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# THEORETICAL STUDY OF COMBUSTION PROCESSES OF BIODIESEL-DIESEL BLENDS IN ICE

**Banari E.**
*Doctor of Engineering Sciences, university lecturer*
*ORCID: 0000-0002-4227-5120*
*Technical University of Moldova, Chisinau, str. Studentilor, 9/8, 2045*

***Abstract.*** *The paper addresses the theoretical analysis of the combustion process in the DC4 11.0/12.5 engine, using pure biodiesel (B100) and biodiesel-diesel blends (B20, B50) as fuels. The study is based on performing the thermal calculation of the combustion process, monitoring the characteristic parameters of the engine cycle, such as pressure, temperature, etc. The analysis highlights the differences in behavior between conventional and alternative fuels, with an emphasis on the influence of the proportion of biodiesel on combustion. The results contribute to the substantiation of the use of biodiesel as a sustainable solution for reducing dependence on diesel.*
***Key words:*** *combustion, mixture, biodiesel, diesel, internal combustion engine (ICE).*

## Introduction.

The progressive reduction of world oil reserves, together with the increasing deficit of petroleum products, the increase in prices of traditional fuels and the continuous tightening of regulations on internal combustion engine emissions, determines the orientation of research towards alternative energy sources *[9, 28]*.

Currently, internal combustion engines represent the main consumers of petroleum fuels. The constant increase in the number of motor vehicles, together with the reduction in the discoveries of new oil deposits, accentuates the problem of the energy crisis. In addition, the emissions resulting from the combustion of fuels in internal combustion engines exert a negative impact on the environment. In this context, it becomes essential to implement methods of production and use of alternative fuels, which would contribute both to reducing dependence on oil and to reducing harmful effects on the environment. One of the promising directions in this field is represented by the use of fuels obtained from vegetable oils *[2, 10, 21-23]*.

Biodiesel is presented in the form of a transparent liquid, yellow-golden in color, with a characteristic pleasant odor. From a chemical point of view, it consists of fatty acid methyl esters (FAME), obtained by the transesterification reaction of triglycerides of vegetable or animal origin. The molecular structure of FAME is similar to that of hydrocarbons in conventional diesel fuel, which determines the high compatibility of physicochemical and combustion properties *[4, 8, 12*]. This similarity allows the use of biodiesel as a partial or full substitute for petroleum diesel fuel, without affecting the combustion processes. A major advantage is its complete miscibility with diesel fuel in any proportion, which facilitates the obtaining of mixtures of the B20, B50 type, etc. and expands the possibilities of application. Due to the closeness of the operating characteristics, biodiesel and its blends can be used in existing internal combustion engines, without requiring constructive modifications to the fuel system or engine components *[3, 5-7, 17, 20]*.

The purpose of theoretical research is to analyze and model the combustion processes of biodiesel-diesel blends in internal combustion engines (ICE), using thermodynamic calculation methods and characteristic relations of the engine cycle. The study aims to highlight the influence of the physicochemical properties of fuels on the parameters of the combustion process, on energy performance and on the formation of polluting emissions. The results obtained through theoretical research will allow the scientific substantiation of the possibilities of partial or total substitution of conventional diesel with biodiesel, contributing to the identification of optimal solutions for improving energy efficiency and reducing environmental impact.

**Materials and methods**

The study of the combustion process was carried out using the graph-analytical method, applied to the DC4 11.0/12.5 internal combustion engine. This method allowed the determination of the thermodynamic parameters of the cycle, based on the fundamental relations that describe the compression, combustion and expansion processes, using the ideal gas equations of state and the heat balance.

The analysis was carried out using the construction data of the DC4 11.0/12.5 engine as follows: compression ratio, cylinder diameter, piston stroke, unit displacement, as well as the characteristics of the analyzed fuel (lower calorific value, elemental composition, stoichiometric coefficient).

For the calculations, the corresponding theoretical values of the fuels were used, namely: diesel, mixtures B20 (diesel 80% + biodiesel 20%), B50 (diesel 50% +

biodiesel 50%) and B100 (biodiesel 100%) transesterified from rapeseed oil *[29]* at the M8-КПБ-01 biofuel production plant developed by SA "Alimentarmaş", city of Chișinău.

The graph-analytical method assumed the representation of the variation of pressure and temperature depending on the angle of rotation of the crankshaft and the volume of the combustion chamber, resulting in P-φ diagrams. Based on the diagram, the characteristic parameters of the combustion process were determined, such as the maximum pressure in the cylinder, the maximum combustion temperature, etc. This approach facilitated the comparative analysis of the behavior of the DC4 11.0/12.5 engine in relation to different types of fuels.

**Results and discussion**

The nature of flame propagation in the combustion chamber of a compression ignition engine is less well understood than in a spark ignition engine *[11, 24]*. In the literature *[19, 26]* it is considered that the fuel combustion process in a compression ignition engine consists of four consecutive phases. This separation is conventional, since many aspects of combustion have not yet been studied. However, the conventional phases of the combustion process reflect the phenomena occurring in the cylinder combustion chamber well enough.

The most complete picture of the combustion process in ICE can be obtained if, when analyzing the development of phases, factors that have a constant influence on combustion are taken into account, for example, the method of fuel injection, the nature of heat release.

The entire combustion period in the ICE cylinder can be divided into the following phases:

I – preparation of autoignition zones (autoignition delay);

II – development of autoignition zones, flame propagation (fast combustion);

III – combustion of the base mass of the mixture (moderate combustion);

IV– relatively slow combustion of the mixture components remaining from the previous phase (post-combustion with expansion intensity).

The combustion process was studied theoretically by the graph-analytical method

*[11, 25-27, 30, 31*] for biodiesel (transesterified from rapeseed oil) and biodiesel-diesel blends. Based on the results obtained from theoretical calculations of the combustion process for the DC4 11.0/12.5 type engine fueled with diesel, biodiesel B100 and their blends (B20, B50), the combustion process was graphically represented in the p-φ diagram (Figure 1).

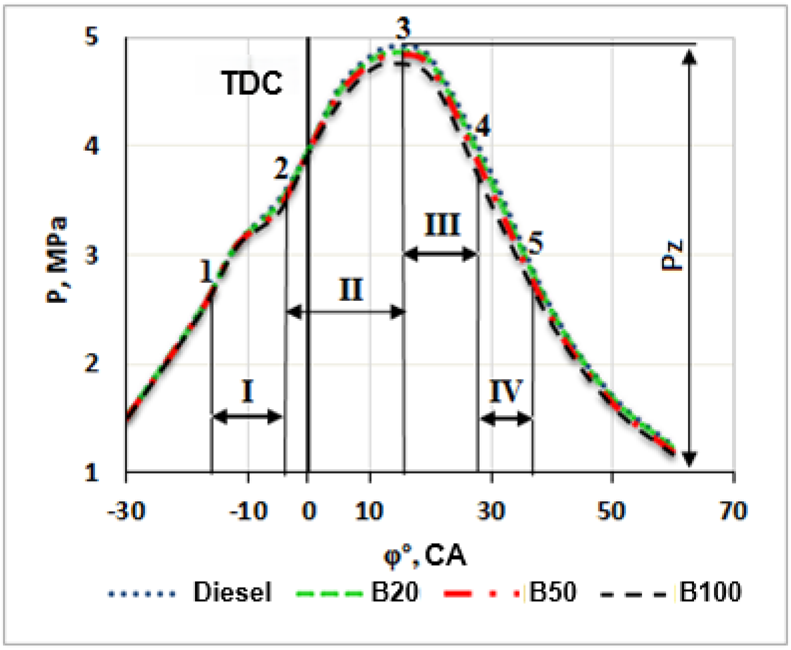


**Figure 1- Graphical representation of the combustion process in the p-φ diagram (TDC- Top dead center, φ- crank angle, degrees CA)**

The first phase takes place in the time interval that actually begins with the fuel injection (point 1, Figure 1) and ends at the moment of rapid pressure increase (2). During this phase, the physicochemical preparation of that part of the fuel that has entered the cylinder during this time interval occurs. However, due to the relatively large distance between the mixture molecules, the rate of heat release during this period is very low and therefore no visible increase in pressure occurs. In phase I, 30-40% of the entire amount of fuel in a cycle is injected into the cylinder.

The duration of the first phase is influenced by the physicochemical properties of the fuel (primarily its autoignition), the pressure and temperature of the fluid, the type of combustion chamber and the intensity of the directed movement of the fresh fluid, the quality of fuel atomization and the engine operating mode under load and speed

*[11]*. Phase I determines the nature of the subsequent phases.

At the end of the first phase (Figure 1, point 2) the process of active heat release begins, i.e. at this point the autoignition zones are already formed. The second phase lasts until point 3 and is characterized by the rapid development of combustion in the entire volume of the combustion chamber with the release of a significant amount of heat in a short time, which explains the rapid increase in pressure and temperature. In this phase, practically all the fuel supplied by the injector in the previous phase, as well as in phase II, burns.

The nature of the second phase is estimated by the pressure increase rate, i.e. the value of the pressure increase in the cylinder per 1° of crankshaft rotation ($\frac{\Delta P}{\Delta \varphi}$). The higher the pressure increase rate, the stiffer the engine operates (trembling engine operation, accompanied by increased noise and wear) and the higher the final combustion pressure (point 2) Pz. The pressure increase rate in the second period depends mainly on the duration of the autoignition delay period. The longer the duration of phase 1, the more fuel, ready for combustion, accumulates in the combustion chamber before autoignition, and the more sharply the pressure increases in the second phase. The pressure increase rate in the second combustion period also increases with increasing fuel supply rate and intensity of vortex (turbulent) movements of the fuel mixture.

The beginning of phase III is determined by the position of the maximum pressure (point 3), and the end - by the position of the maximum temperature of the gases in the cylinder (point 4). Combustion occurs at an almost constant pressure, starting when the piston is close to TDC, when the flame covers the entire combustion chamber and all the previously injected fuel has burned. After that, only the fuel still supplied by the injector into the combustion chamber will burn, but at the end of the supply, the intensity of combustion decreases, since the speed of chemical reactions decreases due to the increase in the amount of inert gases. As a result, the intensity of heat release decreases and the increase in the temperature of the gases contained in the combustion chamber slows down. The last phase of combustion lasts after point 4 (Figure 1) until the combustion reactions slow down due to the effect of the temperature decrease. Combustion in this phase is characterized by a gradual deceleration of the heat release rate, as the fuel combustion conditions become more and more unfavorable - the amount of unused oxygen decreases, the fluid is increasingly diluted with combustion products, the process continues with an increase in volume and a decrease in temperature and pressure. The duration of phase IV corresponds to a rotation angle of $\varphi$=70-80° of the crankshaft from TDC (top dead center), and the total heat release in this phase does not exceed, as a rule, 95-97%.

The results of the calculations performed to construct the theoretical diagram (Figure 1) show that the combustion phases of biofuels largely coincide with those of diesel, since the combustion chamber has not been constructively changed, while the physicochemical properties of rapeseed oil methyl ester ensure the combustion arrangement identical to that of diesel. The results of the calculations show that the maximum values of the combustion pressure pmax decrease in the case of biofuels compared to diesel, respectively: B20-by 0.74%; B50-by 1.67% and B100-by 3.33%. This decrease occurs, probably, because the combustion process of biodiesel B100 and biodiesel-diesel mixtures (B20, B50) proceeds at a lower speed than the combustion process of diesel. This phenomenon reduces the maximum cycle temperature and the operating stiffness of the ICE, reducing the wear of the mating surfaces in the combustion chamber *[1, 13-16, 18]*. The moment of fuel pressure in the theoretical cycle is further shifted to the expansion line (Figure 1), which requires an increase in the advance angle Θ when injecting biodiesel. This allows maintaining the energy performance of the engine fueled with biofuel at the level obtained with diesel.

**Summary and conclusions**.

The decrease in the carbon fractions (by 10.5% wt.) and hydrogen (by 7.7% wt.) in the biodiesel molecule, compared to diesel, is the cause of the decrease in the lower calorific value by 11.3% and, respectively, the increase in the specific $g_e$ consumption of B100 biodiesel. In order to maintain the engine parameters at the nominal values, in the case of B100 biodiesel fueling, a readjustment of the injection pump is necessary to increase the cyclic feed and the advance angle.

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