The use of sunflower oil as Diesel fuel for DI engines

ABSTRACT

Many attempts to use vegetable oils as fuel have been performed since the early days of the Diesel engine. When a Diesel engine is used with vegetable oil fuel for a short period of time, the performance and global efficiency are usually very close to Diesel fuel. However, during long-term engine tests with vegetable oils as fuel, heavy deposits build-up can be observed in the combustion chamber. These deposits can lead to engine breaks. A fuel droplet vaporization experiment proved that the deposits build-up is mainly controlled by the combustion chamber temperature. A new thermally insulated combustion chamber made it possible to raise the combustion chamber wall temperature. With this combustion chamber, the deposits were greatly reduced.

To use vegetable oils as fuel, DI Diesel engines need to be redesigned to accommodate the specificity of the vegetable oils combustion, one possibility is to use a thermally insulated combustion chamber.

Key-words: Diesel - vegetable oils - fuel

INTRODUCTION

The use of vegetable oils as Diesel fuel for DI engines may have several objectives *[5][1]* :

- An ecological concern : the use of vegetable oil is part of the carbon cycle, so the global CO2 balance from production to combustion of vegetable oils is kept.

- A concern about the autonomy of energy resources for developing countries.

- The search for an output (not foodstuff) for the rich countries' vegetable oils surplus.

Since the first day of the Diesel engine, many attempts to adapt Diesel engines for the use of vegetable oils as fuel have been performed. These attempts have sometimes lead to success and sometimes to failure : at a first look, the results from the literature seem inconsistent, indeed even conflicting *[1]*. A more thorough analysis reveals that short term tests are usually successful, while long term tests are often unsuccessful. Moreover, IDI engines generally lead to better long term durability with vegetable oils as fuel than DI engines *[4]*.

The problem in using vegetable oils as a fuel for DI engines is mainly due to the building-up of deposits at the injection nozzle tip and in the main chamber. These heavy deposits can lead to an engine break. Consequently, the aim of this work is to understand the forming mechanisms of the deposits and to propose a technological setup able to reduce the deposit formation.

Short-term and long-term Engine tests

The tests have been performed on a 4 cylinder turbo-charged DI engine. Food quality sunflower oil has been used to perform the tests. Diesel fuel has been used as the reference fuel *[4]*. For the sunflower oil test, the fuel delivery has been adjusted to allow equivalent energy input as with Diesel fuel at reference point 1700 rpm, full load.

SHORT-TERM TESTS : PERFORMANCE AND GLOBAL EFFICIENCY - At low speed, the torque with sunflower oil is higher (Figure 1). This is due to a better global efficiency (Figure 2) in spite of the same energy input. At higher speed, performance with vegetable oil is less than with Diesel fuel. This is due to the fact that the fuel delivery is lowered at high speed by the pressure drop due to high viscosity of sunflower oil.

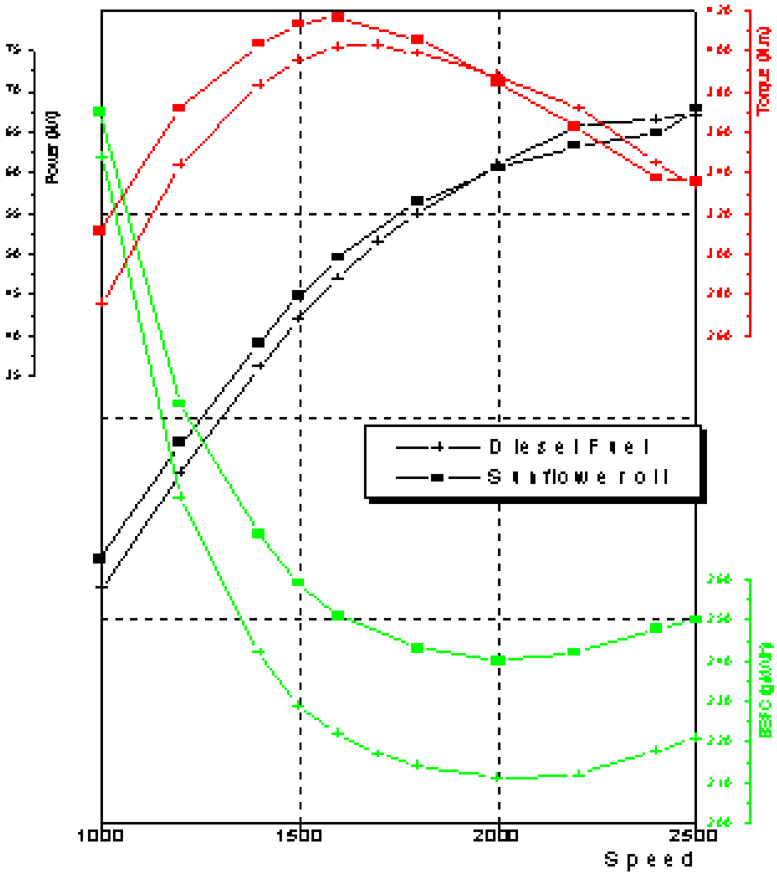


Figure 1 Torque, power, BSFC as a function of speed for sunflower oil and Diesel fuel

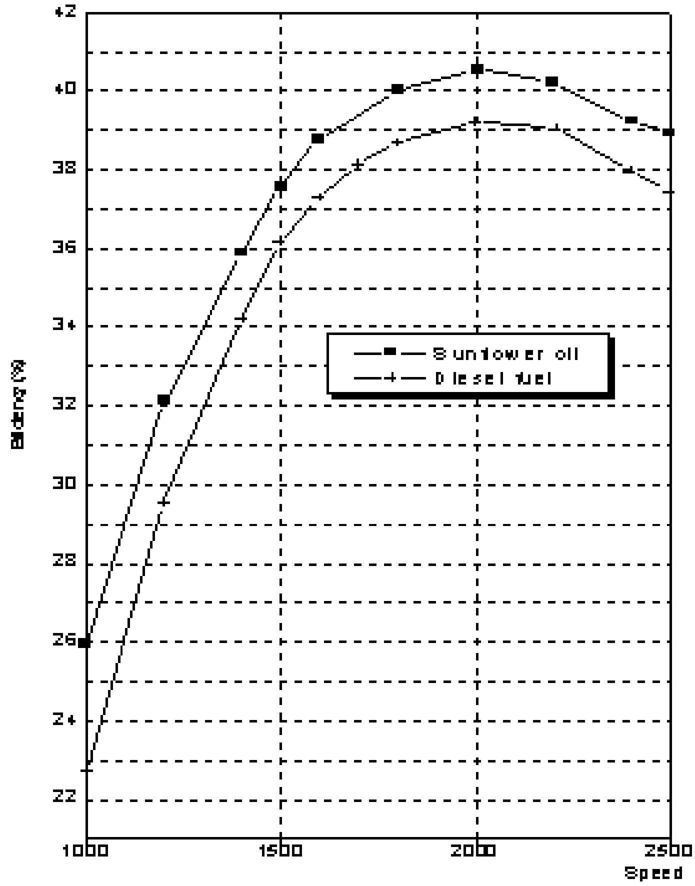


Figure 2 Global efficiency as a function of speed for sunflower oil and Diesel fuel

From the performance point of view, sunflower oil seems to be an adequate Diesel fuel substitute : the global efficiency is usually better with vegetable oil than with Diesel fuel due to a lower combustion temperature *[4]*.

LONG-TERM TESTS : DEPOSITS - Figures 3 et 4 show the heavy deposits in the combustion chamber and injector nozzle tip after a 20 hours test with sunflower oil as fuel. This test was performed at idle speed and low load. The deposits are very heavy behind the piston ring : they can lead to an engine break in the long run. The combustion chamber deposits are significantly lowered with the increase of engine load *[3][4]*. To understand the physical phenomena leading to the deposits build-up, we have studied the vaporization of a single fuel droplet.

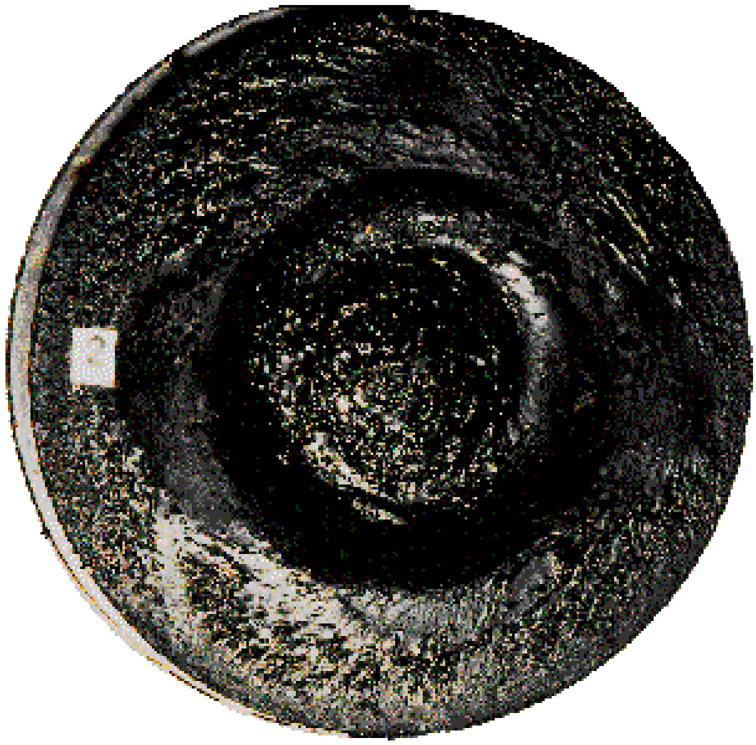


Figure 3 Standard piston after 20 hours of low load with sunflower oil as fuel.

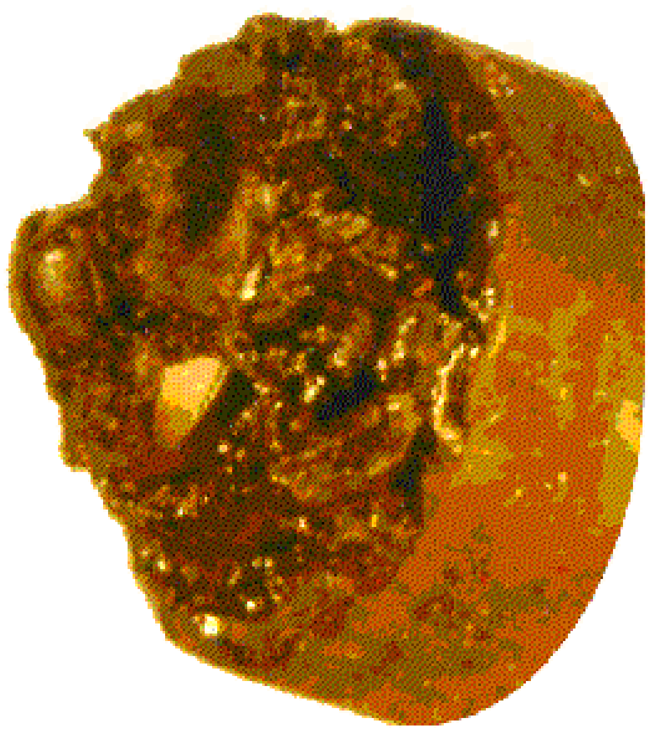


Figure 4 Injector nozzle tip after 20 hours of low load with sunflower oil as fuel.

Study of the fuel droplets vaporization

As the build-up of the deposits in the combustion chamber seemed to be influenced mainly by the temperature, we decided to study the impact of the ambient gas temperature on the vaporization process of a single fuel droplet. The droplet, hanging on a quartz fiber, is put in constant volume vessel, at atmospheric pressure (figure 5).

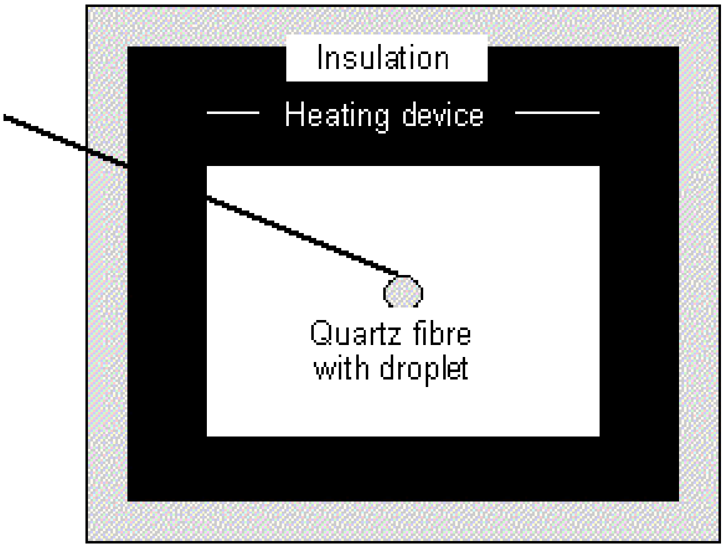


Figure 5 Experimental setup used for fuel droplets vaporization study.

The gas temperature inside the vessel can reach 1000 K *[4]*. To quantify the droplet vaporization, the projected surface of the droplet is measured as a function of time by means of a digital frame grabber card and an image processing software *[2]*. It is well known that for a single component droplet (e.g. water), the evolution of the projected surface against time is a straight line, but real world fuels display a very different behavior. Figure 6 shows that for an ambient temperature of 450ºC, the vegetable oil droplet vaporization is very slow and even incomplete while the Diesel fuel droplet vaporizes perfectly. For an ambient temperature higher than 600ºC, the vaporization mechanism is similar for both fuels after an initial heating up phase. In this case the sunflower oil vaporization is complete *[4]*.

DESIGN OF A THERMALLY INSULATED COMBUSTION CHAMBER

To avoid the deposits build-up in the combustion chamber, the injected fuel drop-lets must be completely vaporized. Consequently, the ambient and combustion chamber wall temperature must be high enough. We have determined a minimum wall temperature of 500ºC.

To obtain such a high wall surface temperature, we had to modify the thermal resistance of the piston by inserting an insulated piston crown between the aluminum alloy standard piston and the combustion chamber hot gases *[6]*.

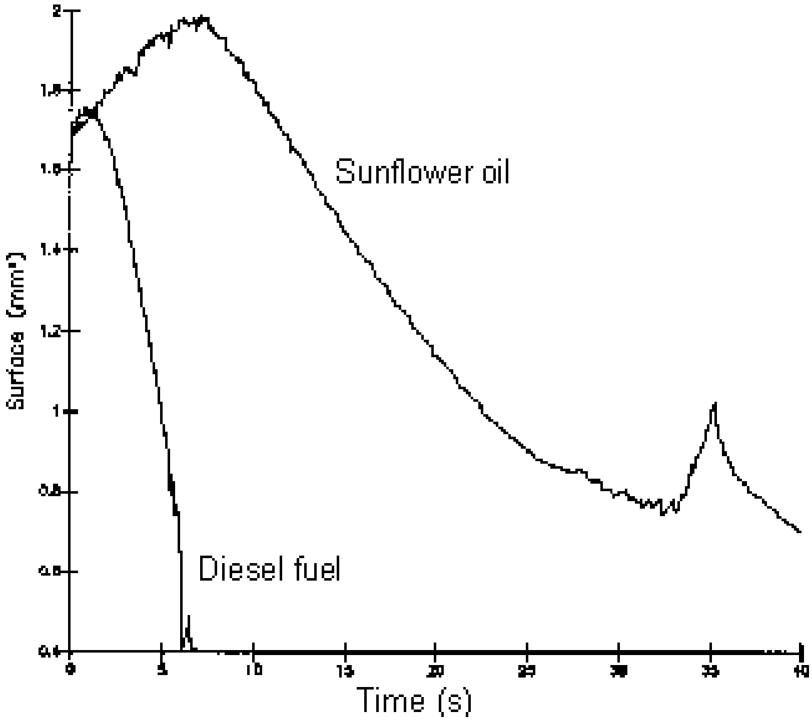


Figure 6 Comparison of the vaporization of a Diesel fuel and a sunflower oil droplet (T=450ºC)

Figure 7 shows the standard piston and figure 8 the insulated piston. The insulating piston crown has been dimensioned by thermal FEM computation including conduction / convection coupling. Figure 9 represents the temperature fields of the standard piston and figure 10 the temperature field of the insulated piston. It is worth noting the high temperature gradients across the insulating crown, and the high maximum crown temperatures around 500ºC.

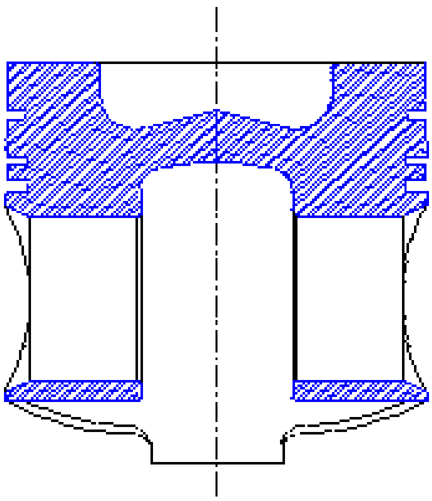


Figure 7 Standard aluminum alloy piston section

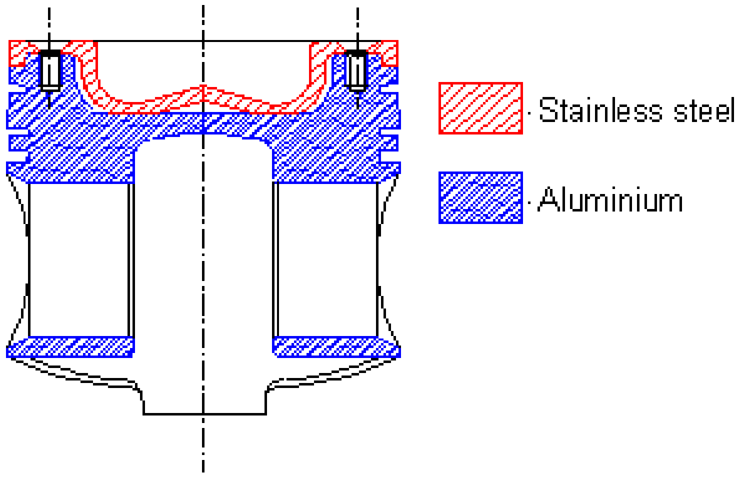
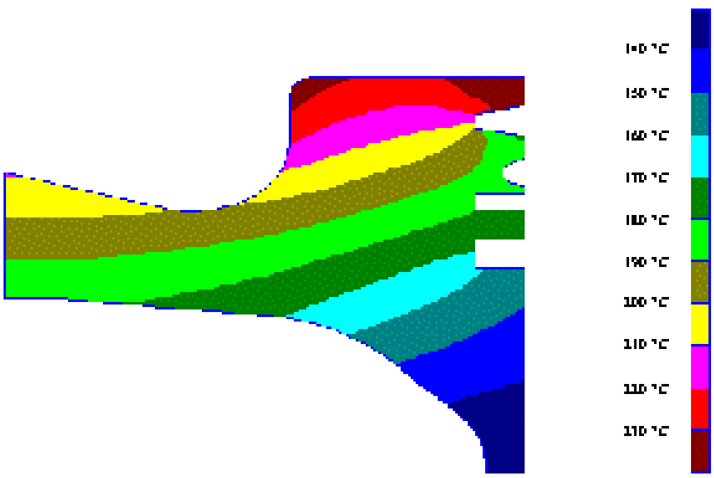


Figure 8 Insulated piston section.



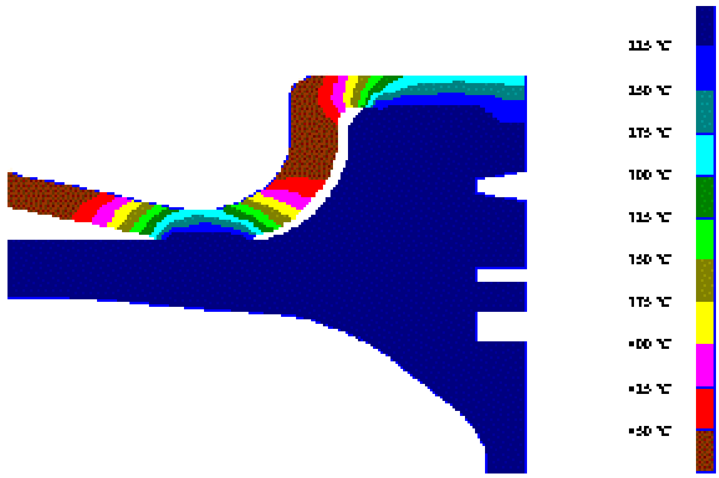


Figure 9 Temperature field of the standard piston

Figure 10 Temperature field of the insulated piston.

The same engine test performed with this insulated combustion chamber produced a much lower deposits level than in the previous test (Figure 11).

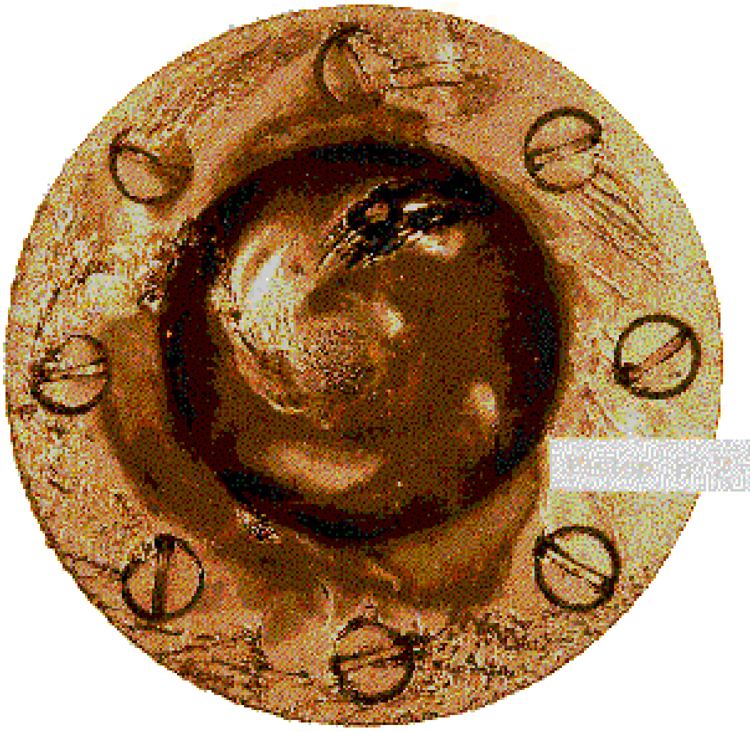


Figure 11 Insulated piston after a low load test with sunflower oil as fuel.

As a counterpart to the strong deposits reduction, a significant increase of 15 g/kWh in fuel consumption was observed. The only explanation to this fuel consumption increase is a strong increase in heat transfer to high temperature combustion chamber walls *[6][7]*.

Conclusion

Sunflower oil has a good ability to replace Diesel fuel for short term runs. But, for long-term use, the deposits produced by the vegetable oil combustion must by eliminated. The deposits build-up is mainly controlled by the combustion chamber wall temperature : above 500ºC deposits build-up can be avoided.

The obvious choice is to use an IDI engine, which provides a high prechamber temperature. For a DI engine, a strong reduction of the deposits can be achieved by the use of an insulated combustion chamber with the penalty of global efficiency decrease.

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