THE ARCHIVES OF TRANSPORT

VOL. XXIV NO 1 2012

10.2478/v10174-012-0002-8

Preliminary Biofuel Treatment in Injector Bodies of Diesel Engines

Oleh Klyus*

Received March 2011

Abstract

The paper discusses possibilities of increasing the performance parameters of a diesel engine and decreasing the emission of toxic compounds contained in exhaust gases by using preliminary catalytic treatment of biofuel, executed directly in the injector body. In order to enhance the impact of the catalyst on the flowing fuel the author proposes to utilize the phenomenon of turbulization in injector passages. The results of tests on a 359 type engine have shown an improvement of operational parameters and a decrease of toxic emission in exhaust gases.

1. Introduction

The use of renewable sources of energy, such as biofuels, is preceded by research in various fields of science, including biochemistry and technology. If we consider piston combustion engines and oils containing fatty acids and their esters, applicable in combustion chambers of self-ignition engines, such oils should meet requirements for injection and atomization. Consequently, such oils should undergo the processes of oxidation accompanied by maximum heat energy produced and minimum level of toxic compounds in exhaust gases – desired parameters of engine efficiency and ecological operation. This, in turn, entails such issues as the production of proper plant species yielding required oil characteristics (biochemistry) and adequate arrangements connected with working processes in the engine (technology). To put it differently, it is the composition of biofuel or its mixture with petroleum-based oil and the design of combustion chamber and injection equipment that will definitely affect the outcome – maximum engine efficiency and minimum toxicity.

* Maritime University of Szczecin, Wały Chrobrego 1-2, 70-500 Szczecin, Poland

2. Biofuel for Diesel Engines

2.1. The biological aspect

Oil plants in the course of their growth accumulate oil in their seeds, which allows them in the first phase of development, before leaves appear and photosynthesis starts, to utilize the energy of its fats [8]. Fat is found in each seed, but the composition of vegetable oil varies depending on the geographical/climatic zones. For instance, the unsaturation index of flax seeds (which defines the number of multiple bonds and rings in a compound) increases as the plant growth areas shift from south to north and northeast. People generally use vegetable oils for culinary purposes. In recent years, due to genetic engineering, oil seeds have been observed to have higher oil content. Some plants bring substantial yield of oil, e.g. Helantus sunflower has 72-75% oil content. This however, makes seeds difficult in storage where special conditions have to be met.

Over the past years there has been a discussion on the use of vegetable oils as fuel. One argument in favour is the significant rise of raw materials prices and the conversion of forests into arable fields. However, the increase in rice prices in the years 2007-2008 cannot be explained in economic terms connected with biofuels, as rice in not a source of oil. Besides, seeds of such plants as *Jatropha Curcas* and *Pongamia Pinnata* can be used as biofuel source, but they are not edible due to the content of toxic compounds.

It follows from the above that non-edible plants can be utilized for the production of fuel oils. Adequate requirements can be set forth for such plants, as they have to have a specific composition of fatty acids. For example, the component known as stearic acid increases deposits in high pressure pipes. The low content of linolenic acid and high content of oleic acid are good properties for storage, but at the same time they raise unit fuel consumption and the level of toxic compounds in engine exhaust gases emitted to the atmosphere. One indicator of unsaturation of fatty acids in vegetable plants is the iodine number – is the number of moles of iodine reacting with one mole of fat/oil which indicates the number of double bonds present in the fat/oil molecule [8]. In vegetable oils unsaturated compounds are unsaturated fatty acids that are highly susceptible to oxidation. In Table 1 example values of induction periods and rates of oxidation for selected fatty acids are presented.

Table 1

Induction period and rate of oxidation of fatty acids [8]

Acid		Symbol	Number of double bonds	Period of induction, h	Relative oxidation rate
Stearic	$C_{18}H_{36}O_2$	C18:0	0	–	1
Oleic	$C_{18}H_{34}O_2$	C18:1	1	82	100
Linoleic	$C_{18}H_{32}O_2$	C18:2	2	19	1200
Linolenic	$C_{18}H_{30}O_2$	C18:3	3	1.34	2500

As shown in Table 1, along with an increase in the number of double bonds the oil oxidation rate significantly rises. Therefore, it is purposeful to determine the influence of unsaturated acids (iodine number) on ecological parameters of diesel engines. In Figure 1 the results of testing a piston self-ignition engine running on biofuels are given [3]. As the iodine number increases, the level of nitrogen oxides emission linearly rises, which can be explained by accelerated fuel oxidation, and consequently, higher temperature in the combustion chamber, while the emission of particulate matter has a visible optimum level at the iodine number 90-120.

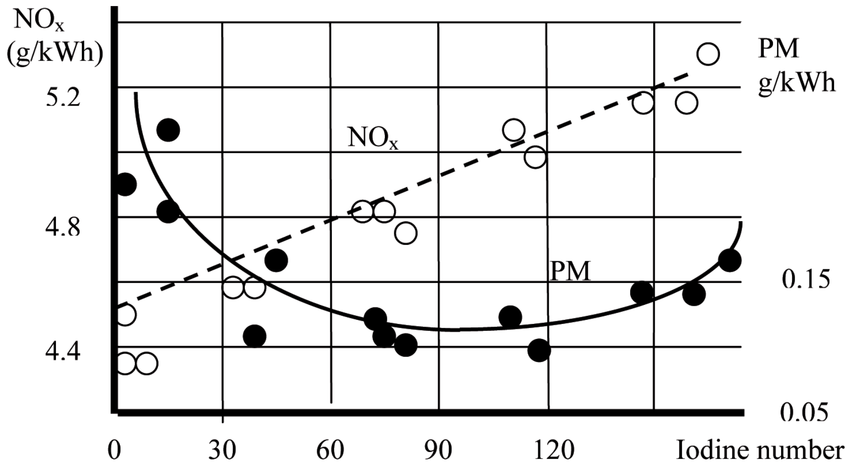


Fig. 1. Effect of the iodine number on NO_x emission (y=0.0068x+4.3476, R^2 =0.9043) and PM (y=3E-0.5x^2-0.005x+0.359, R^2 =0.777) in biofuel combustion [3]

2.2. The technical aspect

It is a known fact that the two phases of the combustion process in self-ignition engines, particularly the second phase – kinetic combustion – characterized by sudden pressure increase, is interconnected with the first phase – the period of ignition delay. The phenomena taking place in both these phases have a significant influence on the limitation of engine speed, and engine mechanical and thermal loads. The delay of self-ignition is due to the fact that fuel has to be prepared for ignition, i.e. fuel droplets have to be heated to the point of partial or complete evaporation, the remaining fuel vapours have to be heated to the point of self-ignition, and at this time preliminary fuel oxidation takes place, leading to self-ignition. Therefore, by fuel treatment during its delivery to the combustion chamber, the first phase and the entire process of combustion can be improved.

Physical parameters of fuel in self-ignition engines are first of all the density, viscosity and surface tension. These parameters are critical for the size of droplet diameter, shape and range of the atomized fuel stream. This, in turn, is connected with the first combustion phase – self-ignition delay. Chemical parameters of fuel depend on the structural composition of hydrocarbons, mostly represented by the paraffin group C_nH_{2n+2}. It should be underlined that in appropriate conditions – the presence of a catalyst – certain reactions can take place that result in converting paraffins into compounds belonging to another group of hydrocarbons, olefins C_nH_{2n}, where a hydrogen particle is freed. Hydrogen, in turn, owing to its high coefficient of diffusion in the air, high ignitability and combustion rate as well as a wide range of mixture flammability, tends to reduce the self-ignition period [7, 11].

In case of fatty acids (biofuels) these problems are of a different kind, because the presence of the oxygen molecule may significantly increase the rate of the initial chemical reaction, while the increased group of olefin hydrocarbons, with their higher value of the iodine number, may accelerate the reaction even more.

Bearing these facts in mind, we can state that adequate treatment of fuel, i.e. changing its physical and chemical parameters, may improve the economical as well as ecological indicators of self-ignition engine performance.

The positive change of physical and chemical parameters of fuel can be achieved by preliminary fuel treatment performed immediately before its injection into the combustion chamber. The treatment consists in simultaneous heating of fuel and its contact with catalytic material in the injector body. It should be underlined that fuel treatment before its discharge in the injection pump or before the injector may essentially change the fuel injection characteristics. This is due to changes in physical parameters of the fuel, and may contribute to increased leaks in precision pairs of the injection equipment and wave changes in high pressure pipes.

The review of literature on the subject shows that in some cases the research centers have not always achieved positive results from fuel preheating tests. Some researchers found that operational and ecological parameters of self-ignition engine work had been improved only within a certain range of loads [1, 2, 6], while according to [5, 9] the improvement is attained for loads up to 50% of rated power, while higher loads resulted in increased fuel consumption and emission of toxic compounds. The obtained data refer to fuel heating before the fuel pump and the injector, which, as previously noted, changes the characteristics of injected fuel. For this reason, the preliminary thermal fuel treatment combined with catalytic conversion and turbulization directly in the injector body, omitting the precision pairs, eliminates the disadvantages of above described solutions.

In previous works of this author the catalytic fuel treatment in the pintle injector body was used in engines with the preliminary combustion chamber [5]. An analysis of indicator charts of this type of engines showed a shortened self-ignition delay time, reduced maximum pressure and cycle temperature values and improved operational parameters of the engine. For engines with direct injection using multi-hole atomizers the previous construction of injectors could not be used and the only solution for implementing catalytic fuel treatment was to enforce the turbulized fuel flow along a catalytic material surface.

Preliminary fuel treatment in multi-hole fuel injector, shown in Fig. 2, involves the non-working surface of the needle, which is covered with catalytic material and crisscrossing channels of the turbulization system. The use of this part of the needle for catalytic and turbulizing fuel treatment enables fuel thermal treatment, as this component is most affected by high gas temperatures in the combustion chamber.

Research results [4] show that during thermal and thermal-catalytic fuel treatment the values of fuel surface tension, density and viscosity decrease depending on the temperature and contact with the catalyst. This is essential in consideration of phenomena that take place during fuel atomization, evaporation and mixing with fresh air in the initial period of combustion and subsequent stages.

Fig. 2. Diagram and image of a multi-hole injector with the preliminary thermal-catalytic-turbulizing treatment of fuel

It has been already indicated how important it is to determine the iodine number, i.e. the changes in chemical parameters of fuel during its contact with a catalyst at increased temperatures, as these correspond to the rate of chemical reactions occurring in the internal combustion engine. The value of the iodine number reflects the content of hydrocarbons belonging to the olefin group. Their quantity in fuel increases due to the reaction of dehydrogenation of the paraffin group. As shown in the research done at the Institute of Marine Power Plant Operation, Maritime University of Szczecin, the value of the iodine number in fuel increased to 3-5% practically in the whole range of temperatures during the thermal-catalytic-turbulizing treatment of fuel.

In order to determine changes in the injected fuel jet, experimental tests were conducted at a lab test stand equipped with a device controlling fuel injectors Bosch EPS 200A and a Spraytec from Malvern Instruments – a laser analyzer for the determination of droplet distribution in aerosols (Fig. 3). Those tests were aimed to compare two types of fuel injectors – conventional and the one with preliminary fuel treatment (359 type engine). The injector was chosen on purpose, as its atomizer has three injection holes positioned at 120 degree angle, which facilitates measurements of one jet in a laser beam, while the other two can be placed beyond the measuring zone. An example distribution of fuel droplets is shown in Fig. 4, where curve 1 illustrates the droplet distribution in a standard injector, Chile curve 2 – in the preliminary treatment injector. The results of experiments with biofuels of varying rapeseed methyl esters (RME) content of 5, 10, 15 and 20% indicated a distinct reduction of the Sauter mean diameter – practically for all examined fuels it decreased from 21.83 to 9.94, and the percentage of droplets with a diameter to 20μm increased from 36% to 50.5%.

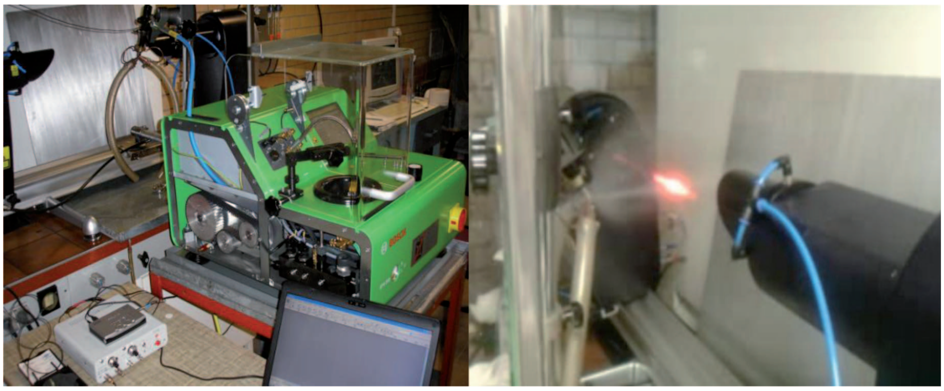


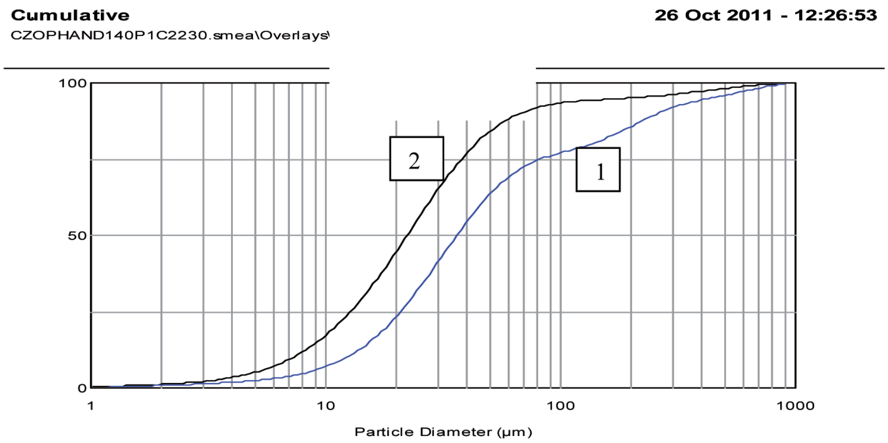
Fig. 3. The stand for testing the distribution and an example of droplet measurements in the atomized fuel jet

The results confirm the positive changes in physical and chemical properties of fuel, although the final assessment whether the method is effective can be made only after tests on a self-ignition engine. Such tests have been done on a 359 type engine, and the results are illustrated in Figure 5. The same set of conventional injectors and those with preliminary treatment of RME fuels was used in these tests as in the lab tests. The tests aimed basically at comparing the operational parameters of the engine fed with biofuels. The level of toxic compound emission in exhaust gases was determined by a MAHA MGT5 analyzer and a MAHA MDO2 Diesel smoke meter (accuracy of the exhaust gas analyzers is given in Table 2).

Table 2

Accuracy of exhaust gas analyzers

	MAHA MGT5 analyzer			MAHA MDO2 Diesel smoke meter
Measured quantities	CO	CO_2	NO_x	Light absorption coefficient k
Measurement range	0-15%	0-20%	0-5000ppm	0-9.99 m^{-1}
Measurement accuracy	0.06%	0.5%	32-120ppm	0.01 m^{-1}



	Date-Time	File	Sample	Dx(10)	Dx(50)	Dx(90)
[V]	26 Oct 2011...	230 1 ...	230	7.22	22.19	66.76
[V]	26 Oct 2011...	230 2 1	230	12.23	36.13	259.85

[V]=Volume [N]=Number

Fig. 4. Example distribution of fuel droplets with 10% content of RME 1 – manufactured injectors, 2 – preliminary fuel treatment injectors

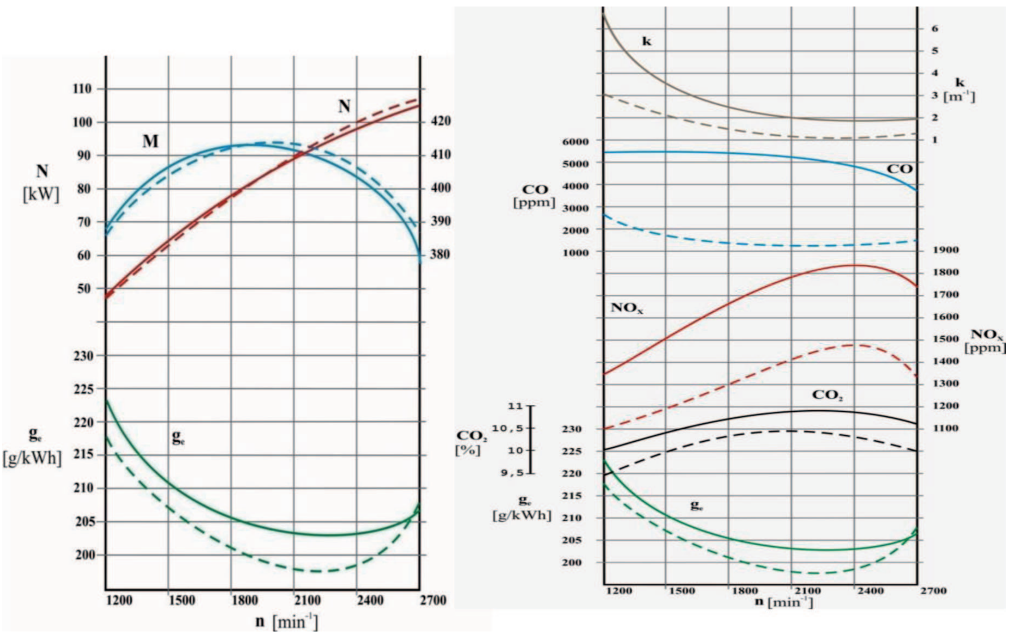


Fig. 5. Speed characteristics of a 359 engine running on diesel oil with a 10% content of RME rapeseed methyl ester

—— – manufactured injectors; ······ – preliminary fuel treatment injectors

3. Conclusions

Regardless of the opinions on the use of biofuels, their applicability for combustion in piston engines goes without saying. Further advancements in genetic engineering will result in new ‘fuel’ type of oil plants. The requirements for the chemical composition of fatty acids from these plants should be aimed at obtaining higher efficiency of working processes and minimized toxicity of exhaust gases from engines running on biofuels.

One possible direction that the development in this field will follow is the use of preliminary thermal-catalytic-turbulizing fuel treatment, applied immediately before the fuel is injected, i.e. in the injector body. The increasing of the iodine number combined with simultaneous acceleration of fuel oxidation is achieved during the fuel-catalyst contact. The effect is enhanced by the release of hydrogen and by the phenomenon of turbulization, as this translates (similarly to engines with indirect fuel injection) into shorter self-ignition delay, lower maximum temperature and pressure in the combustion chamber.

Some authors provide results of self-ignition engine tests where the improvement of ecological parameters (CO down by 100%, NO_x down by 25%) is connected with the use of biofuels [10]. The test data of this author can be explained by the following factors. The results of biofuel droplet distribution in a injected fuel jet, first and foremost an increase in the number of droplets with a smaller diameter as well as the decrease of Sauter diameter indicate that the turbulization of fuel passing through the injector body has a positive effect. Besides, the positive turbulizing effect combined with the presence of a catalyst improves both economical and toxic parameters of a self-ignition engine. The engine running on biofuel, containing oxygen molecules and free hydrogen released due to the action of the catalyst, benefits from sorter self-ignition delay. As a result, the combustion process parameters are improved, which is confirmed by the measurement results of CO and NO_x emission and exhausts smoke content.

At this stage it is difficult to evaluate separately the influence of physical and chemical phenomena during the preliminary fuel treatment, as these processes have to be considered jointly due to the strict relation of the catalytic effect with turbulization at high temperatures.

References

1. Bradstreet S. W.: Flame sprayed catalyst coatings // The Clay Products News and Ceramic Record. 1961. 24. No. 2. pp. 16-17.
2. Corbo P., Corcione F. E., Vaglieco B. M.: Evaluation of the effect a new combustion system and catalyst on engine emissions // SAE Techn. Pap. Ser. 1990. No. 902083. pp. 1-9.
3. Graboski M.S., McCormick R.L., Alleman T.L., Herring A.M.: The Effect of Biodiesel Composition on Engine Emissions from a DDC Series 60 Diesel Engine. National Renewable Energy Laboratory. Final Report 2 in a series of 6. -SR-510-31461, February 2003, 81.

4. Klyus O.: The use of turbulization in preliminary fuel treatment in self-ignition engines. Silniki Spalinowe, PTNSS-2009-SC-038.
5. Клюс О.: Каталитическая обработка топлива в дизелях. Изд. КГТЫ, Калининград 2008, 156с.
6. Клюс О., Васильев И., Ростовская Н.: Анализ показателей дизеля при работе на многокомпонентных смесях растительных масел с дизельным топливом // Eksploatacja Pojazdów Samochodowych – Szczecin: Politechnika Szczecińska, 2004, 1, 45-54.
7. Кутенев В. Ф., Звонов В. А., Корнилов Г. С., Васильев И. П.: Внутри-цилиндровый катализ – средство улучшения экологических показа-телей дизеля// Проблемы конструкции двигателей и экология. Сборник научных трудов. – М., НАМИ, 1998. – С. 18-28.
8. Рябцев Г.: Еще одна ≪беда≫, или куда уходит рынок. Терминал, нефтяное обозрение. 2009, No 39, (469), 6-7.
9. Siegla Donald C., Plee S. L.: Heterogeneous catalysis in the diesel combustion chamber // Combustion Science and Technology. 1982, 27, pp. 97-102.
10. Szlachta Z.: Zasilanie silników wysokoprężnych paliwami rzepakowymi. WKŁ, Warszawa, 2002.
11. Васильев И. П., Звонов В. А., Гавриленко П. Н.: Улучщение показателей дизеля применением турбулизаторов в камере сгорания с каталитическим слоем // Двигателестроение 1990, No 11 С. 47-49.