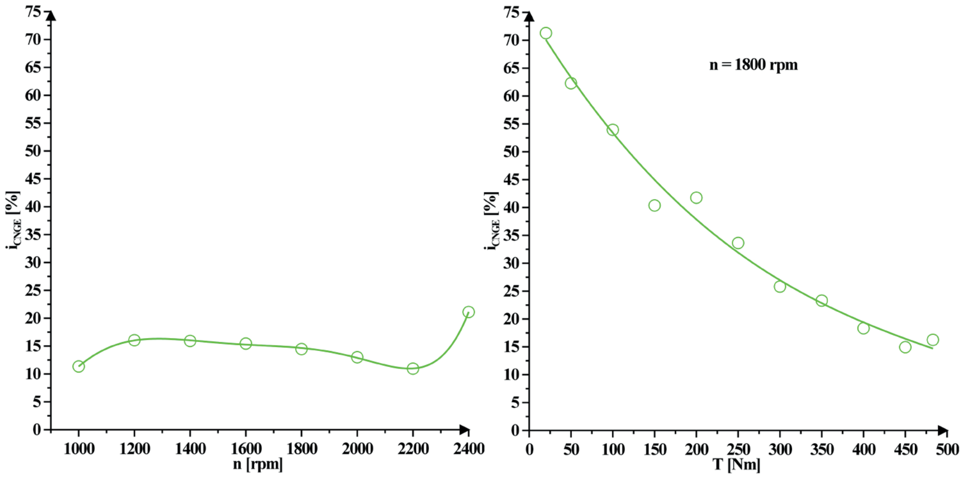

Fig. 4. The energy share of natural gas in the total energy input to the cylinders of the Perkins 1104D-E44TA engine running in dual-fuel operation and according to external speed characteristics and load characteristics for crankshaft speed n = 1800 rpm

The measured concentrations of nitrogen oxides, as shown in Figure 5, are significantly lower when running on compressed natural gas and diesel fuel than when running on diesel only. When the engine is running according to external speed characteristics, as the speed increases, the concentration of nitrogen oxides and the difference between the concentration of nitrogen oxides in diesel and dual-fuel operation only decrease. This is probably the result of shorter combustion duration. At constant crankshaft speed, the concentration of nitrogen oxides increases as the load increases, while the difference between the concentration of nitrogen oxides in diesel only and dual-fuel operation decreases. The increase in concentrations is the result of higher engine loads, while the reduction in the concentration differences between the different modes is the result of a decreasing share of natural gas. A smaller share of natural gas has an impact on the combustion process, which is reflected in the characteristics of heat release.

Figure 6 shows an example of the characteristics of the relative amount of heat released during the combustion process in the Perkins 1104D-E44TA engine operating according to external speed characteristics for selected crankshaft speeds, powered by compressed natural gas and diesel in dual-fuel operation and by diesel fuel only. However, Figure 7 shows exemplary characteristics of the relative amount of heat released during the combustion process in the tested engine operating according to the load characteristics for crankshaft speed n = 1800 rpm, powered by CNG and diesel fuel in dual-fuel operation and by diesel only. The relative heat release curves of a dual-fuel engine are more shifted towards the exhaust outlet process compared to the relative heat release curves of a diesel engine. Supplying the engine with two types of fuel: natural gas and diesel simultaneously, caused a delay in the combustion process in comparison to supplying the engine with diesel oil only, for which it was adapted at the factory.

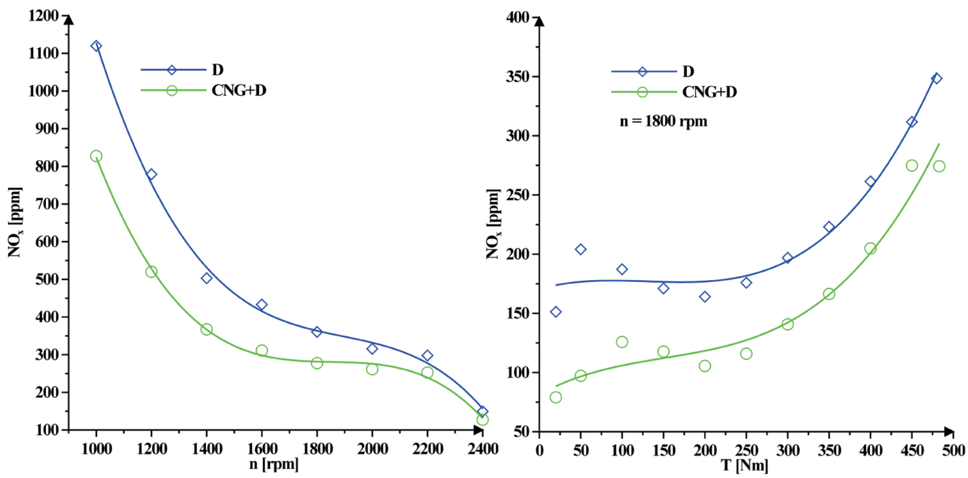

Fig. 5. Comparison of the concentrations of nitrogen oxides in the exhaust gas of a Perkins 1104D-E44TA engine running on compressed natural gas and diesel (CNG+D) in dual-fuel operation and when powered by diesel (D) only, operating according to the external speed characteristics and according to the load characteristics for crankshaft speed n = 1800 rpm

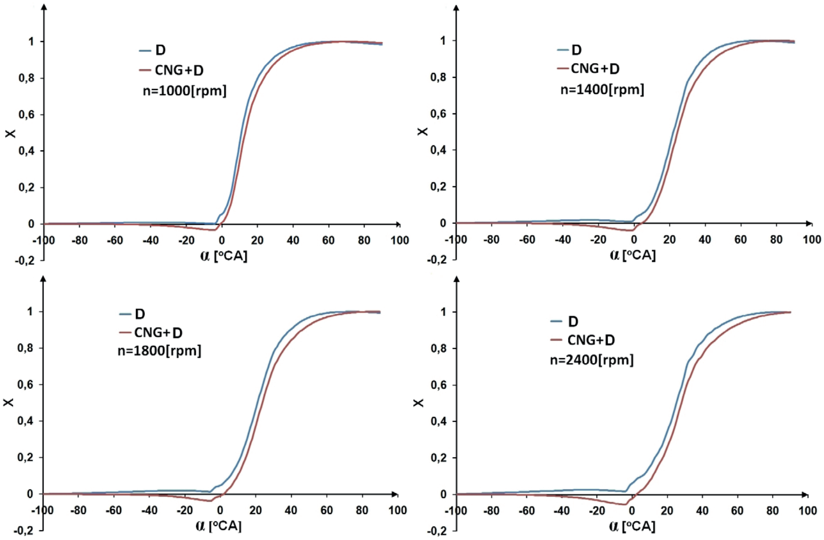

Fig. 6. The relative amount of heat released during the combustion process in the Perkins 1104D-E44TA engine cylinder powered by compressed natural gas and diesel (CNG+D) and by diesel fuel (D) only, operating according to external speed characteristics, at selected crankshaft speeds n

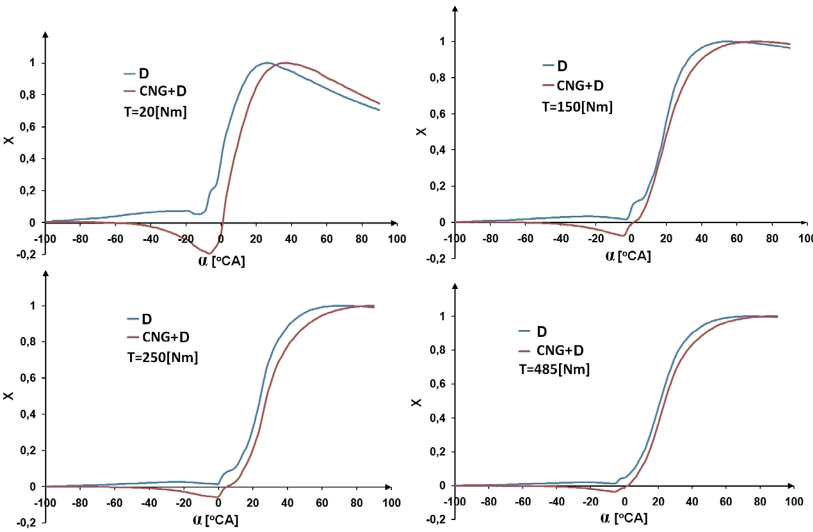

Fig. 7. The relative amount of heat released during the combustion process in the Perkins 1104D-E44TA engine cylinder powered by compressed natural gas and diesel (CNG+D) and by diesel fuel (D) only, operating according to the load characteristics for crankshaft speed n = 1800 rpm, at selected loads determined by the value of torque T

Examples of rate of relative amount of heat released during the combustion process in the Perkins 1104D-E44TA engine cylinder operating according to external speed characteristics, in dual-fuel operation powered by compressed natural gas and diesel, and powered by diesel only are shown in Figure 8. Figure 9 also shows examples of rate of relative amount of heat released for selected loads during the combustion process of the tested engine in dual-fuel operation powered by CNG+diesel fuel and by diesel only, at its operation according to the load characteristics for crankshaft rotational speed n = 1800 rpm. The curves of rate of relative amount of heat released show two maximums. This is probably the result of the diesel fuel injection process. First the pre-injection dose is injected, then it is followed by the main dose. This type of diesel injection takes place both in the case of running on diesel fuel only and in the case of dual-fuel operation. Figure 10 shows the current flows of control of the electromagnetic injector of the Perkins 1104D-E44TA engine running on diesel and on CNG+diesel in dual-fuel operation, working according to the load characteristics for crankshaft speed n = 1800 rpm, for the lowest load T = 20 Nm and the highest load T = 485 Nm.

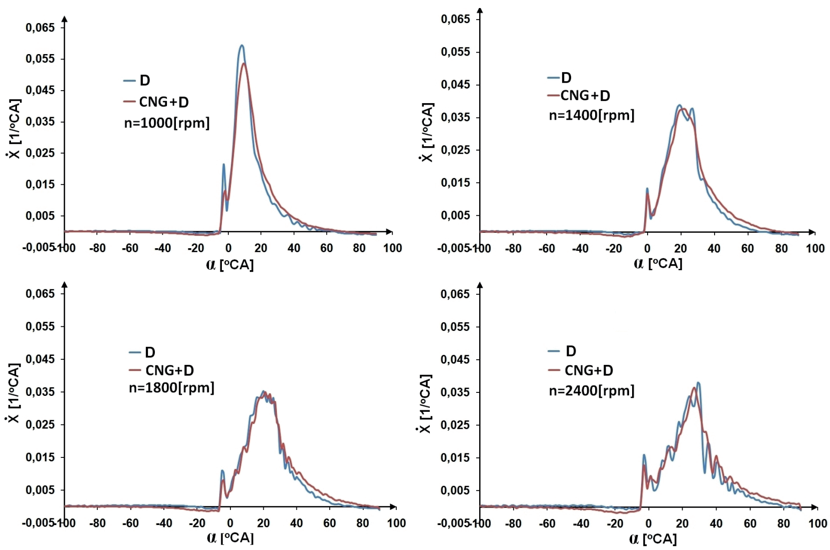

Fig. 8. The rate of relative amount of heat released during the combustion process in the Perkins 1104D-E44TA engine cylinder powered by compressed natural gas and diesel (CNG+D) and by diesel fuel (D) only, operating according to external speed characteristics, at selected crankshaft speeds n

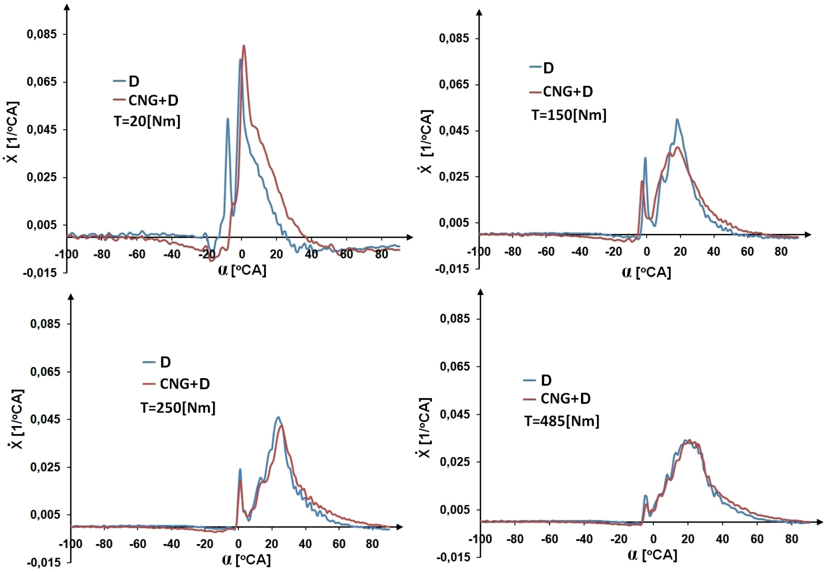

Fig. 9. The rate of relative amount of heat released during the combustion process in the Perkins 1104D-E44TA engine cylinder powered by compressed natural gas and diesel (CNG+D) and by diesel fuel (D) only, operating according to the load characteristics for crankshaft speed n = 1800 rpm, at selected loads determined by the value of torque T

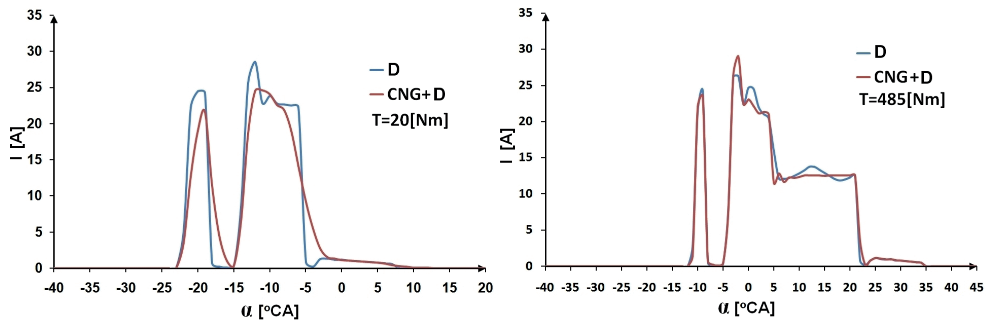

Fig. 10. The current flows of control of the electromagnetic injector of the Perkins 1104D-E44TA engine running on diesel fuel (D) only and on compressed natural gas and diesel (CNG+D) in dual-fuel operation, working according to the load characteristics for crankshaft speed n = 1800 rpm, for two extreme engine loads

Figure 11 shows the values of the first maximum rate of relative amount of heat released x_{1max} during the combustion process in the Perkins 1104D-E44TA engine operating according to external speed characteristics and load characteristics for crankshaft rotational speed n = 1800 rpm, powered by CNG+diesel in dual-fuel operation and by diesel only for which it was factory adapted. The results also indicate that dual-fuel operation, i.e. running on compressed natural gas and diesel causes a decrease in the first maximum rate of relative amount of heat released x_{1max}. This is clearly visible at low loads of the engine operating according to the load characteristics. Under these conditions, detonation combustion is less likely to occur and the energy share of natural gas in the total amount of energy supplied to the cylinder is much higher. A higher proportion of natural gas decreases the rate of heat release. Natural gas burns more slowly than diesel fuel. As the engine load increases, the proportion of natural gas supplied to the engine decreases and the difference between the first maximum rate of relative amount of heat released x_{1max} for dual-fuel operation and diesel only operation decreases.

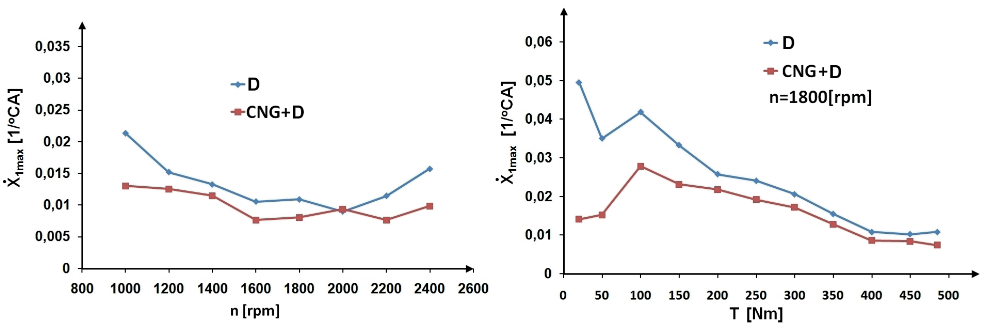

Fig. 11. Comparison of the first maximum rate of relative amount of heat released in the Perkins 1104D-E44TA engine cylinder, operating according to external speed characteristics and load characteristics for crankshaft speed n = 1800 rpm, in dual-fuel operation (CNG+D) and powered by diesel fuel (D) only

Figure 12 shows the values of the second maximum rate of relative amount of heat released x_{2max} during the combustion process in Perkins 1104D-E44TA engine operating according to external speed characteristics and load characteristics for crankshaft rotational speed n = 1800 rpm, powered by CNG+diesel in dual-fuel operation and by diesel only. The values of the second maximum rate of relative amount of heat released x_{2max} are similar for dual-fuel operation and diesel only operation. For an engine operating according to the external speed characteristics for speeds above 1200 rpm, and for an engine operating according to the load characteristics for loads above 250 Nm, the values for the second maximum rate of relative amount of heat released x2max shall be practically the same for dual-fuel and diesel only operation.

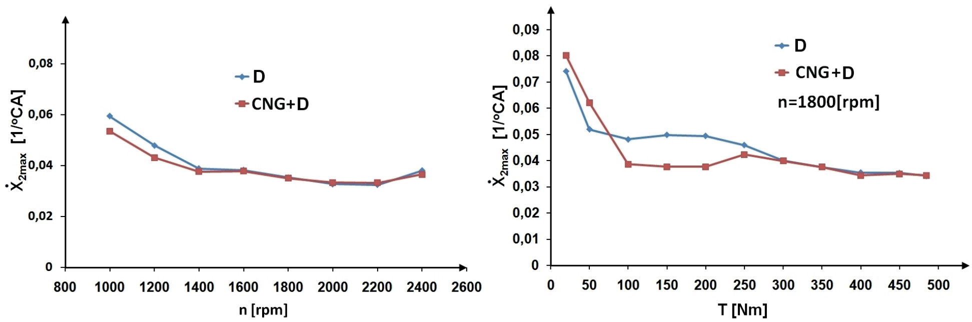

Fig. 12. Comparison of the second maximum rate of relative amount of heat released in the Perkins 1104D-E44TA engine cylinder, operating according to external speed characteristics and load characteristics for crankshaft speed n = 1800 rpm, in dual-fuel operation (CNG+D) and powered by diesel fuel (D) only

7. Conclusions

The results indicate that the dual-fuel operation (compressed natural gas and diesel) of the Perkins 1104D-E44TA engine yields a significant change in heat release characteristics, in particular at low engine loads, where the share of natural gas in the total energy input to the engine cylinders is the largest. In the case of higher engine loads, the energy share of gas decreases, which means that the parameters of heat release characteristics are very similar to those of the engine powered by diesel only. The relative heat release curves and curves of rate of relative amount of heat released of the Perkins 1104D-E44TA engine cylinder powered by compressed natural gas and diesel in dual-fuel operation are more shifted towards the opening of the exhaust valve, compared to the corresponding curves determined with the engine running on conventional fuel only, i.e. diesel fuel, for which the engine is factory-fitted. This means that the dual-fuel combustion process is slower than in the case of diesel combustion. Two maximums are visible on the curves of rate of relative amount of heat released during the combustion process. The first maximum is higher for diesel only compared to natural gas and diesel. The biggest differences between the first maximum rate of relative amount of heat released values for diesel and dual-fuel operation of the engine are visible at low loads for engine operating according to load characteristics. In this case, the share of energy supplied with natural gas in the total amount of energy supplied to the cylinder is the highest. As the load increases, these shares decrease. The differences between the values of the first maximum rate of relative amount of heat released for the two methods of powering the tested engine are also decreasing. The values of the second maximum rate of relative amount of heat released for diesel and dual-fuel operation of the engine are very similar, especially under heavy loads and according to the external speed characteristics of the engine. A different combustion process in dual-fuel operation affects the concentration of nitrogen oxides in the engine exhaust. Significantly lower concentrations of nitrogen oxides in the exhaust were obtained for the engine fuelled with natural gas and diesel as compared to the engine being fuelled with diesel. Differences in the concentration of nitrogen oxides for diesel and dual-fuel operation decrease with the increase in engine load, when the engine is running according to load characteristics. This is due to the fact that as the engine load increases, the share of natural gas in the total amount of fuel supplied to the engine cylinders decreases significantly. Differences in the course of heat release characteristics also decrease.

8. References

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