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Comparative Analysis of Two Injection Systems Fueled with Biodiesel

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Abstract: The paper presents experimental results concerning the fueling of two injection systems for D.I. Diesel engines with Biodiesel fuels. The neat Biodiesel (B100) was obtained from waste vegetable oil (collected from a local branch of McDonald's), using the base catalyzed method; diesel fuel was also used in order to test the injection equipments and obtain reference values. The fuel injection pumps used during the tests were RO-PES4A90D410RS2240 (romanian) and a Bosch type one (PES5MW55/320/RS/120403), with the corresponding high pressure fuel lines and injectors. The injection equipment was mounted on a MIRKOZ test bed, equipped with pressure transducers, rotation angle transducer and a BOSCH injection rate meter. The tests were developed at different pump speeds and displacements of the injection pump control rack. The following injection characteristics were investigated: cyclic fuel delivery, injection duration, pressure wave propagation time, average injection rate, peak injection pressure. For the both types of injection equipment, cyclic fuel delivery, injection duration and peak injection pressure increased when biodiesel was used as fuel (compared to Diesel fuel), while the average injection rate and pressure wave propagation time decreased.
Key words: injection equipment, average injection rate, fuel delivery.

INTRODUCTION

Vegetable oils and animal fats are a renewable and potentially inexhaustible source of energy, with energy content close to Diesel fuel. Due to their poor physical properties (high viscosity, high pour point), these fuels are unsuited to be used in Diesel engines. These properties can be improved by transesterification; when using methyl alcohol, methyl esters are the final product.

According to Directive 2003/30 EC of the European Parliament and Council (*2003*), the term **Biodiesel** is used for any methyl ester produced from vegetable or animal oil, of Diesel quality.

It is agreed that a proportion of 2…5% methyl ester in Diesel fuel does not involve any changes in the construction of the engine's fuelling system and this type of Biodiesel blends can be burned directly in unmodified Diesel engines (*Prankl and Wörgetter, 2000*).

Cooking oils, used for frying food, have a limited life in food production due to their contamination with material from food and due to fatty acids formation; waste cooking oil can be seen as a "near to waste" by-product of food production industry. As a result, the use of waste cooking oil instead of virgin oil in order to produce Biodiesel is an effective way to reduce the raw material cost and helps to solve the problem of waste oil disposal. These vegetable oils contain some degradation products of vegetable oils and foreign material. However, analyses of used vegetable oils claimed that the differences between used and unused fats are not very great and in most cases simple heating and removal by filtration of solid particles makes the oil appropriate for subsequent transesterification (*Rice, Frohlich and Leonard R., 1997*).

Injection characteristics have a significant effect over the engine working process. For the same injection timing, ignition delay and cyclic fuel delivery, an increased injection duration (or decreased average injection rate) leads to the decrease of the peak combustion pressure; the shape of the engine's working cycle diagram is also affected (*Heywood , 1988*).

Table 1. Physical characteristics of the fuels

Item	Test method	Fuel			
		Diesel	Used cooking oil	B100*	B50*
Density at 15^{0}C [g/cm^3]	EN ISO 3675	0.8393	0.891	0.857	0.851
Viscosity at 40 ^{0}C [mm^2/s]	EN ISO 3104	4.9	34.0	5.7	5.2
Acid value [mg KOH/g]	ASTM D664	0.089	2.67	0.92	0.42
Ash content [%]	SR ISO 6245:1995	0.085	0.075	0.038	0.016
Flash point [^{0}C]	ASTM D93	69	115	110	82
Cu strip corrosion	EN ISO 2160	1b	2e	2a	1b
Surface tension [N/m]	-	0.0281	0.0336	0.0296	0.0290

*Note: B100 – pure methyl ester; B50 – 50% methylester+50%Diesel fuel

MATERIAL and METHOD

The material used for the vegetable oil methylester (VOME) production was waste cooking oil collected from a local branch of the McDonalds' restaurants (*Rosca, Rakosi and Niculaua, 2005*).

The main physical properties of the Biodiesel type fuel (BTF) are summarized in table 1.

Two injection equipments were tested:

- injection pump type PES 5MW 55/320/RS 120403 (BOSCH; plunger bore: 5.5 mm);
- injection pump type RO-PES4A90D410RS2240 (plunger bore: 9 mm);
- RO-KCA30S16 injectors with RO-DNOSD21 nozzles, opening at 13 MPa.

The injection equipment was tested on a MIRKOZ (Hungary) test rig, using a BOSCH injection rate meter and an IAN 101 oscilloscope.

The tests were developed at different pump speeds (500 to 1200 rev/min) and displacements of the injection pump control rod; for the both injection pumps the speed governor was disabled.

During the tests Diesel fuel and Biodiesel-Diesel fuel mixture (50% Biodiesel - B50) were used.

The following injection characteristics were investigated:

- cyclic fuel delivery;
- injection duration;
- pressure wave propagation time;
- average injection rate;
- peak injection pressure.

The average injection rate was defined as the ratio between the cyclic fuel delivery and the injection duration.

RESEARCH RESULTS

Cyclic fuel delivery

Figure 1 presents some experimental results referring to the cyclic fuel delivery of the two injection pumps, at different speeds. The cyclic fuel delivery increases with pump speed and control rod displacement, but is affected by the type of fuel used.

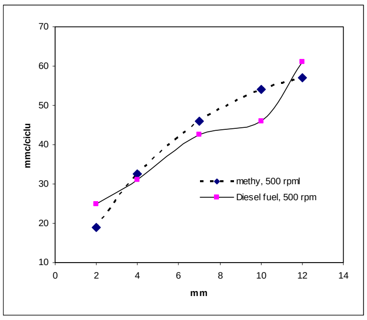
There is a clear tendency towards the increase of the amount of delivered fuel when B50 is used. For the Bosch injection pump this behavior is noticeable even at low pump speeds (500 rev/min), while for the RO-PES injection pump the amount of B50 delivered at 500 rev/min is lower compared to the one of Diesel fuel. As pump speed increases, both the RO-PES and the Bosch injection pump deliver higher amounts of fuel when B50 is used (Figures 1c and 1d).

Injection duration

The results concerning the injection duration are shown in Figure 2. As fuel delivery increases with the displacement of the injection pump control rod, the injection duration also increases. For the RO-PES injection pump the use of the B50 fuels leads to an increased injection duration (with 2.5...18% at 500 rev/min and respectively with 5.6...11% at 900 rev/min), compared to Diesel fuel (Figures 2b and 2d), due to the higher amount of injected fuel provided by this pump.

At low speeds, the injection duration for the Bosch injection pump decreases when fueled with B50 (Figure 2a); at 900 rev/min the values recorded for Biodiesel are very close to the ones registered for Diesel fuel (Figure 2c) and only for the 1200 rev/min regime the injection duration is increased with 9.7...19% when B50 is used as fuel.

The experimental results concerning the time the pressure wave needs to travel between the injection pump outlet and the injector inlet are shown in Figure 3. For the both injection equipments the pressure wave propagation time is shorter when Biodiesel fuel



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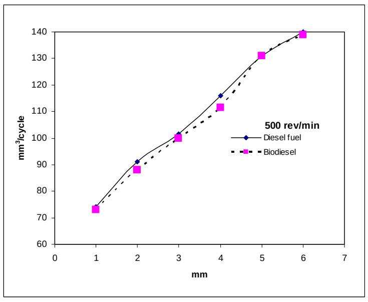

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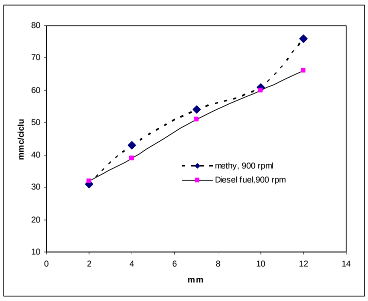

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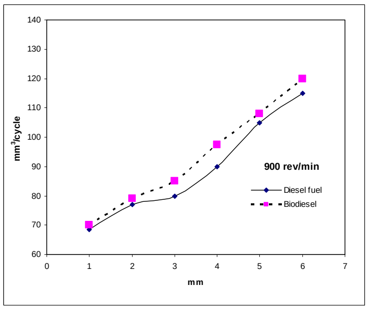

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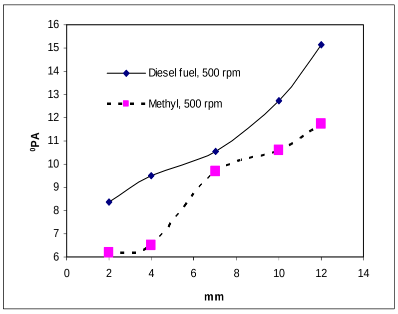
Figure 1. Cyclic fuel delivery
a-Bosch injection pump, 500 rev/min; b- RO-PES injection pump, 500 rev/min; c-Bosch injection pump, 900 rev/min; d- RO-PES injection pump, 900 rev/min



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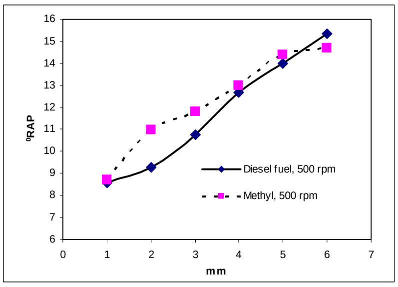

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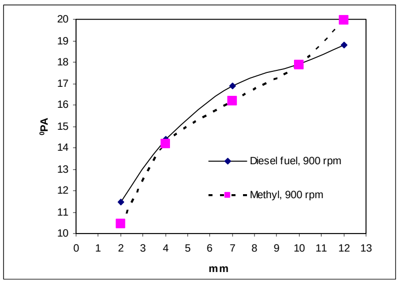

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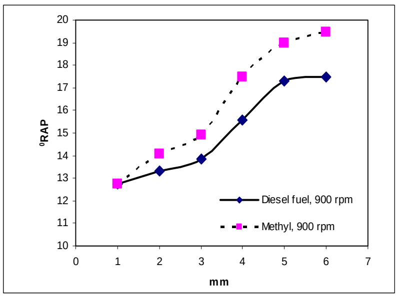

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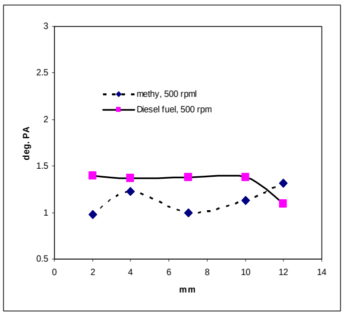
Figure 2. Injection duration
a-Bosch injection pump, 500 rev/min; b- RO-PES injection pump, 500 rev/min; c- Bosch injection pump, 900 rev/min; d- RO-PES injection pump, 900 rev/min



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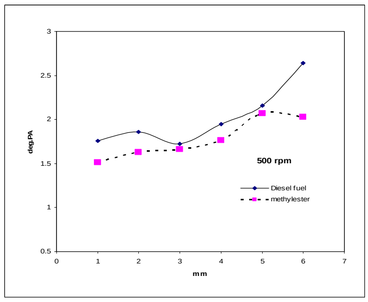

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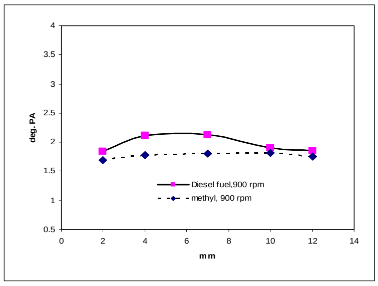

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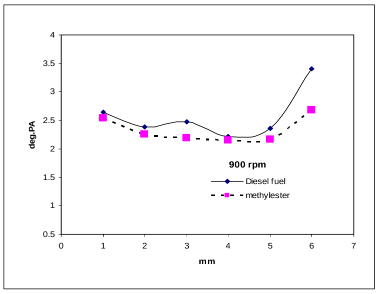

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Figure 3. Pressure wave propagation time
a-Bosch injection pump, 500 rev/min; b- RO-PES injection pump, 500 rev/min; c-Bosch injection pump, 900 rev/min; d- RO-PES injection pump, 900 rev/min

blend is used; this finding, also reported by other authors (*Tat, Van Gerpen, 2003; Yamane, Ueta, Shimamoto, 2001*), seems to be the effect of the higher viscosity and isentropic bulk modulus.

The propagation time has decreased with $0.4…0.8^0$ PA when the B50 was used instead of Diesel fuel. It should be mentioned that a lower pressure wave propagation time is equivalent with an earlier start of injection (injection timing advanced by $0.8…1.6^0$ CA*) and may result in higher levels of NO_x emissions (*Monyem, Van Gerpen, Canakci, 2001; Senatore, Cardone, 2000; Tat, 2003*). As Biodiesel type fuels were reported to have a shorter ignition delay compared to Diesel fuel (*Canakci, Van Gerpen, 2001; Ryan 1985*), the cumulative effect of the lower propagation time and shorter ignition delay is expected to induce an overall advance of the start of combustion that could reach $1.8…2^0$ CA. As a result the NO_x emissions will be significantly affected, unless adjustments of the injection timing are made

Average injection rate

The higher cyclic fuel delivery of the RO-PES pump has conducted to the achievement of higher average injection rates compared to the BOSCH injection pump (Figure 4); increasing the pump speed has led to lower average injection rates because of the higher injection duration.

For the Bosch injection pump the average injection rates achieved by the B50 fuel are higher then the ones recorded for Diesel fuel (Figure 4 a and c); the most significant differences are recorded at low pump speeds (17…53% increase at 500 rev/min, respectively 8…12% increase at 900 rev/min); this behavior shows that the lower injection duration recorded for B50 has a more significant effect then the higher cyclic fuel delivery.

The RO-PES injection pump recorded lower average injection rates for B50 compared to Diesel fuel (6…18% decrease at 500 rev/min and 0…6.4% decrease at 900 rev/min); the higher injection duration obtained for the Biodiesel fuel explains this behavior.

Peak injection pressure

The experiments show that the RO-PES pump achieves higher peak injection pressures then the BOSCH pump. From Figure 5 it is obvious that the use of methylester leads to higher injection pressures, due to the higher viscosity of B50. The pressure increased with 1…4 MPa bar for the Bosch injection pump (Figures 5 a and c) and with 4...6.5 MPa for the RO-PES injection pump (Figures 5 b and d), depending upon pump speed and position of the control rod.

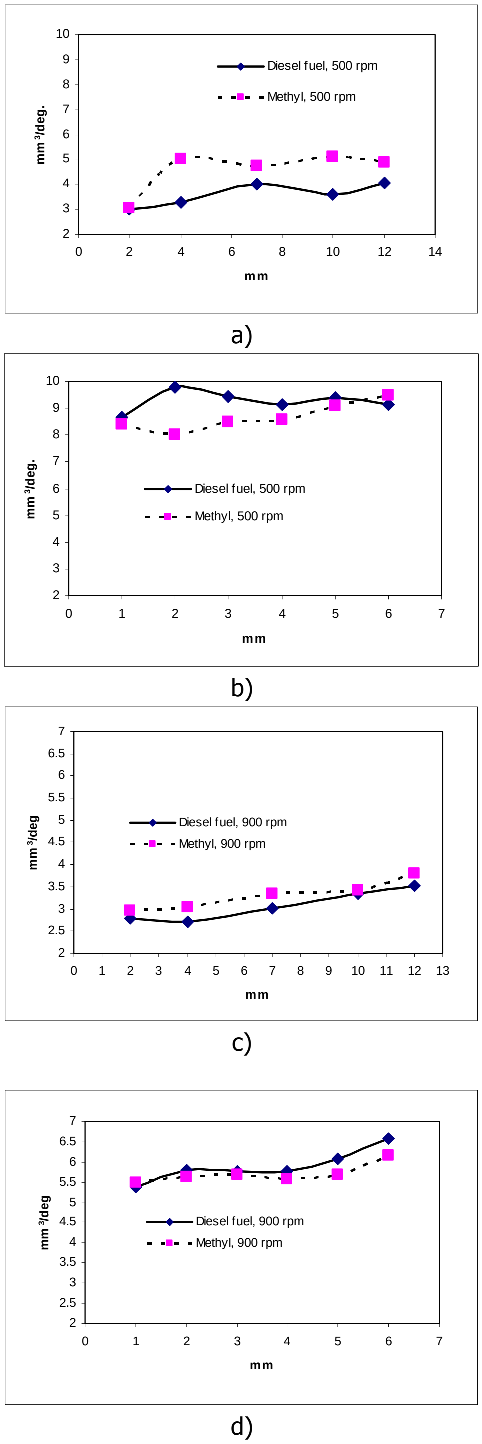
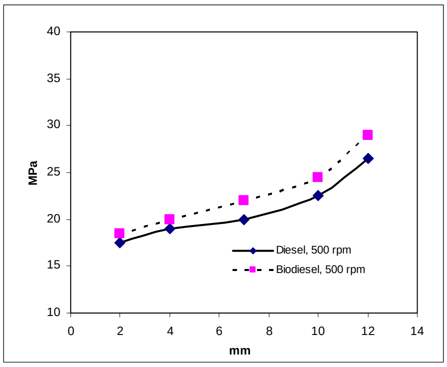


Figure 4. Average injection rate
a-Bosch injection pump, 500 rev/min; b- RO-PES injection pump, 500 rev/min; c-Bosch injection pump, 900 rev/min; d-RO-PES injection pump, 900 rev/min

* CA -crankshaft rotation angle.



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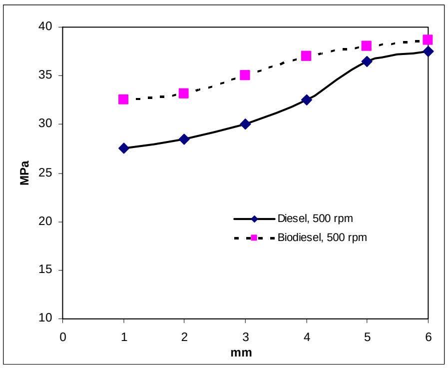

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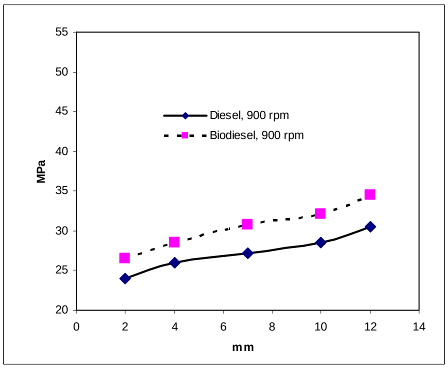

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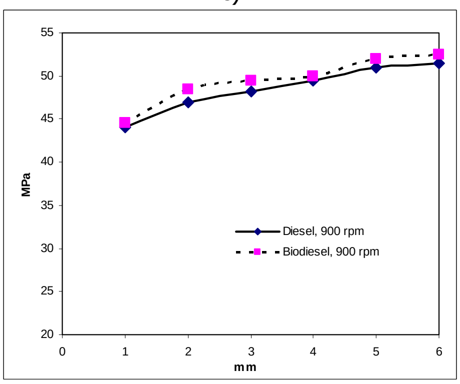

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Figure 5. Peak injection pressure
a-Bosch injection pump, 500 rev/min; b- RO-PES injection pump, 500 rev/min; c-Bosch injection pump, 900 rev/min; d-RO-PES injection pump, 900 rev/min

For the RO-PES pump significantly increased peak injection pressures were recorded at low speeds, while for the Bosch pump this behavior was displayed mainly at high speeds.

DISCUSSION

The use of the B50 Biodiesel blend affects the cyclic fuel delivery increasing the amount of injected fuel; the slightly higher viscosity of Biodiesel diminishes fuel loss through the gap between the piston and pump cylinder, thus increasing the quantity of delivered fuel.

The injection duration decreased when the Bosch injection pump was fueled with B50, but was prolonged for the RO-PES injection pump. This latter behavior could be explained taking into account the fuel delivery correction device mounted on the exhaust valve: due to the higher viscosity of the B50 fuel, higher hydraulic forces are acting upon the valve, thus increasing the lifting height; as a result a larger amount of fuel is needed to compensate the volume dislocated by the correction device and injection duration is increased. For the Bosch injection pump (with smaller plunger bore), the increased bulk modulus of the B50 fuel has a more significant effect then the action of the correction device leading to decreased injection duration.

The average injection rate is higher for the RO-PES injection pump because it has to deliver a higher amount of fuel, while the injection duration is roughly the same time for the both injection systems. The lower injection duration recorded for the Bosch injection pump led to higher average injection rates for this injection pump compared to the RO-PES pump.

The higher viscosity and isentropic bulk modulus of the B50 fuel lead to shorter delays in the pressure wave transmission time and to higher peak injection pressures. The shorter propagation time for the pressure wave and the shorter ignition delay which is usually associated with the Biodiesel type fuels are expected to induce an earlier start of the combustion process. In the meantime, higher peak injection pressures are expected to counteract the negative effect of the viscosity over the fuel spray characteristics. For the Bosch injection pump the higher average injection rates could also improve the fuel spray characteristics.

CONCLUSIONS

1. A Biodiesel type fuel (50% methyl ester + 50% Diesel fuel – B50) was used in order to fuel two injection systems.
2. The two injection systems were equipped with different size in line injection pumps;
3. The injection characteristics (cyclic fuel delivery, injection duration, average injection rate, pressure wave propagation time and peak injection pressure) were measured.
4. Injection characteristics were affected by the use of the B50 fuel, due to its higher viscosity and isentropic bulk modulus.
5. The fuel delivery correction devices mounted on the RO-PES pump exhaust valve produced longer injections compared to the Bosch injection pump; the average injection rate was consequently affected.

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