Fuel 159 (2015) 141–149

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

# Application of canola oil operation in a diesel engine with common rail system

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ARTICLE INFO

*Article history:*
Received 4 May 2015
Received in revised form 16 June 2015
Accepted 17 June 2015
Available online 25 June 2015

*Keywords:*
Canola oil
Viscosity
Surface tension
Diesel fuel
Start of energizing
Rail pressure

ABSTRACT

Straight vegetable oil (SVO) such as canola oil, is one alternative fuel that can be used mainly in agriculture. In this experimental engine study, a diesel engine equipped with a modern common rail system was used to determine engine modifications for canola oil operation. Due to high viscosity and high surface tension of canola oil, engines without specific modifications can cause incomplete combustion, which can lead to combustion chamber deposits and deposits at injectors and valves. This study focused on low and medium load conditions at different engine speeds. These conditions are typical for the occurrence of combustion chamber deposits during canola oil operation. At first, a comparison of carbon-monoxide (CO), total unburned hydro-carbons (THC), nitrogen oxides ($NO_x$) and soot emissions was made for diesel fuel and canola oil operation. A cylinder pressure analysis (CPA) was carried out simultaneously to determine the difference of combustion phasing of both fuels. Subsequently, the injection parameters like rail pressure and injection timing (Start of Energizing, SOE) for five operation points were adjusted to improve combustion and avoid deposits in the cylinder.



## 1. Introduction

During the last two decades, different new technologies are used to improve diesel engine performance and to meet the limits of emission legislation. For example, usage of modern common rail injection systems with high rail pressure combined with external EGR (Exhaust Gas Recirculation) is a method for optimizing combustion process and fuel consumption, and controlling of nitrogen oxides emission simultaneously.

Because of the flexibility of the common rail injection, it was possible to introduce new kinds of combustion processes, such as Premixed Charge Compression Ignition-based combustion (PCCI [1,2] in diesel engines. Recently, modified PCCI process with dual-fuels was reported by different engine researchers [3,4]. Splitter and Reitz [5] tested fuel reactivity and used #2 ULSD and 3% 2-ethylhexyl nitrate doped gasoline on a dual-fuel compression ignition engine, which they named as Reactivity Controlled Compression Ignition-based combustion (RCCI). But these kinds of combustion strategies need either sophisticated engine modifications or new components for the injection system.

For off-road vehicles used in agriculture, one of the possibilities for saving petroleum reserves is the usage of alternative diesel fuels such as vegetable oils and their derivatives, which would not require significant modifications on existing diesel engines. Because vegetable oil as fuel has a closed $CO_2$ circuit, its usage in agricultural diesel engines will even reduce the carbon dioxide emissions to the atmosphere [6,7].

### 1.1. Biofuel

Vegetable oils can be utilized as a substitute for petroleum diesel in different ways:

- Neat vegetable oil (e.g. DIN V 51605, A German pre-standard for canola oil [9,10]) [11–19].
- Vegetable oil-diesel fuel blend [20–25].
- Bio-diesel from vegetable oil by transesterification and its blends [26–30].
- Renewable diesel [31,32].

Apart from these typical biofuels for diesel engine, Rakopoulos et al. investigated the combustion and emission behavior of a one-cylinder research engine that was fueled with petroleum diesel and its blends with bio-diesel, ethanol, n-butanol and diethylether [33]. They also studied the influence of the diesel fuel

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http://dx.doi.org/10.1016/j.fuel.2015.06.060
0016-2361/

blends of bio-diesel, ethanol, n-butanol on combustion and emissions under steady and transient conditions, in which a six-cylinder engine equipped with a in-line injection pump was used [34]. Since the focus of this study is on the application of SVO, the usage of SVO will be discussed in the following sections. According to the precise review works of No [35,36], vegetable oils can be classified as edible and inedible oils. The edible vegetable oils fueled in diesel engines are soybean, sunflower, canola, coconut, palm, corn and olive kernel oils and the inedible vegetable oils used as substitutes are jatropha, karanja, mahua, linseed, rubber seed, cottonseed and neemoils. Vegetable oil belongs to the group of triglycerides which consists of three fatty acids and a trivalent alcohol glycerin. Because of the specific physical and chemical nature of fatty acids, vegetable oils have higher viscosity [37], higher surface tension [38] and lower volatility than petroleum diesel.

### 1.2. Engine performance and issues of vegetable oil application

Although short-term engine tests do not show significant disadvantages with SVO [39], researchers have reported different operation problems since the beginning of SVO usage [22,40–42]. The main issues of SVO are poor atomization, injector nozzle coking, which can cause incomplete combustion, carbon deposits in combustion chamber, higher particulate emissions (PM), piston ring sticking, dilution of lubrication oil and even fatal mechanical damages. The unburned vegetable oil can also accumulate at the surface of after-treatment systems and reduce the engine efficiency [43].

The fundamental reason for these issues is that the physical and chemical properties of SVO can interfere the injection system and affect the spray behavior. Both the macroscopic spray and microscopic spray properties of vegetable oil can differ from petroleum diesel. The studies of Yoshimoto [44] and Wloka [45] confirmed that spray cone angle of neat rapeseed oil is smaller. The spray tip penetration of neat rapeseed oil is shorter with the same duration of injection time [45]. Higher sauter mean diameter (SMD) of neat vegetable oil and its blends compared to petroleum diesel was reported in the experimental studies [46,47].

Esteban et al. [38] investigated the dependence of surface tension of different vegetable oils and diesel and resulted that the analyzed vegetable oils have to be heated up to 120 °C to match the surface tension value corresponding to petroleum diesel fuel at 40 °C. Additionally, the viscosity of vegetable oils decreases exponentially with increasing temperature [37]. According to these characteristics, preheating is the most practical and effective method for neat vegetable oil operation [17,36,45–48]. However, the preheating temperature has to be restricted, because polymerization of neat canola oil can take place at approximately 75 °C [42].

In spite of poor spray behavior of vegetable oil relative to petroleum diesel, exhaust emissions, such as CO, THC and PM emissions, can be reduced with increase of $NO_x$ emission under full load condition [20,21,49,50]. The reason is that vegetable oil belongs to the group of oxygenated fuel, whose oxygen content ensures a more complete combustion [11,51,52]. In contrast, at low engine speeds and loads, an inverse trend of exhaust emissions was reported in different studies [49,53,54], where combustion condition is not suitable for vegetable oil. Moreover, the investigation in Germany by Krahl et al. [55] reported a strong increase in mutagenicity of canola oil exhaust compared to petroleum diesel, because diesel engines without suitable modifications can emit more malondialdehyde (MDA).

### 1.3. Focus of study

In this study, commercial canola oil is used. The target of this research was to study how injection strategy affects the combustion process at different load conditions and to determine the best engine modifications for canola oil operation. The focus of research was aimed at investigating the effects of common rail pressure and start of energizing the injector, on the engine combustion characteristics and exhaust gas emissions.

## 2. Experiments

### 2.1. Experimental apparatus and fuels

The research of this study was carried out with a commercial 6-cylinder 6.8 l heavy-duty diesel engine, as shown in Table 1. The engine was equipped with a modern common-rail diesel injection system, which can supply a maximal rail pressure of 200 MPa. The 6 injectors and the fuel tank were equipped with a heating system. The temperature of canola oil in tank was kept at 55 °C, which corresponds to 24.28 $mm^2/s$ of kinematic viscosity, respectively. The inner-nozzle data were gained by a special polymer cast investigation [45]. The outlet-diameter of the injector nozzle was 160 μm. The k-factor was 1.

The engine was connected to an electric engine with type number of Siemens 1SH8314. The engine had an air-to-water charge air cooler and a Burkert 6223A solenoid valve was used to regulate the cooling water flow to control the charge air temperature. The mass flow of canola oil was measured with a Rheonik RHM03 coriolis mass flow meter. A Kistler 6065 uncooled piezoelectric sensor was installed on one cylinder through the glow plug hole to measure the cylinder pressure. Two Kistler 4075 A10 cooled piezoresistive sensors were installed on the inlet and outlet of the same cylinder to measure the inlet and outlet pressures. The resolution of dynamic pressure measurement was set to 1°CA. Acquired cylinder pressure traces were averaged for 50 cycles, and the time reference device used in this study is a shaft encoder with type number of WDG 58B. For the thermodynamic analysis of combustion process, 4 thermocouples type K were installed on the liner and 3 thermocouples type K were installed on the cylinder head. The entire composition of the engine test bench can be seen in Fig. 1.

For emission measurement, a Horiba MEXA-7170HEGR analytical system was used. THC measurement was based on the hydrogen flame ionization detector (FID) method and CO and $CO_2$ measurement was based on the Non-Dispersive Infra-Red (NDIR) technique. The chemiluminescence detector (CLD) and the magnetic-pressure-type-oxygen analyzer (MPA) were installed for the measurement of $NO_x$ and $O_2$. Soot emissions were measured using an AVL Micro Soot Sensor. The wide band lambda sensor Bosch LSU 4.9 is installed after the turbocharger to detect the lambda ($\lambda$) values. The measuring error of exhaust gas analyzer and computed results are summarized in Table 2. For each operation point the measurements were repeated twice, which was recorded for two minutes with a sample rate of 1 Hz, and has a standard deviation of all measured quantities of less than 2%. The typical and important fuel properties of diesel fuel and canola oil used in this study are listed in Table 3.

**Table 1**
The engine specifications.

| Parameter [unit] | |
|---|---|
| Displacement volume [l] | 6.8 |
| Rated speed [rpm] | 2100 |
| Rated power [kW] ([HP]) | 147 (200) |
| Compression ratio [–] | 17:1 |
| Maximal rail pressure [MPa] | 200 |
| Number of cylinders [–] | Inline 6 |
| External EGR | Yes |