

Evaluation of the heat release in the various phases of the FAME type fuel combustion process in the compression ignition engine

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Abstract. The article presents selected results of experimental research of the compression ignition engine running on a new type of Fatty Acid Methyl Esters fuel and on a comparative standard fuel which is diesel oil. As a part of the test assessment, the waveforms and maximum values of pressure and temperature of the working medium in the combustion chamber under the same operating conditions of the engine supplied with the mentioned fuels were compared. Moreover, the phases of the combustion process were determined together with the exact determination of the share of the amount of heat released in each phase. New data is presented as analyzed and evaluated the tests results. Thus, it was established that the amount of heat released in the afterburning phase, for FAME type fuel, has reached higher values compared to standard fuel. Empirical studies were carried out in the Combustion Engines Laboratory at Institute of Vehicles, Warsaw University of Technology. For this purpose, the experimental stand equipped with a CI engine and AVL IndiSmart system that has an ability of registration of fast-changing parameters was used. An experimental setup has AVL Concerto software that was utilized for analysis.

1. Introduction

The combustion process is a fast exothermic oxidation reaction of the air-fuel mixture, which is accompanied by a significant temperature increase of the reaction products in relation to its substrates with simultaneous intensive lighting [1]. The combustion process in the compression ignition engine can be divided into four stages, during which fuel is prepared for combustion, an intense heat generation phase, combustion of the basic mass of the combustible mixture and post-combustion when unreacted components of the combustion process are burning [2, 3, 4].

The first phase of the combustion process is a period of rapid combustion often referred to as kinetic combustion. It lasts from the moment of ignition of the combustible mixture until the maximum pressure in the cylinder is reached. The heat generated at this stage comes from the combustible mixture prepared during the first stage, i.e. the self-ignition delay.

The intensity of heat release in this phase of the combustion process affects such aspects of engine operation as noise defined by the level of mechanical and thermal loads of engine components. This is due to the very rapid increase in pressure and temperature changes caused by a sudden increase in the heat released.

The intensity of the second phase of the combustion process is lower due to decreasing amount of oxidant inside the cylinder. Moreover, in this period, combustion mixture reaches maximum



temperature, and for this reason, further growth of heat release is not possible. This period is also called diffusion combustion and lasts from the point where the combustible mixture has reached its maximum pressure until it has reached its maximum temperature. The maximum temperature point is shifted in relation to the maximum pressure, which is caused by further intensive heat release with a simultaneous increase in volume after exceeding the GMP by the piston. The effect of expanding the volume of the combustion chamber is more evident in the course of pressure than the temperature. Combustion in the second phase is diffusive, occurring with the intense mixing of fuel and air. The fuel is injected directly into the flame and burns quickly. The duration of the second combustion phase is influenced by the injection characteristics, the degree of charge turbulence and air-excess factor value [5, 6].

The third phase of combustion called afterburning, it lasts from reaching the maximum temperature of the cycle until the end of the heat release process. This phase is often regarded as part of the diffusion combustion phase, especially when the temperature drop rate after exceeding the maximum value is significant. Diffusion combustion also takes place in this phase, however, it occurs at a lower mixing speed of fuel vapours and air. This is due to the fact that the main part of the fuel and oxidant has already been reacted. During this phase, some conditions may occur that will allow sufficiently full burning of soot generated during the previous phases [7, 8].

2. Research methodology

In this article, the chosen parameters of PERKINS 1104C-E44T – a CI, turbocharged engine were presented and analysed. It was done based on averaged values of working medium pressures in the combustion chamber, obtained as a result of empirical research. During the research, the engine was running on standard diesel fuel (DF) and 100% Camelina oil methyl ester (COME). The basic parameters of the fuels are shown in Table 1.

Table 1. Parameters of fuels used in the test

Parameter	DF	COME
The cetane number	52.4	51
The calorific value [MJ/kg]	43.2	37.7
Density at temperature 15°C [g/cm ³]	0.835	0.8917
Kinematic viscosity at temperature 40°C [mm ² /s]	2.64	4.2573

The results showed in this work were obtained for below specified conditions of the engine work:

- crankshaft rotational speed of maximum torque – 1400 rpm, and 50% of maximum load,
- crankshaft rotational speed of maximum power – 2200 rpm, and 50% of maximum load,

The diagram of the test bench is shown in Figure 1.

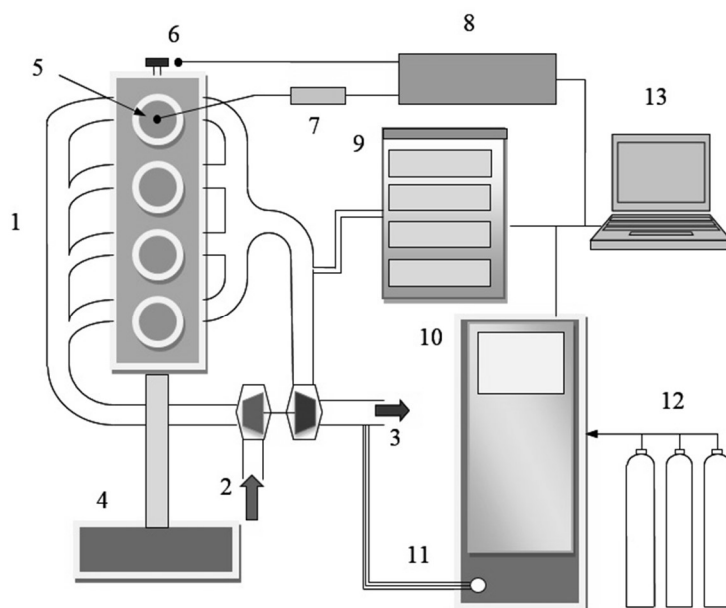


Figure 1. Diagram of the test bench **Błąd! Nie można odnaleźć źródła odwołania.:** 1 – Perkins 1104C-E44T engine; 2 – air inlet; 3 – exhaust outlet; 4 – dynamometer SCHENCK W450; 5 – in-cylinder pressure indicator AVL GM 12; 6 – engine crankshaft angle indicator; 7 – signal amplifier; 8 – system indicator AVL IndiSmart; 9 – Horiba MEXA 1230 PM; 10 – gases analyzer AVL CEB II; 11 – heated gas lines; 12 – set of reference gases; 13 – PC computer with data acquisition.

3. Experimental research results

The comparison of the heat released in the three phases of the combustion process is shown in Figure 2. As it can be seen, the greatest amount of heat during the combustion of diesel was released during the diffusion combustion phase and it was over 70% of the total heat release. Combustion of plant origin fuel results in a similar heat release for the kinetic and diffusion phase, i.e. about 40%. At the same time, the share of the afterburning phase increases significantly from 5% for DF to over 20% for COME.

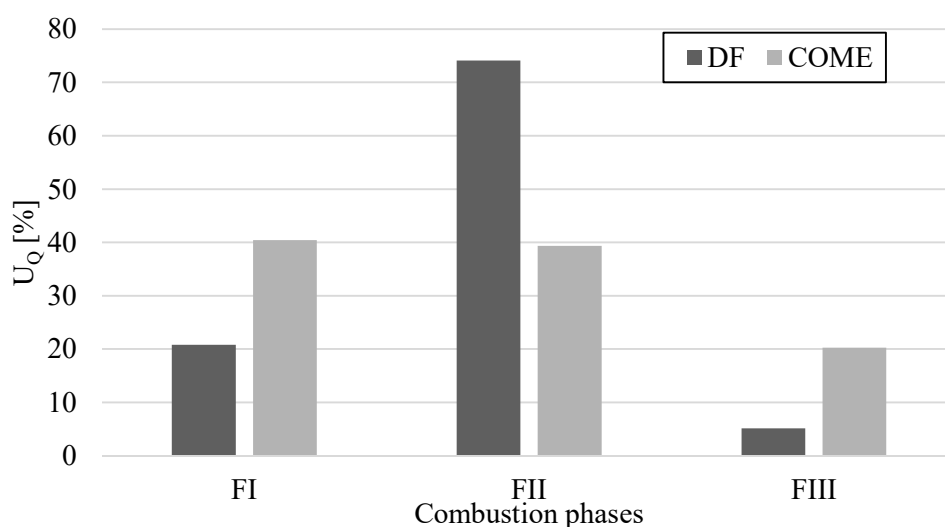


Figure 2. Comparison of the share of the heat release in the individual phases of the DF and COME combustion, determined at the crankshaft rotation speed 1400 rpm and 50% of the maximum load.

A comparison of the relative heat released in the three phases of the combustion process is shown in Figure 3. It can be observed that during combustion of diesel oil the greatest heat was produced during the diffusion combustion phase and it constituted over 70% of the total heat. Combustion of fuel of vegetable origin results in similar heat release for the kinetic and diffusion phase, however, with a slight advantage of the latter of around 5%. However, the share of the afterburning phase at this speed is about 10% and is 5% greater than the DF value is.

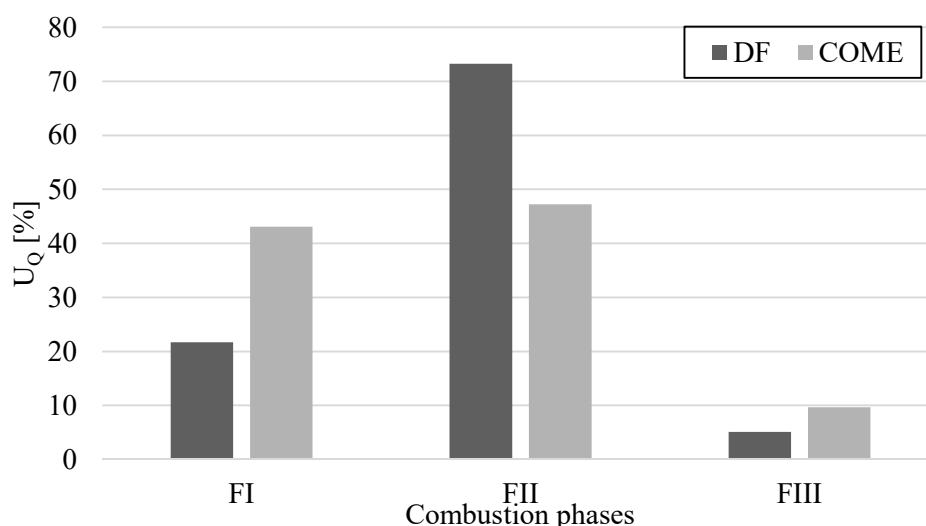


Figure 3. Comparison of the share of the heat release in the individual phases of the DF and COME combustion, determined at the crankshaft rotation speed of 2000 rpm and 50% of the maximum load.

4. Conclusions

Analysis of DF, and COME combustion process allows to formulate below presented conclusions:

- Determination of individual phases of the combustion process and the share of the released heat in each phase allows to observe the growing importance of afterburning.
- The greater duration of the afterburning phase, that was observed, affects the combustion process, causing significant differences in the duration of individual phases for biofuel compared to diesel fuel.
- The heat release characteristics developed for the FAME type fuel showed a change in the duration of the individual combustion phases by approximating the duration of the kinetic and diffusion phases and extending the duration of afterburning phase. It is caused by different physicochemical properties of this fuel. Viscosity and density are the most important factors here, which determine the properties of the injected fuel spray.

Nomenclature

FAME – Fatty Acid Methyl Esters,

FI – Initial Premixed Combustion phase,

FII – Mixture-Controlled Combustion phase,

FIII – Post-Combustion phase,

COME – 100% Camelina oil methyl ester,

DF – diesel fuel,

U_Q – participation of heat release in individual phases of the combustion process.

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