Dževad Bibić, Ivan Filipović, Breda Kegl, Boran Pikula

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INFLUENCE OF BIO FUELS ON POLLUTANT EMISSIONS OF DIESEL ENGINES

Abstract

Introducing fuels from renewable energy sources in form of blends or pure fuels has its purpose in the tendency of saving conventional energy sources and reduction of global CO_2 emission. However, in dependence of kind of renewable energy source the fuels are obtained, it is to expect differences in pollutant emissions in reference to conventional fuels. Common theoretical considerations are also pointing out the potential of fuels from renewable energy sources to reduce regulated pollutant emissions.

The use of biodiesel, as a fuel from renewable energy source, for reducing regulated pollutant emissions in IC diesel engines for heavy duty vehicles is considered in the paper. The applied test procedures comply with the requirements of the European standards for IC diesel engines that are obligatory during homologation approval, so called European Stationary Cycle. On the basis of test results and corresponding calculations of pollutant emissions for both bio and conventional fuel use in the IC engine with the same adjustment parameters are shown. With appropriate argumentation, the importance of engine parameter optimization, at first the fuel injection angle in dependence of kind of used fuels is pointed out.

1. Introduction

A number of studies show that organic oils, such as rapeseed oil, soyabean oil and sunflower oil are potential different alternative fuels for diesel engines. They are renewable, biodegradable, with lower particle emissions and higher cetane number when compared with diesel fuels. Pure oils have high viscosity so as such they can not be used in the engine, but within certain procedures they are transformed into the so called biofuels.

There are many advantages of using biofuels as alternative fossil fuels. Some history facts relating energy supply in the European Union are:

- industry dependence of Europe is based on the fossil sources,
- energy dependence on the import is 50 %, with high sensitivity due to unstable political situation in the countries with major fossil fuel sources,

- the accumulation of green house gases due to fossil fuel emission within the period of more than 100 years which increases the global pollution – there is a consensus on climate changes as the result of this accumulation [1].

Some facts significant for the energy supply in Europe:

- the supply of fossil fuels decreases more and more and it is evident that one day it will be exhausted,
- dramatic price increase of fossil fuels,
- the renewable sources made only 5,61% of total energy consumption in Europe in 2004 (5,5 % in 2003) [1].

The European Union accepted the strategy of the presentation and development of biodiesel as an alternative fuel within the traffic sector. Europe directed its strategy on the traffic sector since it takes more than 30 % of total energy consumption in the European Union and it keeps growing. Fossil fuels make 98 % of it. According to the recent information, if this trend of traffic increase does not change, we can expect that the emission of CO_2 from the traffic sector will be increased even by 50 % when compared to the emission in 1990. The road traffic sector takes 84 % of the CO_2 emission and that is the reason for the EU strategy to be directed on the introduction of the renewable energy sources which release less CO_2. Basically, biodiesel is neutral. When they grow, plants absorb CO_2, and after they are harvested the plants are used for biofuels which combust in vehicle engines and release CO_2. That makes the "ideal" CO_2 cycle, Picture 1. Nevertheless, the current cycle is not exactly ideal since biodiesel releases more CO_2 than it's absorbed by the plants.

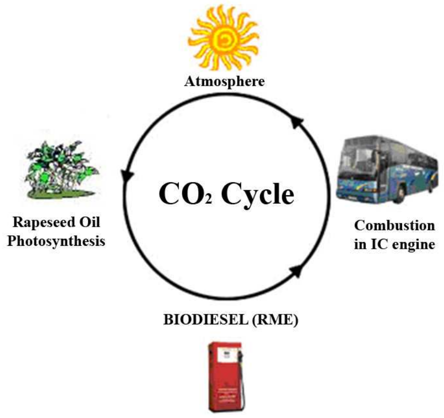


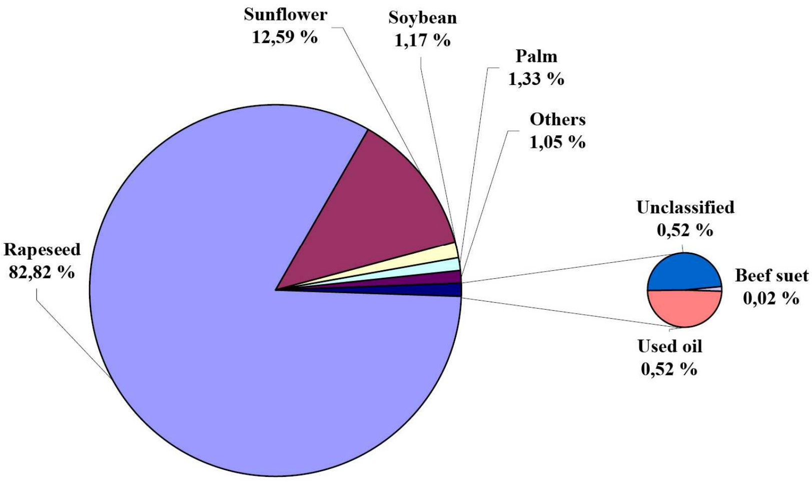
Figure 1: "Ideal" CO_2 cycle [2]

There is a great emphasis put on the public transport in all the larger EU cities. All the cities dispose of large bus fleet, mainly using diesel engines. Within this sector there is a tendency to produce diesel buses with economic fuel consumption and less harmful substances in exhaust gases. Biomass fuel could solve this dilemma since it has the potential to establish the "ideal“ CO_2 cycle and the potential to reduce emissions of regulated pollutants from exhaust gases of diesel engines.

All these facts led to providing certain legislative solutions of this problem. The EU brought the Directive 2003/30/EC on the promotion of the use of biofuels or other renewable fuels for transport. Here are some of the highlights of this directive:

- By the end of 2005 the EU member states have to provide 2 % of the minimum share of biofuels in the total consumption of all the petrol and diesel fuels (as their energy value is concerned and 5,75 % of it by the of 2010;
- Biofuels can be available as:
  a) pure biofuels or with high concentration in fossil fuels;
  b) blended with fossil fuels according to the proscribed European norms;
  c) as liquids derived from biofuels, such as ETBE (ethyl-tertiar-butyl-ether), biofuels based on bioethanol with at least 47 % bio-ETBE [6].

Biofuels can be gained from vegetable oil, recycled waste edible oil or animal fat. Today about 55 % of biodiesel industry uses fats or oils of any origin, including recycled cooking, while the rest of the production relates to vegetable oils. We can get vegetable oils from different sources, but the most frequent ones are rapeseed, sunflower, soybean, palm and others. In Europe the main raw material for the production of biodiesel is rapeseed, while in America that is sunflower. Therefore, this fact depends on the available natural resources of a given geographical area. Sunflower oils and rapeseed oils are of high quality and the simplest for the biodiesel production process. The Picture 2 shows the global proportion of certain raw materials in the biodiesel production in percentages.



Picture 2: Raw materials for the production of biodiesel [2]

The basis of the change possibility for all the sources of biodiesel is that they contain fat in any form. Oils are fats in the liquid state at room temperature. These fats are triacylglycerides (often called triglycerides) which consist of carbon, hydrogen and oxygen combined in a specific form. Soybeans contain around 20 % of oil and rapeseed, which is the main source of biodiesel in Europe, contains 49 % of oil.

This paper also presents some results of the authors' work from the area of the use of biodiesel fuel for heavy IC engines which are typical for city buses. The emission of regulated substances from exhaust gases in the use of diesel and biodiesel fuels is presented, too.

2. Legal limits for pollutant emissions and test cycles

Regulations relating emissions of harmful substances for heavy diesel vehicles were introduced for the very first time by the Directive 88/77/EEC, which was amended for several times later on. In 2005 this Directive was improved and confirmed by the Directive 2005/55/EC and it relates heavy trucks and city buses. This directive works for all the motor vehicles having total weight over 3500 kg. The Table 1 shows the emission norms with dates of their implementation.

Table 1: European emission norms for heavy duty vehicles with diesel engine, [g/kWh] (dim [m^{-1}]) [3,4,5]

norm	date and category	test cycle	CO	HC	NO_x	particles (PM)	DIM
Euro I	1992 <85 kW	ECE R-49	4,5	1,1	8,0	0,612	
	1992 >85 kW		4,5	1,1	8,0	0,36	
Euro II	1996/10		4,0	1,1	7,0	0,25	
	1998/10		4,0	1,1	7,0	0,15	
Euro III	*1999/10 EEV only*	*ESC and ELR*	*1,5*	*0,25*	*2,0*	*0,02*	*0,15*
	2000/10	ESC and ELR	2,1	0,66	5,0	0,10 0,13*	0,8
Euro IV	2005/10		1,5	0,46	3,5	0,02	0,5
Euro V	2008/10		1,5	0,46	2,0	0,02	0,5

* for engine capacity less than 0,75 dm^3 per cylinder and n_{nom}>3000 min^{-1}
EEV (Extra low emission vehicles)

Emission norms for heavy duty vehicles with diesel or gas engines tested according to the ETC test cycle are summed up in the Table 2.

Changes in engine test cycles were introduced with the Euro III norm, which replaced earlier stationary test cycle ECE R-49 with two new cycles: *ESC* (*European Stationary Cycle*) and *ELR* (*European Load Response*) test. Smoke value is evaluated by the *ELR* cycle. In order to get a certification a new vehicle needs to meet these requirements within a test cycle:

– Conventional diesel engines can be tested via a ESC or ELR cycle
– Diesel engines with subsequent treatment of exhaust gases are tested via two test cycles: *ESC* or *ELR* and *ETC* cycle
– Gas engines are tested via *ETC* cycle.

We are explaining the *ESC* test cycle since all the tests in this paper were performed on a so-called conventional diesel engine.

Table 2: Emission norms for diesel and gas engines, ETC cycles, [g/kWh] [3,4,5]

norm	date and category	test cycle	CO	NMHC nonmethane hydrocarbons	CH_4[A]	NO_X	particl. (PM)[B]
Euro III	*1999.10, EEV only*	*ETC*	*3,0*	*0,4*	*0,65*	*2,0*	*0,02*
	2000/10	ETC	5,45	0,78	1,6	5,0	0,16 0,21[C]
Euro IV	2005/10		4,0	0,55	1,1	3,5	0,03
Euro V	2008/10		4,0	0,55	1,1	2,0	0,03

A – for gas engines only
B – not applicable for gas engines in 2000 and 2005
C – for engine capacity less than *0,75 dm³* per cylinder and n_{nom} > *3000 min⁻¹*

The concentration of harmful substances which is evaluated in the exhaust gases coming out from an engine includes gaseous components (CO, HC, NO_x) and particles. All these measurements are performed on the samples continuously taken from raw exhaust gases. A test cycle consists of a number of work regimes with precisely given rotation speed, load and time of retaining a prescribed work regime. Work regimes cover a typical working area of IC engines which are used in heavy commercial vehicles and buses. While retaining the IC engine in each work regime, we measured the concentration of estimated components in exhaust gases, the flow of exhaust gases and effective strength, or in other words, effective torque of the IC engine.

A ESC cycle was introduced along with *ETC* and *ELR* test cycles for the certification of diesel engine emission which came into force in 2000. It replaced the former R49 test cycle. That is actually a 13-mode stationary test which evaluates the emission of harmful substances from exhaust gases and compares it to the approved emissions.

An IC engine is mounted on a test gig and by using an engine test brake it is brought to a certain work regime and in each of them it remains during a certain period. The change of the rotation speed and the load while switching from one regime into another should occur within 20 seconds. The rotation speed and IC engine torque have to be constant allowing ± 50 min^{-1}, or ± 2 % of the maximum torque in a current mode. The Table 3 shows the duration in particular modes, required rotation speeds and prescribed engine load. The Picture 3 illustrates weight factors of particular modes, which actually present a percentage share of the emissions of harmful substances from particular modes in the final estimated mean of the emission of harmful substances from the exhaust system of an IC engine for the whole test cycle [3, 4, 5].

Table 3 Characteristics of particular modes of ESC cycles [3, 4, 5]

Mode	Rotation speed	Load [%]	Weight factor [%]	Duration [min]	Mode	Rotation speed	Load [%]	Weight factor [%]	Duration [min]
1	Idle	0	15	4	8	B	100	9	2
2	A	100	8	2	9	B	25	10	2
3	B	50	10	2	10	C	100	8	2
4	B	75	10	2	11	C	25	5	2
5	A	50	5	2	12	C	75	5	2
6	A	75	5	2	13	C	50	5	2
7	A	25	5	2					

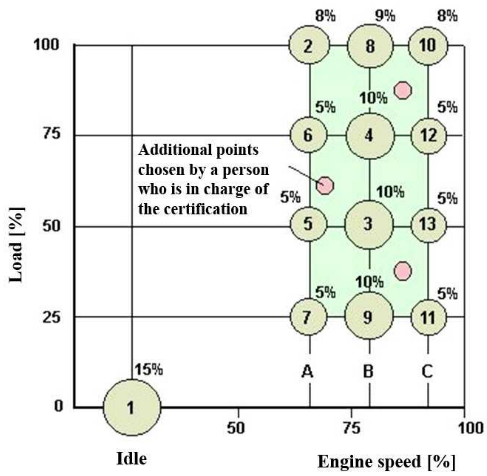


Figure 3: ESC cycle with shown characteristic modes [3,4,5]

During each mode the emission is measured, and then we get the mean in a precisely defined way [3,4,5]. The results are expressed in [g/kWh] and then compared to the prescribed values.

All the research and measurements done in this paper relate to medium fast water cooled diesel engine with M injection procedure, model MAN type D2566MUM. We have chosen this engine (MAN type D 2566 MUM) for testing based on the fact that it is mostly used as a drive unit in city and suburban buses, and that means that it has a significant proportion in the fuel consumption and the total emission of harmful substances in urban areas. In the Table 4 you can see the basic information on the tested engine, while in the Table 5 you have basic information on the used fuels [7].

Table 4: Basic information on the tested engine

Engine type	*In line-six cylinder-horizontal-naturally aspirated-diesel engine*
Engine displacement	*11,413* dm^3
Cylinder bore	*125 mm*
Piston stroke	*155 mm*
Connecting rod length	*244 mm*
Rated engine power at engine speed	*160 kW/2200* min^{-1}
Maximum torque at engine speed	*775 Nm/1400* min^{-1}
Compression degree	*18:1*

Table 5: Basic physical-chemical properties of biodiesel and diesel fuels

	Diesel	**Biodiesel**
Density at 15 °C [kg/m^3]	845	865
Viscosity at 40°C [mm^2/s]	2,5	4,3
Heating value [MJ/kg]	42,6	37,3
Cetane number	46	> 49

The tests were done according to the regulations of the *ESC* test cycle for two different static angles of fuel pre-injection, 21°K V and 23°KV prior to UDP, and this is the reason for the angle 21°KV prior to UDP to have , based on the previous tests [6], the optimal work regime of an engine with bio-diesel fuel as exhaust gas emissions, realized power and specific fuel consumption are considered. According to the information given by the manufacturer of the engine when conventional diesel fuel is used the optimal angle of exhaust gas emission is 23°KV prior to GMT.

The test results are summed up in the Table 6 which shows the values of regulated pollutants such as CO, HC and NO_x, for two different angles of pre-injection and two different fuels. It is evident that the CO and NO_x values are larger than limit values stated in the Tables 1 and 2, while the HC emission is within the approved limits. The reason therefore lays in the fact that the tested engine was constructed a long time before these prescribed limit values stated in the tables came into force.

Table 6: Emission values according to the ESC cycle [g/kWh]

pre-injection angle		CO	HC	NO_x
diesel	21 °KV	2,22	0,2	9,83
	23 °KV	2,36	0,191	8,73
biodiesel	21 °KV	2,04	0,186	12,97
	23 °KV	2,177	0,16	15,728

The observations of such an IC engine are justified by the fact that it is often used as the drive unit in city buses even today. In order to justify this research we can also add that the main aim of this test was not the classification of an IC engine within one emission group, but the analysis of advantages and disadvantages of the use of biofuel from the aspect of the regulated emission of harmful substances from exhaust gases.

The results shown in the Table 6 uniformly indicate that the values of CO emission when using biodiesel by cca. 8 % lower and the values of incombusted hydrocarbons HC are by 7-17 % lower, while the emission of nitrogen oxides NO_x is higher with biodiesel than with diesel by 25-45 %. These emission proportions of particular components in exhaust gases with these two tested fuels can be found in the mechanism of formation. Nevertheless, the main reason of CO formation is incomplete fuel combustion, which means insufficient blending of air/fuel mixture and the lack of oxygen in the reaction zone. Since the molecules of biodiesel have chemically bound oxygen, the combustion is more complete which explains lesser values of CO and HC emissions when related to the use of diesel fuel [7]. On the other hand, it is due to oxygen contained in biodiesel fuel and reagent longer staying in the reaction zone at increased pre-injection angle that NO_x emissions when biodiesel is used are increased when related to the pre-injection angle as well as diesel fuel.

3. Conclusion

The paper shows the test results of IC diesel engines using fuels from renewable energy sources with two different static angles of fuel pre-injection, which confirm the standpoint and theoretical analysis of numerous authors that biofuels have the potential to reduce regulated pollutant emission from engine exhaust gases. Measurements and evaluation confirmed that with biodiesel the emission of CO and HC is lower and the emission of NOx is higher when compared to regular diesel fuel.

Different physical-chemical features of the observed fuels dictate differences in the emissions to become even more significant when reducing the static angle of pre-injection, in favor of biodiesel, primarily due to prominent differences in the values of viscosity and cetane number.

The use of alternative fuels is no longer an act of an individual and his/her choice to spare money or to preserve the environment, but this is the matter of global politics and legislative determination. Therefore we expect that the interest in the research and the use of alternative fuels in IC engines will intensely grow, especially in the sector of renewable energy resources such as biodiesel fuel.

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621.436.068.3	ispušna emiisija dizelskog motora	diesel engine exhaust emission
621.436.038	kut zadržanog ubrizgavanja dizelskog motora	diesel engine injection delay angle

Authors

Doc. dr. sc. Dževad Bibić, prof. dr. sc. Ivan Filipović, doc. dr. sc. Boran Pikula
Faculty of Mechanical Engineering, Department for engines and vehicles, Vilsonovo šetalište 9, 71000 Sarajevo, Bosnia and Herzegovina, e-mail: bibic@mef.unsa.ba, prof. dr. sc. Breda Kegl, University of Maribor, Faculty of Mechanical Engineering, Maribor, Republic of Slovenia

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