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Emissions of Diesel Engines Running on Different Biofuels and their Health Related Aspects

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1. Abstract

Fossil fuels (sometimes called petro-diesel) for use in compressed ignition (diesel) engines are increasingly being replaced by fuels consisting of a blend of petro-diesel and oils from a vegetable origin (either pure or after a process called transesterification, as their mono-alkyl esters). Mixtures of such esters and petro/diesel are generally called biodiesel.
In addition, the use of pure oils (SVO = Straight Vegetable Oil or PPO = Pure Plant Oil) is becoming of interest as alternative fuels for diesel engines. This is especially the case in remote areas in developing countries, where petro-diesel and biodiesel are often not readily available and/or expensive.

In many countries, the emissions of diesel engines running on petro-diesel are strictly regulated. Upper limits for the emission of e.g. CO, NOx, THC (total unburned hydrocarbons) and PM (particulate matter) have been defined. Currently, these limits are in most cases also used for biodiesel in countries where the use of biodiesel is permitted.

There is little specific legislation related to the use of SVO as fuel for diesel engines; however it is assumed that the emission of regulated components will generally have to meet the same criteria as set for petro-diesel and biodiesel.

Various studies on emission characteristics and related health effects of the use of biofuels (both biodiesel and SVO) showed conflicting results.
Early in 2007 results were published from a study, carried out in Germany, determining possible negative health effects of diesel engine emissions using vegetable oil as fuel.
It was found that the use of rapeseed oil resulted in a strong increase (more than tenfold) of mutagenic substances emitted, as compared to the use of standard petro-diesel as fuel (046).
At that time, there was a lack of information on the health effects of biodiesel and SVO exhaust, but it was recognised that more research on this topic was needed (025).

In order to get a better understanding of the risks and health effects involved with the use of these fuels, a comprehensive web-based literature search on this subject was started in 2008.

The objective was to collect information, available on the internet, on the emission of both regulated and non-regulated compounds.

More specifically, this literature search was directed at the following topics:

- Emissions of engines running on petro-diesel vs. engines running on biodiesel;
- Emissions of engines running on petro-diesel vs. engines running on SVO;
- Specific studies of emissions of engines running on SVO in general and Jatropha oil in particular.

The following general conclusions can be drawn from the hundreds of reports and papers published on the internet on the above subjects:

- The use of biodiesel in modern diesel engines generally results in a reduction of regulated pollutants such as CO, THC and PM. In most cases emission of NOx is at comparable levels or is higher with biodiesel than with petro-diesel.
- In modern diesel engines, the use of biodiesel also generally leads to a reduction of non-regulated compounds such as aldehydes, ketones, polycyclic aromatic hydrocarbons (PAH), nitrated PAH's, sulfates and mutagenic substances.
- Most (also modern) diesel engines need to be modified or adapted to enable an efficient combustion of SVO's. In suitably modified diesel engines, the use of SVO as fuel generally results in a reduction of both regulated and non-regulated pollutants (with the possible exception of NOx). In many cases these reductions are to levels lower than observed for biodiesel as fuel.
- In properly modified diesel engines, the use of SVO's (including pure Jatropha oil) decreases the emission of mutagenic compounds and cancer progenitors as compared to petro-diesel or biodiesel.

Several studies are available where emissions of diesel engines running on different types of SVO's have been compared (113) (117) (128). It was found that emissions vary, depending on parameters such as the fatty acid composition of a particular SVO, its cetane number and iodine number. In most cases the differences were small.

Because Jatropha oil finds an increasing use in projects in developing countries, special attention was paid to the properties and use of (toxic) oil from *Jatropha curcas* L., either as SVO (016) (086) (121) or as a constituent of bio diesel (002) (019) (081).

2. Comparative studies

2.1 Selection process

A search query on the internet related to the emission characteristics of petro-diesel and biodiesel fuels in a variety of diesel engines, resulted in over 250000 entries. A very large number of studies and experiments have been carried out to evaluate and compare the emissions of both regulated and non-regulated components in the exhaust of diesel engines. Biodiesel fuel in these studies consist mostly of a blend of petro-diesel with the methyl- or ethyl-esters of a SVO such as rapeseed oil, palm oil etc. Biodiesel fuels are differentiated by the amount of biomaterial present. B20 is a biodiesel with 20% esters; B100 completely consists of these esters.
In a number of cases, experiments were carried out with biodiesel fuels consisting of a blend of SVO with petro-diesel. Tests and experiments using straight vegetable oils were smaller in number.
Within the framework of this web-based literature study, a selection had to be made of the large amount of available information. The objective was to locate the most relevant data and to draw meaningful conclusions from the data selected.
In this selection process, the following general criteria and rules were applied.

*The first step in the selection process was to create a list of studies or entries which contained relevant information. Articles were considered relevant if they contained original studies of the emission of diesel engines or provided useful references to original data.

*In the second step the list was reduced by selecting the most important studies. Studies were considered important if they described results of research on the combustion of petro-diesel and biofuel in diesel engines and accurately documented data such as engine manufacturer, engine model and type number. They also had to provide quantitative information about the emitted pollutants.

*In addition to original studies, a few literature surveys (such as the EPA report) were also included when they provided useful information about early studies mostly not published on the internet.

*The next step was to create the reference list as the basis for this article. This list is attached.
Some of the studies containing information of particular relevance are summarized in the next paragraphs.

*The last step was to formulate conclusions based on the information collected.
These conclusions are supported by a very large majority of the studies in the reference list. Studies reporting results that do not support the conclusions, mostly describe the combustion of biofuels in unmodified diesel engines.

2.2 Petro-diesel compared to Biodiesel

In the next part, some of the selected studies and publications are discussed in somewhat more detail, to provide a basis for some general conclusions.

In 1996, Krahl et al published a review of various research programs carried out to determine the exhaust gas emissions of diesel engines run on Rapeseed Oil, Rapeseed Oil Methyl Ester (RME) and (unspecified) standard diesel fuel (094).
In this review, engine test procedures were compared. As expected, different procedures yield different results. In the USA, engines are tested according to the American Federal Test Procedures (also known as e.g. FTP-75), whereas in Europe the ECE test procedures are used (e.g. ECE-15). Both test procedures list specific but incomparable duty cycles, which are assumed to be the main reason for the difference in the data collected.
In this review, data on the emission of regulated components such as Hydrocarbons (HC), CO, NOx and Particulate Matter (PM) were compared for different fuel types. Although results varied, the general conclusion was that, with the possible exception of pure rapeseed oil, the emission of total hydrocarbons, CO and PM were reduced when bio fuels were used. In addition, data on the emission of several non-regulated components such as Polycyclic Aromatic Hydrocarbons (PAH), Aldehydes, Ketones and Aromatic Compounds were evaluated. It was concluded that more research will be needed to properly investigate the emission characteristics and possible mutagenic properties of exhaust from engines running on biodiesel and pure rapeseed oil.

Also in 1996, the University of California published an interesting study (085) in which Particulate Matter (PM) from the emissions of a diesel engine running on (unspecified) low sulphur diesel fuel, and B20, B50 and B100 biodiesels based on the Ethyl Ester of Rapeseed oil (REE).

The diesel engine was mounted in a 1995 Dodge pickup truck. The engine was a Cummins B 5.9 litre Turbo diesel, fitted either with or without a catalytic converter. The goal of the study was to determine the health effects of organic matter, mostly PAH, associated with PM emitted from the tailpipe of the car. Organic matter was collected, analysed and subjected to a bioassay analysis to determine genotoxic (mutagenic) activity.
When no catalyst was used, it was found that the emissions of mutagenic substances were a factor 3-7 lower (as compared to standard diesel fuel) when REE and REE blends were used as fuels. With the catalytic converter operational, the mutagenic activity increased for all types of fuel. The highest mutagenic activity was measured for a 20% REE blend.

PAH and Nitro-PAH (n-PAH) emissions resulting from three types of fuel were measured and compared in a study carried out by the Southwest Research Institute USA (060).
The FTP test procedures were used. The test engines were a 1997 Cummins N14, a 1997 Detroit Diesel Corporation Series 50 and a 1995 Cummins B5.9 engine. Tests were done with and without a catalyst fitted. The fuels used were B100 biodiesel from the Methyl Ester of Soy Bean Oil (SME), a blend of 20% SME and (unspecified) 80% standard diesel and neat standard diesel (2D).
Both gas phase samples and PM samples were collected and analysed. 8 different PAH compounds and 5 n-PAH compounds were identified and their concentrations measured.
It was found that B100 biodiesel produced much less PAH and n-PAH than standard diesel fuel. With only a few exceptions, this was also the case for the B20 fuel. The catalyst reduced PAH emissions of all fuels on the two test engines. The catalyst increased n-PAH emissions of most fuels for the two test engines.

In the fall of 2002, the Environmental Protection Agency (EPA) in the USA published a study on the environmental aspects of the use of biodiesel in diesel engines (008,009).
Using existing data, an analysis was performed on the emission of (mainly) regulated compounds from mostly unmodified engines and the results were compared with emissions from engines running on petro-diesel.
The results of this study show that on average, the emission of CO and PM decreased by appr. 15% for B20 to approx. 48% for B100 compared to standard diesel. For NOx, the emission increased on average by 10% with the use of B100.

In 2006, the Department of Mechanical Engineering of the Yale University published a study in which on-the-road emissions were measured from a truck running on standard diesel fuel (meeting the ASTM D6751 standard) and 3 different biofuels (013).
The car was a 1991 suburban truck, equipped with an 8 cylinder 6.5 litre diesel engine. Fuels used were standard diesel (2D), B20 based on soy bean oil methyl ester (SME), B100 (SME) and SVO (pure soy bean oil). Only regulated components in the tailpipe emission were studied: PM, CO, NOx and unburned hydrocarbons (THC). The experimental methods and procedures to determine these components were discussed in great detail.
One of the conclusions was that biofuels produce less particulate matter (PM) than diesel when the engine is in a steady state. The amount of PM decreased proportionally with an increasing content of biofuel. When the engine is in a transient state, more PM is emitted for biofuel than for standard diesel.
Emission values of CO were found to be always lower for biofuel than for standard diesel fuel, with B20 producing less CO than B100.

As in many other studies, it was found that the emission of NOx increases with the use of biofuels, as compared to standard diesel fuel. However it was noted that the engines were not adapted or modified for the use of biofuel. It was expected that such modification, especially optimizing the injection timing, could bring NOx emission levels for biofuels to the levels observed for standard diesel.
THC emission characteristics were less pronounced from these tests as the emissions were very much influenced by factors such as load and engine temperature. All THC emissions were very low with the lowest emissions generally observed for standard diesel and B100 fuel.

In a Taiwanese research paper, published in 2007, the effects of biodiesel on the emission of regulated air pollutants and PAH's were investigated under engine durability testing (061).
Two identical brand-new modern 4 cylinders, DDI, turbocharged 2.835 litre Mitsubishi Model 4M40-2AT1 were employed. One engine was fuelled with standard diesel fuel (ASTM D6751 standard), while the other ran on B20 biodiesel derived from the methyl ester of waste cooking oil. A durability test was performed equivalent to 80000 km. Every 20000 km, emission levels of CO, NOx, HC and PM were measured. In addition, PAH emission factors were determined. A total of 21 individual PAH's were identified and their toxic equivalency factors were assessed.
Emission levels of HC, CO and PM at the beginning of the durability tests were lower for B20 than those for diesel fuel. However after 20000 km or longer, these emission levels became slightly higher for B20. This detoriation effect was attributed to the higher viscosity of B20 fuel, compared to standard diesel. The PAH emission factors for B20 were approx. 15% lower than for standard diesel. For both B20 and diesel, total PAH emission levels decreased with accumulating driving mileage. However, particulate PAH emissions increased for B20 as the mileage increased.

The Francisco Josephinum Institute (FJ-BLT) in Austria published a report in 2006 on the effects of using a variety of biodiesel fuels in a combustion engine (067). A large number of biodiesel types were analysed and the fatty acid compositions determined. Most biodiesel fuels met the EN 14214 standard.
All engine tests were performed on a SUPRA diesel engine manufactured by the HATZ company. It is an air cooled single cylinder 4-stroke direct injection diesel engine. Seven test fuels were used for the endurance tests:

*Diesel fuel
*Rapeseed oil ethyl ester (RME)
*Animal fat methyl ester (TFME)
*Coconut oil methyl ester (KOME)
*Soy bean oil methyl ester (SOME)
*Blend of 30% jet fuel A-1 and 30% RME (KERM)
*Jatropha oil methyl ester (JAME)

Emission quantities of regulated compounds were measured and were reported as a function of the iodine value of the fuel and compared with the emissions from standard diesel fuel in the same engine. An engine load cycle according to ISO 8178-4: 1996 was applied to mimic realistic operation.
It was found that the emission of NOx depends somewhat on the iodine value of the biofuel (higher iodine value leads to more NOx emission) and that the NOx emission using standard diesel was always higher than in the case of biofuels.
The emission of CO and HC were not related with the iodine value but was again always higher for standard diesel than for biofuels.

In 2005, the German Federal Research Institute for Technology and Biosystem Technology, (FAL) published the results of research work on the emission and particle size distribution in the exhaust of a modern Euro-4 diesel engine, fitted with a catalytic converter and running on standard diesel and RME fuel, according to the DIN 14214 norm (111).
The test engine was a 6 cylinder turbocharged, common rail Tector F4A engine, manufactured by IVECO. The engine was adjusted to run in an optimal way on standard diesel fuel. It was not modified to run on biofuels. The ESC test cycle was used. The SCR catalytic converter was fed with a 35% solution of Urea in water.
Three types of fuel were used: (unspecified) Standard Diesel fuel, RME and RME to which tributylphosphate was added in two different concentrations (RME+P). The phosphorous was added to simulate a worst case situation for the SCR catalyser and to enable a better comparison of the emission data.
It was found that the emission of PM was significantly reduced when biofuel was used instead of standard diesel fuel. This was also the case for the emission of CO. A reduction of approx. 45% was observed.
Of all PM emitted, 3 fractions were determined: a fraction soluble in an organic solvent (SOF), a fraction soluble in water (WLF) and a solid fraction.
The SOF fraction measured before and after the SCR was always higher for RME+P than for standard diesel. The catalyser reduced this fraction considerably. After the SCR, the SOF fraction consisted mainly of lubricating oil and an undetermined rest. The fuel concentration was reduced to a very small amount, both for diesel and biofuel, indicating that the SCR very efficiently converts any unburned fuel.
The emission of NOx measured before the SCR was approx. 10% higher when RME+P was used as compared to petro-diesel. The NOx concentration measured after the SCR was lower in all cases and was dependent on the age of the SCR, indicating that the performance of the catalyser was negatively influenced by the phosphorous present in all fuels. In the case of RME+P, the NOx concentration after the catalyser was always above the EURO IV limit.
It is known that diesel engines emit a number of aldehydes and ketones. These compounds are currently not regulated but are considered to have potentially negative health effects. The study investigated the occurrence of 7 different aldehydes and ketones and determined their concentrations in the exhaust gas. It was found that the total concentrations of these compounds were lowest with the use of RME as fuel (appr. 18 mg/kWh). RME+P produced about 2.5 and petro-diesel about 3.5 times that quantity, with the catalyser in use. Formaldehyde was present in the largest concentration.
Ames tests were used to study the mutagenic effects of the PM emitted. These mutagenic effects were found to be very small for all 3 fuels. No significant differences were observed when petro-diesel was compared with biofuel.

In a related research project, the FAL Institute investigated the quantity and properties of ultra-fine particles in the exhaust gas of diesel engines fuelled with biodiesel (according to the DIN EN 14214 standard). The report was published in 2007 (112).
The test engine was a Euro-III Mercedes-Benz 6.37 litre diesel engine OM 906 LA with turbocharger. The engine was tested with and without an oxidation catalyst (DOC). Four types of fuel were tested: standard petro-diesel (DK), Shell V-Power diesel fuel, a blend of Aral Ultimate diesel fuel with 5% (RME based) biodiesel (B5Ult) and B100 (RME) biodiesel. The 13-phase ESC test cycle was used.

Without the use of the oxidation catalyst, the emission of unburned hydrocarbons (THC) was found to be highest for the standard DK and for V-Power. B5Ult yielded approx. 15% lower emissions whereas the THC emission from RME as fuel was approx. 35% lower than for DK.
The use of the oxidation catalyst resulted in a reduction of THC emissions of 80-90% for all fuels. The emission of CO was well below the Euro-III limit for all fuels. The emission from RME was about 50% lower than for the other three fuels. The use of the oxidation catalyst resulted in a reduction of approx. 90% of the CO emission levels for all fuels.
NOx emissions were found to be similar and just below the Euro-III limit for all fuels except RME for which the emission was 15-20% higher than the Euro-III norm. The catalyst had no significant influence on the emission of NOx for all fuels.
The emission of particulate matter (PM) was at 60-80% of the Euro-III limit for all fuels with the exception of RME which was at about 35% of that limit. The use of the catalyst increased the emission of PM (10-20%) for B5Ult and V-power but decreased the emission for DK (15%) and for RME (35%) as fuels.
The composition of the particulate matter was determined in terms of the fraction soluble in an organic solvent (SOF), a fraction soluble in water (WSF) and an insoluble fraction (ISF). It was found that the SOF-fraction was 82% by weight for RME and 38-42% by weight for the three other fuels. The catalyst reduced the SOF-fraction by a factor of approx. 4 for all fuels.
The SOF-fraction was further analysed and it was found that this fraction consisted for about 70% of unburned fuel and about 30% lubricating oil for RME. For the other three fuels these ratios were about 50-50. The catalyst reduced both the unburned fuel and the oil fraction by a factor of approx. 20 for all fuels.
The WSF fractions were also analysed. The WSF fractions of RME, V-Power and DK were similar in size and consisted for about 50% of nitrate. The WSF of B5Ult was a factor 2 smaller and contained also 50% nitrate. The catalyst increased the size of the WSF fractions by a factor 3-5 for all fuels except DK where this fraction remained constant. For all fuels, the nitrate content increased by a factor 2 for DK to 10 for V-Power.
The ISF fraction was determined as a percentage of weight of all PM. For RME a very low value of 2% was found, indicating that PM emitted by RME consists mainly of SOF and WSF fractions. The other 3 fuels showed values between 47% and 59% for their ISF fractions.
Finally, the mutagenic properties of the SOF-fractions of all fuels were determined, using the Ames tests, with and without metabolic activation (TA98+S9 and TA98-S9). The values were very low for all fuels between 35 and 60 mutations per cubic meter exhaust gas without catalyst. The use of the catalyst decreased these values by 30-50%.

2.3 Petro-diesel and biodiesel compared to SVO

In 2006, the research department of the German “Lehr-, Versuchs- und Fachzentrum Kringell” published the results of a study on the emissions from tractors for agricultural work with (unspecified) standard petro-diesel and pure rapeseed oil as fuel. Both regulated and some selected unregulated components were measured (045).
Two different engines were studied. One engine was mounted in a Deutz-Fahr Agroton TTV 1160 tractor. This engine was a 6 cylinder, 162 HP, Diesel engine, Type BF6M1013EC built by Deutz. The other

engine was a 4 cylinder, 125 HP Diesel engine, Type BF4M2013C, also built by Deutz but mounted in a Fendt Farmer Vario 412. Both engines were modified for the use of SVO as fuel.
With a few small exceptions, all tests were made according to the 2000/25/EG test procedure.
It was found that at high rpm, the emission of CO was at the same level for petro-diesel and rapeseed oil as fuels. At low rpm, rapeseed oil led to higher CO emissions than petro-diesel.
Hydrocarbon emissions were found to be a factor 2-3 lower with rapeseed oil as fuel, both for high and low rpm. NOx emissions were approx. 10% higher with rapeseed oil. PM emissions were lower for rapeseed oil than for petro-diesel at medium to high engine loads, but comparable at low engine loads.
The results were similar for both engines. The general conclusion was that at high and medium loads, the emissions of regulated compounds were lower for rapeseed oil than for petro-diesel as fuel. The exception is NOx, which was 10-15% higher for rapeseed oil at medium and high engine loads.

Early in 2007 a report was published by Bünger et al in which the health aspects of diesel engine emissions were described for a diesel engine running on rapeseed oil, rapeseed oil methyl ester (RME) and on standard diesel fuel (meeting the EN 590 standard) (046). The standard European Stationary Cycle was used.
The test engine was a standard, unmodified Mercedes Benz engine OM 906 LA with turbocharger and intercooler. The engine met the Euro 3 exhaust limits. PM was sampled using glass fibre filters. Gas phase constituents were sampled as condensates. The mutagenic properties of the particle extracts and the condensates were tested using the Salmonella tester strains TA98 and TA100.
When the engine was running on rapeseed oil, it was found that the particle extracts were significantly more mutagenic (a factor 5 to almost 60) as compared to the results from standard diesel fuel. Also, the condensates showed a higher mutagenicity (up to a factor 13.5) than the reference fuel.
With RME as fuel, the extracts and condensates showed a moderate but still significant increase in mutagenic response as compared to standard diesel fuel.
The emissions of regulated compounds were well below the Euro 3 limit for all fuels, with the exception of NOx. For the biofuels an increase of NOx emission was observed of up to15-25% over the Euro 3 limit. The authors of the report could not offer a plausible explanation for their findings. It was suggested that the higher viscosity of the biofuels and the different combustion behaviour in the engine could perhaps (partly) explain the results. More systematic research was recommended.

In august 2007, the German environmental institute BIFA, published a paper which described the results of a detailed analysis of the mutagenic properties of the emission of a diesel engine running on rapeseed oil (047).
The engine used was a DAF XF 105 (Euro5) diesel engine. The 13-step European Stationary Cycle was used. The engine was modified for the use of rapeseed oil as specified in the DIN 51605 norm. The diesel fuel was standard EN 590.
The exhaust of the engine was diluted and passed through glass fibre filters. The filters were then extracted with dichloromethane. The solvent was removed and the remaining oily substance was dissolved in ultra pure dimethylsulfoxide.
These samples were used to determine the mutagenic properties of the extracts with the well-known Ames test, using the TA98 and T100 mutant species of *Salmonella typhimurium LT2*.
Contrary to results published earlier by Bünger et al (046) it was found that, related to the weight of the PM on the sample filters, the number of revertants (a measure for the mutagenic properties of a substance; more revertants = more mutagenic) occurring with the extracts from rape seed oil (as fuel) were a factor 2-3 lower than the extracts from PM sampled when standard diesel fuel was used.

In addition the amount of PM in the exhaust from the engine was roughly a factor 2 lower for rapeseed oil as compared to diesel fuel. The general conclusion was that the amount of mutagenic substances emitted by a properly adjusted diesel engine was a factor 4 or more lower for pure rapeseed oil than for standard diesel as fuel.

In 2008, a study was published by workers from the University of Offenburg, Germany, on the gaseous and particle emission of diesel engines fuelled with different non-esterified plant oils (048,159).
The engine used was a state of the art common rail 4 cylinder 1.7 litre Euro 4 engine with 16 valves, EGR and VTC turbo charger. A heat exchanger was installed to enable to heat the plant oil to 80-90 deg. C prior to injection. A special fuel pump was used to yield the higher pressures required for the proper injection of plant oils. For comparison reasons, an old, non modified heavy duty engine from 1969 was analysed, using similar procedures as applied to the state of the art engine. Three load conditions were applied.
Four different oils were investigated and compared with conventional (unspecified) petro-diesel:
*Rape seed oil
*Sunflower oil
*Soy bean oil
*Peanut oil
The state of the art engine did not show large differences in the nature of the emitted particles for the different fuels. All primary particles emitted were in the range of approx. 15 nm and their TEM pictures were very similar. The composition of these particles is carbon. No ash traces were found. The concentration of the emitted particles depended strongly on the engine load, but was very similar for all fuels.
Gaseous emissions were also measured. The concentration of CO and THC (unburned hydrocarbons) were below the detection limit. NOx values were found to be up 15% higher for plant oils as fuel, except at very high load conditions, where the values were comparable for petro-diesel and plant oil.
Experiments with the old unmodified and heavy duty engine with 6 fuels:

*Petro-diesel
*Low sulphur diesel
*Esterified rape seed oil
*Rape seed oil
*Soy oil
*Waste cooking oil

A striking difference was observed between the size and number of particles emitted by the modern and the old engine, especially when the old engine was fuelled with rape seed and cooking oils. Petro-diesel and low sulphur diesel yielded similar particle quantities and sizes with both engines. Particles emitted by the plant oils in the old engine were wax-like and were found to contain unburned long chain hydrocarbons. In addition, the size of the particles emitted by the old engine with plant oils as fuel was very sensitive to the engine load. Low and medium load conditions generated large particles. At high and very high engine loads, particle sizes were comparable to those from particles emitted by the modern diesel engine.

3. Conclusions

From the massive amount of data available, it is still difficult to accurately assess the environmental and health effects of the use of biofuels such as biodiesel or straight vegetable oils (SVO) in a particular diesel engine. However, some general conclusions can be drawn.

1. Compared to standard petro-diesel, the emission of regulated and non-regulated compounds are generally equal or lower when bio fuels are used. An exception is NOx, which is generally higher with biofuels.
2. The amount of compounds emitted depends considerably on the type of diesel engine, the configuration, the load condition and the use of a catalyser.
3. In most cases, reducing the emission of unwanted compounds requires modification standard diesel engines for the use of biodiesel and/or SVO. Pre-heating of fuel to reduce the viscosity is often required.
4. In a properly modified and adapted diesel engine, using biodiesel or SVO results in reduced emissions of non-regulated compounds (including carcinogenic and mutagenic substances) as compared to the use of petro-diesel.
5. Compared to biodiesel, the use of SVO as fuel in a properly modified diesel engine, leads to a further reduction of non regulated compounds, again including mutagenic and other health affecting components.
6. No evidence has been found indicating that the use of toxic Jatropha oil (either pure or esterified in biodiesel) as fuel in properly modified diesel engines will result in the emission of these specific toxic compounds in health effecting quantities.