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INFLUENCE OF ALTERNATIVE FUELS ON COMBUSTION INDICATORS WITH DIESEL ENGINES

Abstract

Constant lowering of natural reserves of fossil fuels as well as continuous increasing of its exploitation costs influences more intensive researching in finding alternative energy recourses that are able to decrease an import dependent of expensive raw oil and its products from one side and give contribution to decreasing toxic emission as a product of combustion process. As result of this consideration majority of developed European countries endeavor to fulfill proposals of the European parliament and the Council for promotion bio fuels to substitute petroleum and diesel fuels with bio fuels in proportion of 5.75% of their total sold amount, measured by its energy content, by the year 2010.

In the paper usage of bio fuels in IC diesel engines for mobile applications is considered. Accent is given on combustion processes of so called biodiesel fuel, as a full alternative for classical diesel fuel, as well as their blends, where important role has beginning, character of heat release and duration of combustion process. Calculation results of relevant combustion parameters for the used fuels and comparison with appropriate parameters of combustion processes with fossil origin based diesel fuel are presented. Verification of the calculation results where carried out through tests made on one diesel engine.

1. Introduction

The idea of using alternative fuels in the internal combustion, IC engines is neither new nor revolutionary. More intensive consideration of possible alternative fuels which would partially or completely substitute the oil and its products started in the 1970s when the first bigger oil crisis appeared. At the time the motivation for it was obviously making the market less dependant on the basic and the most expensive oil products, petrol and diesel fuels. During the 1980s with the awakening of ecological consciousness caused by significant toxic emission increase from the vehicles exhaust, the motivation for introducing alternative fuels was extended to possibilities of reducing emissions, so called law regulated emissions, especially of CO, HC, NO_x and smoke values. The promotion of introducing and using alternative fuels was based on pointing out the advantages of alternative fuels from the financial and ecological aspect, but all that was done on a voluntary basis.The end of the 1990s in the EU brought a completely different approach to promoting and introducing alternative fuels. Therefore, using an alternative fuel is now as important as it being from renewable resources of energy.

Thus in 1997 with, so called, *White paper on renewable resources of energy* the new goal is set: 12% of total energy source consumption should be from renewable resources by the end of 2010. The instruction for the improvement and use of biofuels and other renewable fuels for the transport sector set by the European parliament in 2003 is very important and commiting [1]. Specifically, this instruction directs all the members of the EU to provide corresponding measures for substituting petroleum and conventional diesel fuels with the fuels from renewable resources, measured by its energy content, in proportion of 2% by the end of the year 2005 and 5,75% by the end of the year 2010. With the implementation of this instruction the EU expects a certain decrease of the dependance on the import of high-priced fossil fuels and the lowering of the emission of CO_2, being a greenhouse gas, and other regulated emissions as well as the development of the new and inovative fields of economy. The reasons for introducing biofuels as an alternative to conventional fossil fuels are very clear from the political and sociological aspect. Nevertheless, technically speaking, especially when the biofuels of plant and animal origin are concerned, it represents a suitable solution since the constructive changes on the IC engines are not needed. Still, it is necessary to optimize IC engines due to specific physical and chemical properties of these new kinds of fuels.

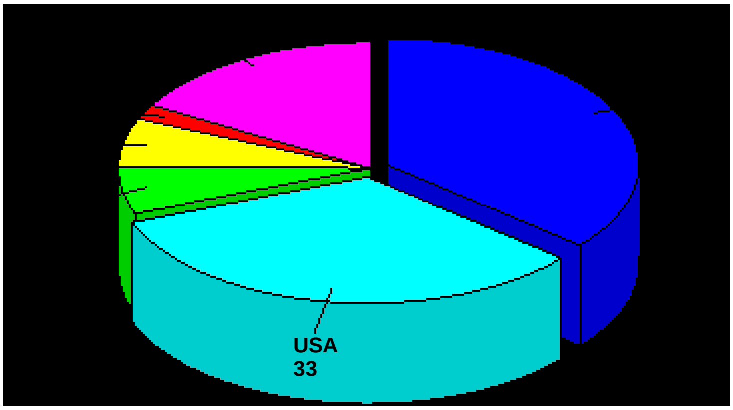
2. Biofuels as an alternative to fossil fuels

Since the basic difference among IC engines is based on the ignition characteristic of fuel blends (spark ignition and compression ignition IC engines) there have to be different kinds of fuels for each of them on the market. Today there are two prevailing fuels on the market, bioethanol and biodiesel, one for each kind of an engine, while other sorts of biofuels are hardly found in a commercial use. Figure 1 shows the overview of biofuels, those used in the past and those we expect to be used in the future[2].

Figure 1: Overview of biofuels

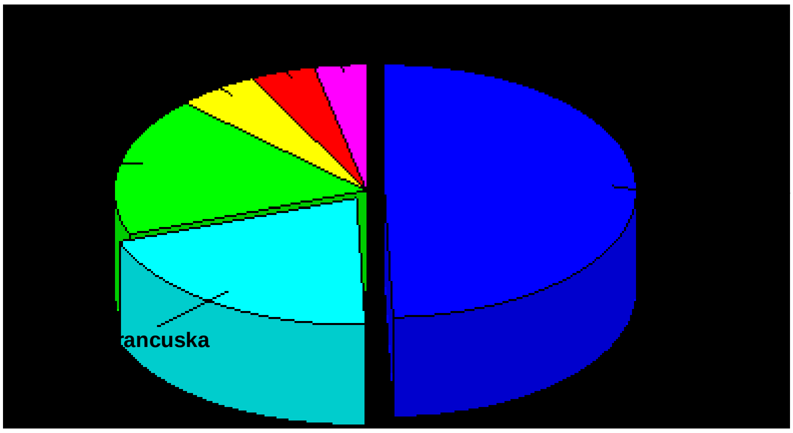
	Gasoline engine fuels	Diesel engine fuels
Today	Ethanol Other liquid fuels based on bioethanol:	FAME (Fatty Acid Methyl Esters)
Soon	ETBE (Ethyl Tertiary Bytil Ether) TAME (Tertiary-Amil Methyl Ether) TAEE (Tertiary-Amil Ethyl Ether)	FAEE (Fatty Acid Ethyl Esters)
Future	Ligno-cellulose Ethanol	BTL (Biomass To Liquid)
Far future	Treated vegetable oil New biofuels	Treated vegetable oil New biofuels

Figure 2: World production share of bioethanol for the year 2004



As expected the North and South America have the supremacy in the production of bioethanol. There are two reasons for that: the natural resources and the market orientation toward the gasoline engine as a generating unit for road vehicles. The situation with the biodiesel production is quite different. In Figure 3 is obvious that the European market has the supremacy in the production and use of biodiesel. A great number of personal vehicles and almost all the commercial road vehicles in Europe use the diesel engine so this proportion is logical.

Figure 3: World production share of biodiesel for the year 2004



Within this research special attention was paid to biodiesel as the IC engine fuel. In Table 1 the basic physical and chemical properties of biodiesel and conventional diesel fuels are compared.

Table 1: Basic physical and chemical properties of biodiesel and diesel fuel

	D2	Biodiesel
Density at 15ºC [kg/m^3]	845	865
Viscosity at 40ºC [mm^2/s]	2,5	4,3
Thermal power [MJ/kg]	42,6	37,3
Cetane number	46	>49
Content		
Mass content C	0,860	0,7750
Mass content H	0,134	0,1210
Mass content S	0,003	0,0001
Mass content O	-	0,1040
Stehiometric ratio of combustion	14,5	12,4

3. Characteristic engine indicators and combustion process analysis

The experiment evaluates 6-cylinder, 4-stroke diesel engine used as a drive unit in buses. In Table 2 the basic parameters of the tested engine can be seen.

Table 2: Basic parameters of the tested engine

Engine	Intake, 4-stroke with MAN injection fuel procedure
Cylinder number	6
Bore and stroke	125 mm x 155 mm
Engine capacity	11,413 dm^3
Compression ratio	18
Static angle of preinjection	23° before TDC
Rated power	160kW/2200 min^{-1}
Torque	775 Nm/1400 min^{-1}

We have also estimated other relevant indicators such as the engine cylinder pressure, the maximum values for the engine pressure, the intake flow, the cooling water flow, the content of exhaust gases, the fuel consumption, etc. Based on the engine indicators, constructive characteristics and fuel properties (density, thermal power, etc.) we have estimated some indicators (loading degree, equivalent air relation, left gases coefficient, thermal balance of the engine, etc.). The diagram shows the static angle of preinjection with both fuels (Figure 4). In this figure you can also see the suppressed combustion period (φ_I), the preinjection angle (φ_{pu}), the start of visible combustion (φ_{pvi}).

Figure 4: In-cylinder pressure for biodiesel and diesel fuel for maximal torque regime

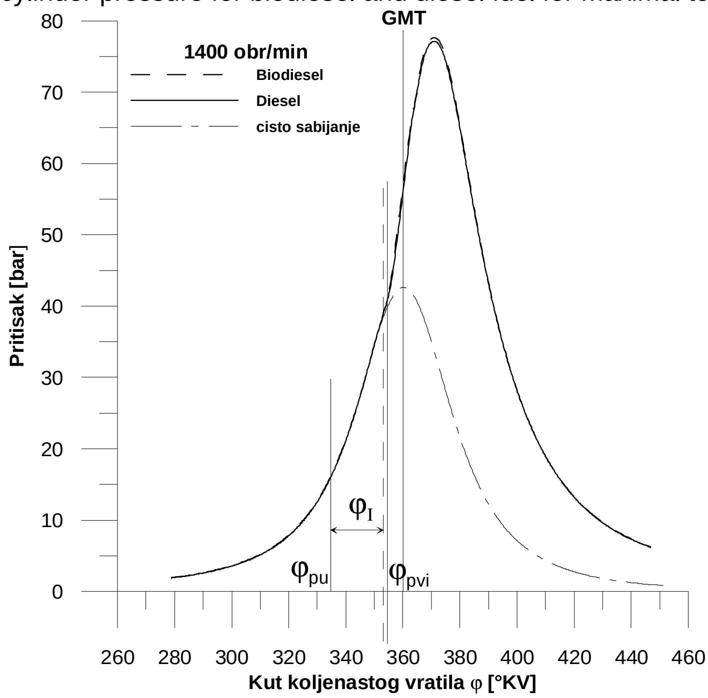


Figure 4 presents the diagram of the in-cylinder pressure for a engine RPM which correspond with maximum torque with the engine under full load. The pressure difference in two extreme cases, the use of biodiesel and diesel fuels, is not big. You can also notice slight, but significant differences in the angle interval of suppressed combustion. The angle interval of suppressed combustion with biodiesel is slightly smaller which can be related to its slightly higher Cetane number as well as higher viscosity of biodiesel. All these factors make its fuel injection process different from diesel fuel.

With the increased engine speed and coming closer to maximum power regime the differences in in-cylinder pressures with neat biodiesel and diesel fuels are lessening.

Using all the mentioned engine indicators we developed the preconditons for the analysis of combustion process indicators.

3.1 Combustion process indicators

Most of all the engine performance depends on adjusting the indicators of fuel supply, fuel mixing with air, the beginning of mixture ignition and the combustion flow. To make the perfect match we need to know the combustion process indicators. They are:

- maximum combustion pressure *(p_{max})* and maximum cycle temperature *(T_{max})*,
- angle of start of visible combustion at TDC (φ_{pvi}),
- angle period of combustion duration (φ_{ti}),
- gross heat release rate (combustion characteristic),
- cumulative gross heat release (Q_{akt}).

Maximum combustion pressure as well as the angle of start of visible combustion are determined on the basis of the recorded pressure diagram in the engine and the pressure diagram of pure compression. The period of combustion duration can not be directly determined on the basis of measuring results. It is defined by a combustion characteristic got from pressure diagram analysis. The gross heat release rate (combustion characteristic) can be estimated by a one-zone model as [6, 7, 8]:

$$\frac{dQ_{akt}}{d\varphi}=\frac{\dfrac{dQ_c}{d\varphi}+p\dfrac{dV}{d\varphi}+\dfrac{1}{R}\dfrac{\partial u}{\partial T}\dfrac{p\dfrac{dV}{d\varphi}+V\dfrac{dp}{d\varphi}-mT\dfrac{\partial R}{\partial p}\dfrac{dp}{d\varphi}}{1+\dfrac{T}{R}\dfrac{\partial R}{\partial T}}+m\dfrac{\partial u}{\partial p}\dfrac{dp}{d\varphi}}{1+\left[\dfrac{\partial u}{\partial T}\dfrac{T}{1+\dfrac{T}{R}\dfrac{\partial R}{\partial T}}-u\right]\dfrac{1}{H_g}-c_\alpha m\left[\dfrac{\partial u}{\partial \alpha}-\dfrac{\partial u}{\partial T}\dfrac{\partial R}{\partial \alpha}\dfrac{T}{R}\dfrac{1}{1+\dfrac{T}{R}\dfrac{\partial R}{\partial T}}\right]}, \qquad (1)$$

where are:

Q_c heat loss,

u	specific internal energy,
R	gas constant,
T	temperature,
H_g	low caloric value of fuel,
α	air surplus coefficient,

$$c_{\alpha} = -\frac{m_g H_g \left[\alpha_0^2 (1+\gamma) + \alpha_0 (\mu_0 - 1)\right](\alpha_0 + \mu_0 - 1)}{\left[\alpha_0 \gamma H_g m_g + (\alpha_0 + \mu_0 - 1) Q_{akt}\right]^2},$$

γ	left gases coefficient,
μ_0	theoretic molecular change coefficient,
m_g	fuel mass.

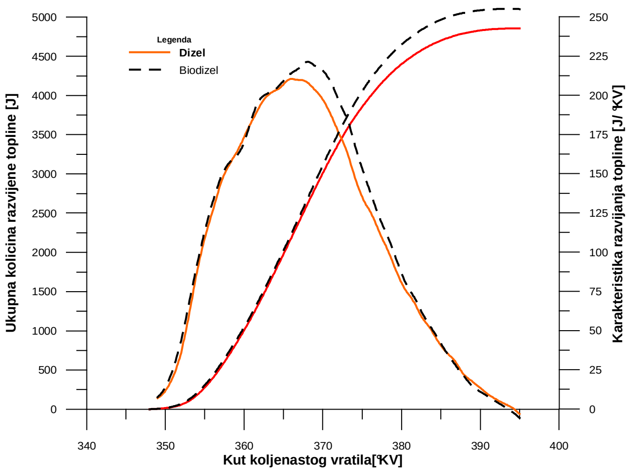
Concerning the flow of recorded pressures in the engine, it was necessary to do the 'balancing' [8] in the zone of intensive oscillations in order to get the average values of Q_{akt} and $dQ_{akt}/d\varphi$.

All the other values such as:

- current cylinder capacity V(φ),
- working substance mass m(φ),
- gas constant R(φ) etc.

are defined by the change of crankshaft revolution angle (φ) also taking into account the geometrical values of the piston mechanism, the content of working substance in the cylinder, the combustion gases content in the cylinder and so [6, 7, 9]. Figure 5 shows an example of characteristic values for both kinds of fuels at the nominal power regime.

Figure 5: Gross heat release rate and cumulative gross heat released



These results show that the deviations of gross heat release rate for diesel and biodiesel fuels are relatively small under the given regime. In this paper the results of only one regime are presented, but the final conclusion is based on a large number of results under the different engine performance regimes.

4. Conclusion

This paper presents parallel results of the basic combustion process indicators with diesel engines using diesel and biodiesel fuels. It can be concluded:

- Maximum pressure and maximum cycle temperature are almost the same or biodiesel has higher values.
- Biodiesel consumption is increased in both cases due to the lower caloric values and keeping approximately equal output indicators of the IC engines.
- Suppressed combustion angle is less with biodiesel.
- Combustion period angle stays unchanged.
- Gross heat release rate is approximately equal for both fuels, but the extreme values for biodiesel are higher.

All these indicators work for the same engine efficiency, approximately equal output power, but it should be noticed that the same fuel preinjection angle is retained which results in an unoptimized engine performance with biodiesel. Being seen through output power the process efficiency is retained with the fact that the output power is P_e α ∫ pdV, and the combustion rate is big enough not to worsen the combustion conditions at the period (increased smoke, CO, HC). The NO_x emission is increased due to slightly increased peak combustion temperatures in relation to conventional diesel fuel use. All this leads us to the conclusion that knowing the indicators of biodiesel combustion helps us to adjust the optimal indicators which provide the best engine efficiency along with very low toxic emission.

UDK	ključne riječi	key words
665.3.094.942	biodizelsko gorivo, metilni esteri masnih kiseline	biodiesel fuel, fatty acids methyl ester (FAME)
665.753.4	dizelsko gorivo	diesel fuel
.004.15	gledište djelotvornosti	performance viewpoint
.001.36	gledište usporedbe	comparison viewpoint

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