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# Some aspects of the CI engine modification aimed at operation on LPG with the application of spark ignition

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# Some aspects of the CI engine modification aimed at operation on LPG with the application of spark ignition

**J Kaparuk[1], S Luft[2], T Skrzek[3], M Wojtyniak[4]**

[1] PhD Student at the Faculty of Mechanical Engineering at University of Technology and Humanities in Radom
[2] Professor at the Faculty of Mechanical Engineering at University of Technology and Humanities in Radom
s.luft@uthrad.pl
[3,4] Doctor in the Faculty of Mechanical Engineering at University of Technology and Humanities in Radom

**Abstract**. A lot of investigation on  modification of the compression ignition engine aimed at operation on LPG with the application of spark ignition has been carried out in the Laboratory of Vehicles and Combustion Engines at Kazimierz Pulaski University of Technology and Humanities in Radom. This paper presents results of investigation on establishment of the proper ignition advance angle in the modified engine. Within the framework of this investigation it was assessed the effect of this regulation on basic engine operating parameters, exhaust emission as well as basic combustion parameters.

## 1. Introduction

LPG enjoys great popularity in Poland due to its low price comparing to gasoline and diesel oil. It has also a well-developed distribution infrastructure. In recent years, it has been observed a trend toward modification of older generation CI engines aimed at operation on LPG. This modification consisted in reduction of the compression ratio and spark ignition application. Such kinds of modifications in CI engine constructions started in the last years of the XXth century. Description and discussion of investigations undertaken in this area are presented, among others, in [2]. Comparing to the investigations on dual-fuel engines operating on diesel oil and LPG, the scale of these investigations is much smaller. Very often the presented results do not refer to the effects resulting from the applied modifications, mainly to the following changes:

– operating engine parameters (effective power, fuel consumption and engine overall efficiency),
– parameters influencing natural environment (exhaust emissions),
– combustion parameters (that determine engine durability).

Investigation on the above-mentioned topics were carried out in the Laboratory of Vehicles and Combustion Engines at Kazimierz Pulaski University of Technology and Humanities in Radom.
The first stage of the investigation was focused on the establishment of the compression ratio of the modified engine. The obtained results were presented at the conference KONMOT 2014 and published in [1]. A further investigation concerned the establishment of the proper ignition advance angle of the modified engine. Within the framework of this investigation it was assessed the effect of this regulation on basic engine operating parameters, exhaust emission and combustion parameters.

## 2. Description of the test bed

The investigations were carried out with the use of a single cylinder 1HC102 research engine. In the standard version, this is a compression ignition engine fuelled with diesel oil. In the modified version, this is a spark ignition engine with a compression ratio of 9 – the value which was established earlier. This engine was coupled with an electrorotational brake Vibrometr 3 WB 15. The test bed was equipped with systems providing measurements of:

- – engine torque
- – engine speed
- – hourly fuel consumption
- – exhaust emissions
- – combustion pressures.

General views of the test bed and the engine control room are presented in (figure 1 and 2).
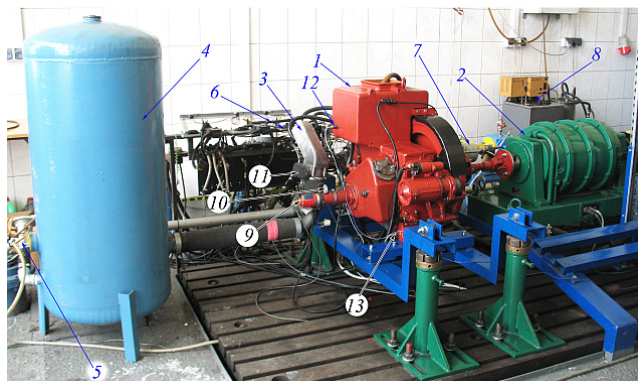


**Figure 1.** Test bed: 1– 1HC 102 engine, 2 – electrorotational brake, 3 – intake manifold, 4 – air reservoir, 5 – laminar flow meter $\varnothing 20$, 6 – ignition system, 7 – catalytic converter, 8 – cooling system of the cylinder pressure sensor, 9 – crankshaft rotation angle transducer, 10 – camshaft position sensor, 11 – throttle assembly, 12 – coolant temperature sensor, 13 – engine oil temperature sensor.
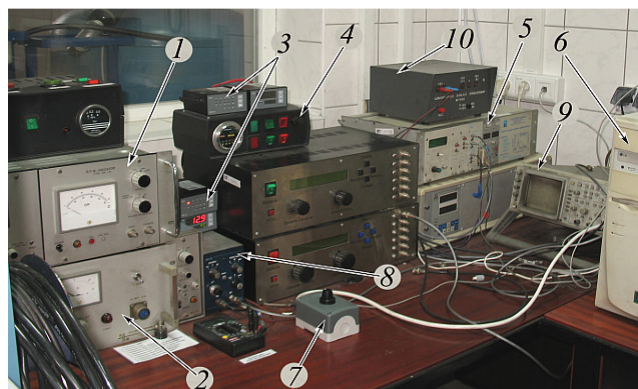


**Figure 2.** The engine control room: 1 – engine speed measurement system, 2 – engine torque measurement system, 3 – multi-channel temperature meters WRT-9, 4 – engine starting system, 5 – measurement system of the cylinder pressure and of signals from the crankshaft rotation angle transducer, 6 – PC-computer with a data acquisition card, 7 – potentiometer controlling the throttle opening, 8 – amplifier of the signals from the cylinder pressure sensor and from the crankshaft rotation angle transducer, 9 – oscilloscope, 10 – stabilized laboratory power supply.

**Table 1.** Comparison of characteristic features of the investigated engine.

| Engine type | 1 HC102 | 1 HC102 |
|---|---|---|
| Way of ignition | CI | SI |
| Displacement [dm$^3$] | 0,980 | 0,980 |
| Compression ratio | 17 | 9 |
| Maximum engine speed [rpm] | 2200 | 2200 |

### 3. Investigation procedure

In the first stage of the investigation, regulation characteristics of maximum load $Mo_{max}$ [Nm] versus the ignition advance angle $\alpha$ (C.A. BTDC) were prepared and engine overall efficiency obtained in these conditions. Characteristics were prepared at three values of the engine speed: $n_1$=1200 rpm, $n_2$=1700 rpm, $n_3$=2200 rpm. The obtained results provided a basis for further investigations taking into consideration the beneficial value of ignition advance angle at each of the selected engine speeds. The following stage of the investigation consisted in preparation of load characteristics of the main exhaust emissions from the modified engine at each of the selected engine speeds. The final stage of the investigation consisted in preparation of load characteristics of the basic combustion parameters (maximum pressure $P_{max}$ , mean rate of pressure rise $\frac{\Delta P}{\Delta \alpha}$ mean  and maximum rate of pressure rise $\frac{\Delta P}{\Delta \alpha}$max). The present paper presents results obtained at the engine speed of 2200 rpm only. The relationships  obtained for the modified engine were compared with those obtained for the standard engine operation. Results of the investigation and comparisons are presented in chapter 5.

### 4. Selection of the beneficial ignition advance angle regulation taking into consideration the developed torque Mo [Nm] and engine overall efficiency ηo

Selection of the beneficial ignition advance angle regulation taking into consideration the developed torque Mo [Nm] and engine overall efficiency $\eta_o$ was done analyzing the regulation characteristics presented in (figure 3 and 4).
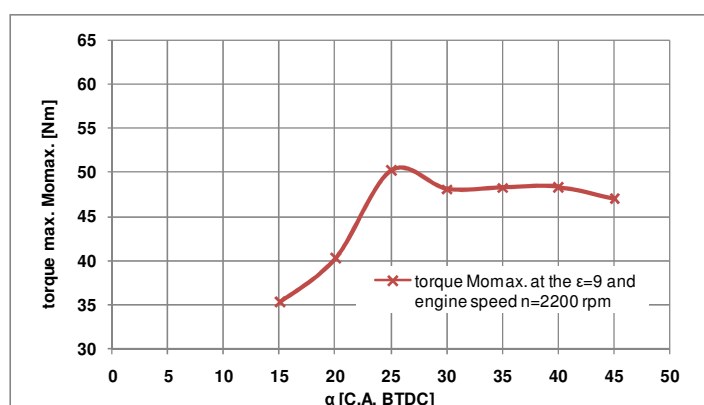


**Figure 3.** Characteristics of the maximum torque $Mo_{max}$ versus the ignition advance angle $\alpha$, at the engine speed n=2200 rpm.
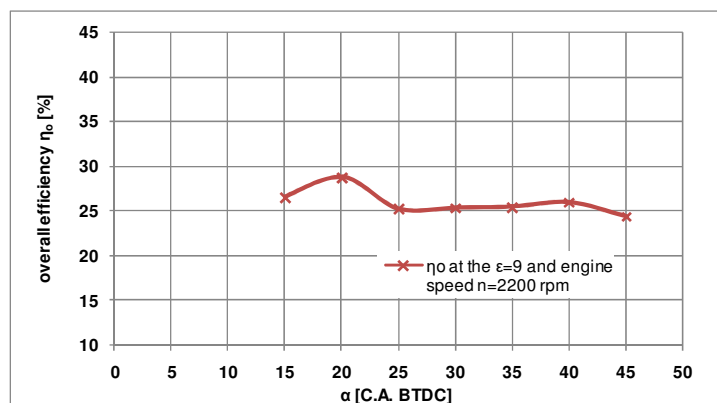
**Figure 4.** Regulation characteristics of the overall efficiency of the modified engine operating on LPG with the application of spark ignition for the established compression ratio ε = 9, at the engine speed n=2200 rpm.

It results from these characteristics that, taking into consideration the developed torque Mo [Nm], the most beneficial regulation of the ignition advance angle is α =25 C.A. BTDC (at the engine speed n=2200 rpm). The established ignition advance angle was set in further investigation on the main exhaust emissions and combustion parameters.

## 5.  Comparison of basic operating parameters, main exhaust emissions and combustion parameters for the modified and the standard engines

In order to carry out the necessary comparisons, load characteristics of the above-mentioned parameters were prepared. In the case of the engine operating on diesel oil, the standard ignition advance angle α =20 C.A. BTDC was maintained. In the modified engine, there was applied the established earlier ignition advance angle equal to 25 C.A. BTDC.

### 5.1.  Comparison of the engine overall efficiency $\eta_o$ characteristics

The overall efficiency $\eta_o$ characteristics of the investigated engines were prepared on the basis of measurements of the engine torque $M_o$[Nm], the hourly fuel consumption $G_e$[kg/h] and heating values of the applied fuels [kJ/kg]. The characteristics are presented in (figure 5).
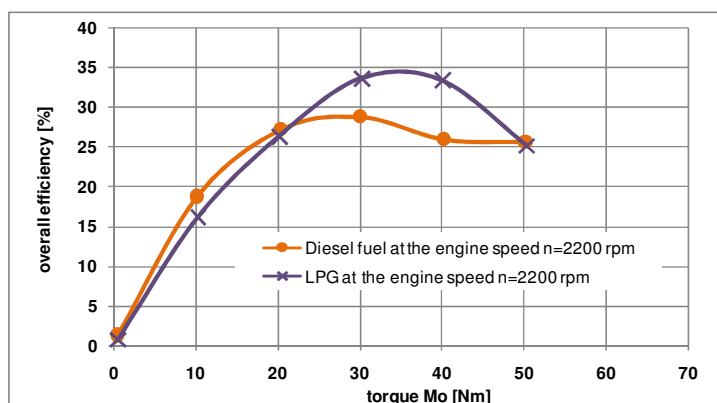


**Figure 5.** Comparison of the load characteristics of the overall efficiency $\eta_o$ = f($M_o$) for the standard engine operating on diesel oil, at the constant ignition advance angle α =20 C.A. BTDC and the compression ratio ε = 17 and for the modified engine operating on LPG with the application of spark ignition, at the constant ignition advance angle α =25 C.A. BTDC and the established compression ratio ε = 9, at the engine speed n=2200 rpm.

Analysis of the characteristics presented in figure 5 shows that the modified engine delivers higher overall efficiency comparing to the standard operating engine, especially at loads close to the maximum ratings. It is worth mentioning the fact that both engine versions deliver the same maximum load rating of Mo=50 [Nm]. Achievement of such result was possible, to a large degree, due to the proper regulation of the ignition advance angle $\alpha$ for the modified engine.

*5.2. Comparison of characteristics relating to the main exhaust emissions*
The engine exhaust emissions were measured under load characteristics for both engine versions. The obtained characteristics are presented in (figure 6, 7 and 8). It should be noticed, that during investigation on the modified engine, the air – LPG mixture was kept at the stoichiometric ratio ($\lambda\cong1$).
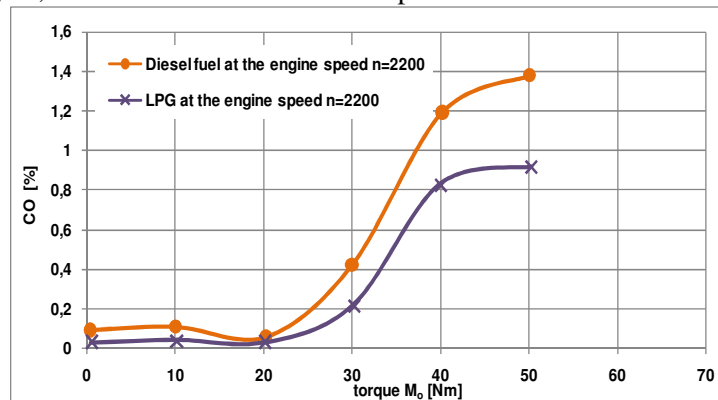


**Figure 6.** Comparison of the load characteristics of the CO emissions for the standard engine operating on diesel oil, at the constant ignition advance angle $\alpha$ =20 C.A. BTDC and the compression ratio $\varepsilon$ = 17 and for the modified engine operating on LPG with the application of spark ignition, at the constant ignition advance angle $\alpha$ =25 C.A. BTDC and the established compression ratio $\varepsilon$ = 9, at the engine speed n=2200 rpm.
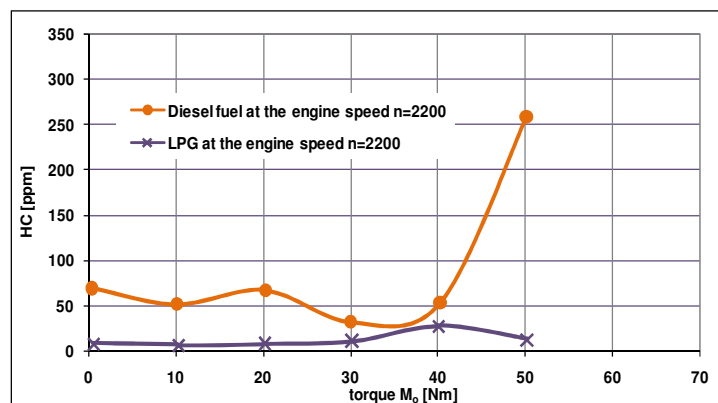


**Figure 7.** Comparison of the load characteristics of the HC emissions for the standard engine operating on diesel oil, at the constant ignition advance angle $\alpha$ =20 C.A. BTDC and the compression ratio $\varepsilon$ = 17 and for the modified engine operating on LPG with the application of spark ignition, at the constant ignition advance angle $\alpha$ =25 C.A. BTDC and the established compression ratio $\varepsilon$ = 9, at the engine speed n=2200 rpm.
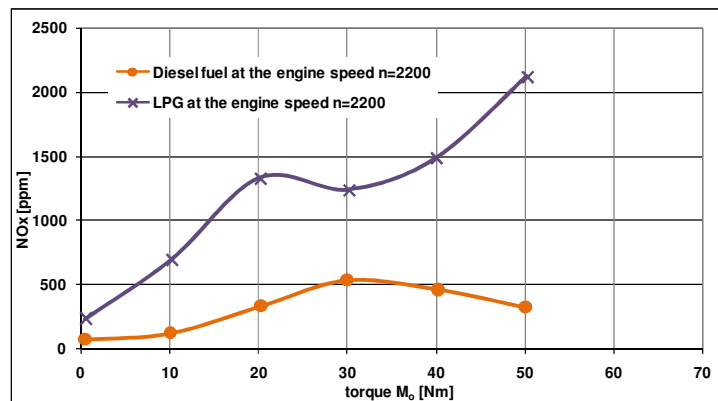
**Figure 8.** Comparison of the load characteristics of the $NO_x$ emissions for the standard engine operating on diesel oil, at the constant ignition advance angle $\alpha$ =20 C.A. BTDC and the compression ratio $\varepsilon$ = 17 and for the modified engine operating on LPG with the application of spark ignition, at the constant ignition advance angle $\alpha$ =25 C.A. BTDC and the established compression ratio $\varepsilon$ = 9, at the engine speed n=2200 rpm.

It results from these characteristics (obtained at the engine speed n=2200 rpm and the ignition advance angle regulation $\alpha$ =25 C.A. BTDC) that:

- CO emission from the modified engine is lower than from the standard operating engine, particularly at loads close to the maximum ratings,
- HC emission from the modified engine is also lower than from the standard operating engine particularly at loads close to the maximum ratings as well,
- NOx emission from the modified engine is also higher than from the standard operating engine.

According to the authors, the positive effect reduction of CO and HC emissions of the modified engine is due to the following facts:

- the standard CI engine was equipped with an old style injection pump (of the inline type) operating at low injection pressure (ca. 17 MPa)
- the modified engine operated on a gaseous fuel (LPG). Fuel of this type, as a rule, has beneficial combustion characteristics.

The air–fuel equivalence ratio of the modified engine was kept at the stoichiometric condition for a SI engine $\lambda \approx 1$. In the standard CI engine, this ratio had a value varying from $\lambda \approx 8 \div 10$ (at the minimum load) to $\lambda \approx 1,3$ at the maximum load. At this stage of investigation, it is difficult to give a clear answer to the question of why a higher NOx emission is observed in the modified engine.
However, it should be mentioned that the investigated engine was not fitted with a catalytic converter. It is expected that application of a catalytic converter will result in lower emissions, especially in view of the fact that the engine is operating at stoichiometric conditions ($\lambda$=1).

*5.3. Comparison of characteristics relating to the basic combustion parameters*
During the investigation on both engine versions, measurements of the combustion pressure versus crankshaft rotation P[MPa] = f($\alpha$) [C.A.] were taken. The registered courses for consecutive load levels M[Nm] enabled to prepare the characteristics of basic combustion parameters. The characteristics relate to the following parameters:

- maximum combustion pressure $P_{max}$ [MPa] = f(M) [Nm],
- mean rate of pressure rise $\frac{\Delta P}{\Delta \alpha}$ mean [$\frac{MPa}{°CA}$] = f (M) [Nm],
- maximum rate of pressure rise $\frac{\Delta P}{\Delta \alpha}$max. [$\frac{MPa}{°CA}$]= f (M) [Nm].

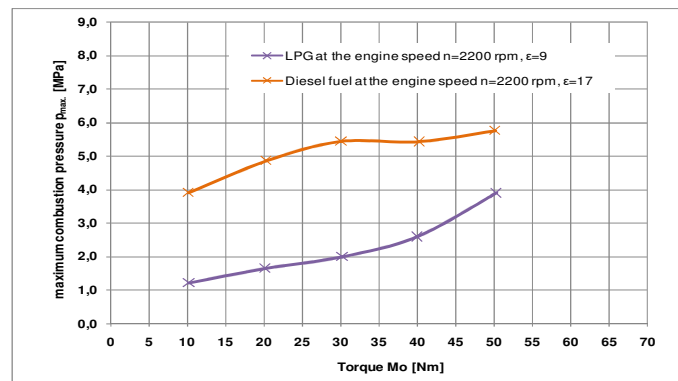These characteristics are presented in (figure 9, 10 and 11).

**Figure 9.** Characteristics of the maximum combustion pressure $P_{max}$ [MPa] versus the engine torque $M_o$ [Nm], at the engine speed n=2200 rpm
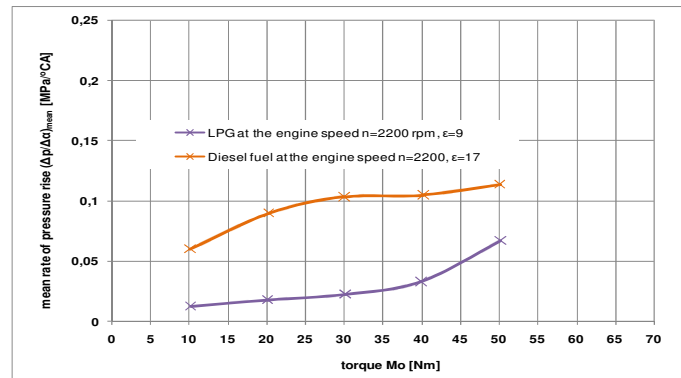


**Figure 10.** Characteristics of the mean rate of pressure rise $\frac{\Delta P}{\Delta \propto}$mean [$\frac{MPa}{°CA}$] versus the engine torque $M_o$ [Nm], at the engine speed n=2200 rpm



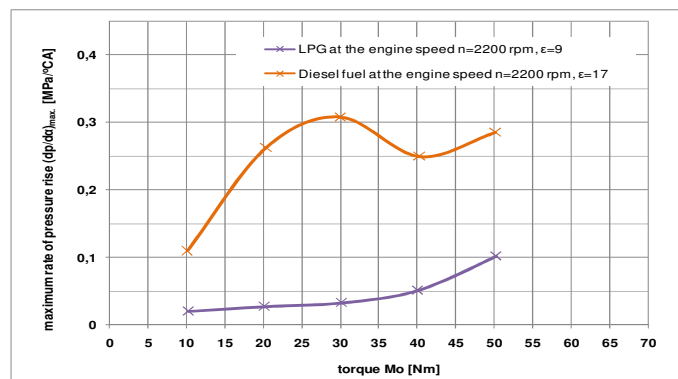**Figure 11.** Characteristics of maximum rate of pressure rise $\frac{\Delta P}{\Delta \propto}$max. $\left[\frac{MPa}{°CA}\right]$ versus the engine torque $M_o$ [Nm], at the engine speed n=2200 rpm

The presented characteristics of basic combustion parameters reveal that, at the established engine speed n=2200 rpm and at the established regulation of the ignition advance angle α =25 C.A. BTDC, the investigated combustion parameters (maximum combustion pressure $P_{max}$, mean rate of pressure rise $\frac{\Delta P}{\Delta \propto}$ mean and maximum rate of pressure rise $\frac{\Delta P}{\Delta \propto}$max) of the modified engine are lower, over the full range of load, than corresponding parameters of the standard operating engine. It should be mentioned, that this feature is beneficial regarding engine durability.

## 6. Summary – conclusions

Modification of a compression ignition engine should be preceded by investigation aimed at establishment of the compression ratio $\varepsilon$ and the ignition advance angle $\alpha$.

Proper establishment of the above-mentioned parameters enabled to obtain higher engine overall efficiency $\eta_o$ of the 1HC102 engine maintaining the developed torque $Mo_{max}$.

Operation of the modified 1HC102 engine resulted in lower CO and HC emissions and higher NOx emission. It should be noticed, that fitting the engine with a catalytic converter would enable a further decrease of these emissions.

The process of combustion in the modified engine, in comparison to the standard operating engine, is characterized by lower values of the following parameters:

- maximum combustion pressure $P_{max}$,
- mean rate of pressure rise $\frac{\Delta P}{\Delta \propto}$ mean,
- maximum rate of pressure rise $\frac{\Delta P}{\Delta \propto}$ max.

This feature is beneficial regarding engine durability.

The above-presented observations enable a statement that the analysed modification of older generation CI engines would bring about a number of benefits (increased engine performances, higher engine overall efficiency, lower exhaust emissions) provided that the compression ratio $\varepsilon$ and the ignition advance angle $\alpha$ will be established in a proper way.

Further improvement of the analysed operating parameters of the modified engine may be obtained in result of an accurate design of the combustion chamber.

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