A STUDY OF EMISSION REDUCTION FROM A LIGHT DUTY VEHICLE FUELLED WITH BIOFUEL (VEGETABLE OIL)

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Abstract

The aim of the study is to obtain an overall assessment of the opportunities and costs for reducing emissions of CO, NOx and "soot" (black carbon - BC). It should also address the potential positive effects of such measures for health, ecosystems and climate from worldwide perspective. This research work was carried out for to control the emissions of regulated pollutants (CO, NOx, and soot) from a light vehicle fuelled with Diesel fuel, unused and waste vegetable oils, and blends of Diesel fuel and oils were measured, as a function of engine speed. Formaldehyde emissions were also quantified, as well as the smoke opacity. The emission levels when using pure or blended oil (25%, 50%, 75%) with diesel fuel are quite similar to the ones from diesel fuel alone, but patterns are found with a small overproduction of CO together with a decrease in NO emissions for the 50% blends. No considerable effect of the nature or previous use of the oil has been found.

Key words: Diesel fuels, alternative fuel, exhaust emissions, Vegetable oil, regulated pollutants.

I. INTRODUCTION

Diesel exhaust is a major source of combustion soot that contributes to poor air quality nationwide. Since maximum light duty vehicles are operated with diesel engines, diesel engine exhaust can thus also be a source of concern, specifically with regard to exposure to children. Soot is a complex and unhealthy mixture of inorganic and organic carbon soot with adhered toxic substances and metals. The purpose of the study was to investigate the causes of light duty vehicle self-pollution and to document in-cabin diesel soot exposures in vehicles retrofit with a variety of available soot emissions control combinations. The possibility of replacing fuels derived from petroleum by biogenic fuels from renewable resources is of undeniable worldwide interest, because of uncertainties about the petroleum supplies and cost in the future, and because of the environmental benefits that such alternative fuels would provide, in particular the reduction of greenhouse gases. One of the alternatives is the use of fuels derived by esterification from vegetable oil, and in most of the states diesel contains up to 5 vol% biodiesel, i.e. fatty acid alkyl (generally methyl, but also occasionally ethyl) esters, with a maximum countries proposed target at 10% by 2020. The esterification of the vegetable oils presents the interest of obtaining a replacement fuel with physical characteristics, in particular its viscosity, close to those of conventional diesel fuel, and therefore compatible with most of the vehicles. The exhaust emissions from these fuels are reasonably well documented [1-3], especially for the regulated emissions, though the non-regulated emissions such as carbonyls [5,6] lack extensive research and are still under close scrutiny, both for their ecological effects and their health effects.

On the other hand, from an environmental point of view, the oil esterification also raises concerns, because of petroleum-derived reactants used in the process, of the reactants toxicity, methanol in particular, and because of the profitable cost of transforming the oil [7].

This has triggered some work on the use of vegetable oil as fuel or additive with no prior chemical transformation. The viability to use vegetable oil as diesel fuel was first demonstrated in 1895 by Rudolph Diesel, who operated a diesel engine with peanut oil. Vegetable oils do not however present the same physical characteristics as Diesel fuel and can lead to damages to the engine, and modifications have be made to the tank and injection lines, in addition to the tuning of the engine arrangement.

A modern development of this research, uses of waste material such as used cooking oil [8-11], as there is a growing concern about a possible considerable rise of food and water prices induced by the agricultural development needed to produce the oil specifically for fuel use. Waste oil consists basically of the same components (triglycerides) as unused oil, but they differ because of the presence of products resulting from thermal, oxidation and hydrolysis processes, as well as the presence of food residues [12]. Emissions from vehicles with unesterified oil are not as well documented, and lead to results widely diverging, in particular for CO and NOx. The single universal observation is the emission of soot, which are reduced compared to vehicles fuelled with Diesel fuel.

In this paper, we report the analysis of the regulated pollutants and some unregulated pollutants emitted by a lightweight vehicle fuelled with Used Vegetable oil or blends of Used Vegetable oil and diesel fuel. This study was performed with the vehicle at rest, while maintaining a constant engine speed. The results from this pilot study will be used as reference data for a future large scale study of the emissions of vehicles fuelled with alternative fuels made from waste cooking oil, using standard and real-world driving cycles and chassis dynamometer facility with constant volume sampling equipment.

II. EXPERIMENTAL SETUP & SAMPLING METHOD

A. Fuels

The fuels used in this study are standard commercial gasoil, two unused sunflower oils, thereafter labeled Pure Vegetable Oil1 and Pure Vegetable Oil2, containing an antifoaming additive (E900, polydimethylsiloxane) in unspecified proportions, and four samples of Used Vegetable oils (Used Vegetable Oil1 to Used Vegetable Oil4) collected from restaurants in the Lille area. No chemical characterization of the oils has been performed. According to the restaurant owners indications, Used Vegetable Oil1 to 4 each come from single commercial oil, containing either pure sunflower or sunflower mixed with palm, rape seed or grape seed. Additional experiments were performed on a mixture of oils collected from several restaurants, hereafter labelled Used Vegetable Oil5. The origin of the constituents of Used Vegetable Oil5 has not been traced, and it can therefore be considered as generic waste oil. All the used oils may also contain the E900 additive. Used Vegetable Oil1 to 4 has been used as collected (unfiltered), while Used Vegetable Oil5 was centrifuged before use, and contains less than 0.3% water.

Emissions measurements were performed for pure Diesel fuel, pure oil, and for blends of oil and Diesel fuel (B25: 25 vol% vegetable oil, B50: 50 vol% vegetable oil, and B75: 75 vol% vegetable oil). Whatever the origin or previous use of the oil, the mixtures are immediately uniform and used without further treatment.

As the oil viscosity is the main problem encountered when using them as fuel, this parameter was measured for our fuels at ambient temperature (20°C) and at 50°C, which we consider to be the temperature of the fuel when it is injected in the fuelling line to the engine. Former studies recommended, on the basis of empirical results, to preheat the oil to about 70°C before injecting it to the engine. Viscosity of blends varies almost linearly with the oil content between the values of pure diesel and pure oil.

B. Test vehicle

The test vehicle was a standard Fiat Uno 1997; it was taken after travelling kilometer is 58,000. No specific attention was paid to the repair, servicing or modifications record of the vehicle since its first use, except for the change of the exhaust pipe prior to the experiments. The only specific adaptation to prepare the vehicle for our study was the modification of the

Fig. 1 External tank and of the fuelling lines

fuelling lines, with the addition of an external tank, in order to control the composition of the fuel, avoiding mixing the different fuels in the internal tank of the vehicle.

After each change of fuel in the tank, all lines were drained and then filled with the next fuel. The engine was first purged with the new fuel, while the excess fuel was discarded, before the emissions can be measured. For each fuel, the emissions were measured with the vehicle at rest, while maintaining different engine speeds by inserting a metal block in the throttle: starting conditions (710 rpm) and 3 engine speeds (730, 1700, and 1930 rpm respectively). Each run lasted about 10 minutes.

C. Sampling and analysis

The general experiment setup is arranged just like as on Figure 2.

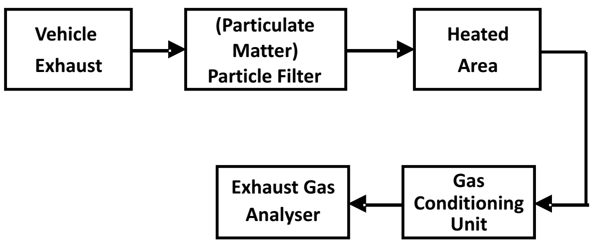

Fig. 2 Experimental Setup

The exhaust gas was sample in the centre of the exhaust pipe in order to stay away from the capture of wall deposits. The exhaust gas was carried through a cellulose filter to remove larger soot and a water condenser filter before being diluted with nitrogen so as to bring the concentration of pollutants in the measuring range of the analyzers (dilution by a factor ~15 and ~200 for CO and NOx measurements respectively). Exhaust emissions were transferred from the exhaust pipe to the analysis equipment through a 120°C heated line. Carbon monoxide (CO) was determined with a non-dispersive infrared (NDIR) gas analyzer (model CO11M). Nitrogen oxides (NOx) were analyzed with a chemiluminescence gas analyzer (AC31M). Exhaust soot were measured using the high volume sampler. Carbonyl compounds are quantified by UV-HPLC after trapping on a DNPH coated cartridge. Additional measurements of formaldehyde were performed using tunable diode laser infrared absorption spectroscopy [13].

The opacity of the exhaust gases was measured in a separate set of experiments with a Diesel smoke meter chamber 495/01 for the Diesel fuel, Pure Vegetable Oil1, and the waste oil UV5, in starting conditions and the three accelerating engine speeds.

III. RESULTS AND DISCUSSION

Experiments for each fuel and engine speed have been simulated several times to check for repeatability. From one run to the other, in the same conditions, variations in the concentrations of up to 25% have been observed, as is usually the case for vehicular emissions.

A. Regulated gaseous pollutants

Gaseous emissions of CO and NOx when the vehicle is fuelled with unused oils pure or in blends (25%, 50%, and 75%) are shown on Vegetable oils are shown on Figure 5, for pure oils and the 50% blends with Diesel. Except in a few runs with pure Diesel fuel, where concentrations of NO_2 of about 15 ppm have been measured, only NO has been found in the exhaust gases.

With Diesel fuel, CO emissions increase with the engine speed, from 200 to 450 ppm, whereas NO emissions decrease from 150 to 80 ppm respectively.

When using oil, pure or in blends, the observed pollutants levels do not vary much compared to Diesel fuel, the main differences being in CO concentrations in the exhaust gases. CO concentrations in that case range from 200 to 750 ppm, with differences between the oils appearing clearly from

Figure 3 and Figure 4, At starting speed CO emissions increase clearly with the amount of oil, new or used, in the fuel. With unused oil, at high engine speed, CO emissions decrease with increasing oil proportion. This behavior at higher engine speed is less marked with Used Vegetable oils (Figure 4). Maximal CO concentrations are obtained for intermediate (1700 rpm) engine speed. This behavior may be linked to the injection timing, which was not modified in our experiments. It is indeed expected that the auto ignition delay depends upon the composition of the fuel, with oil having a shorter ignition delay [14].

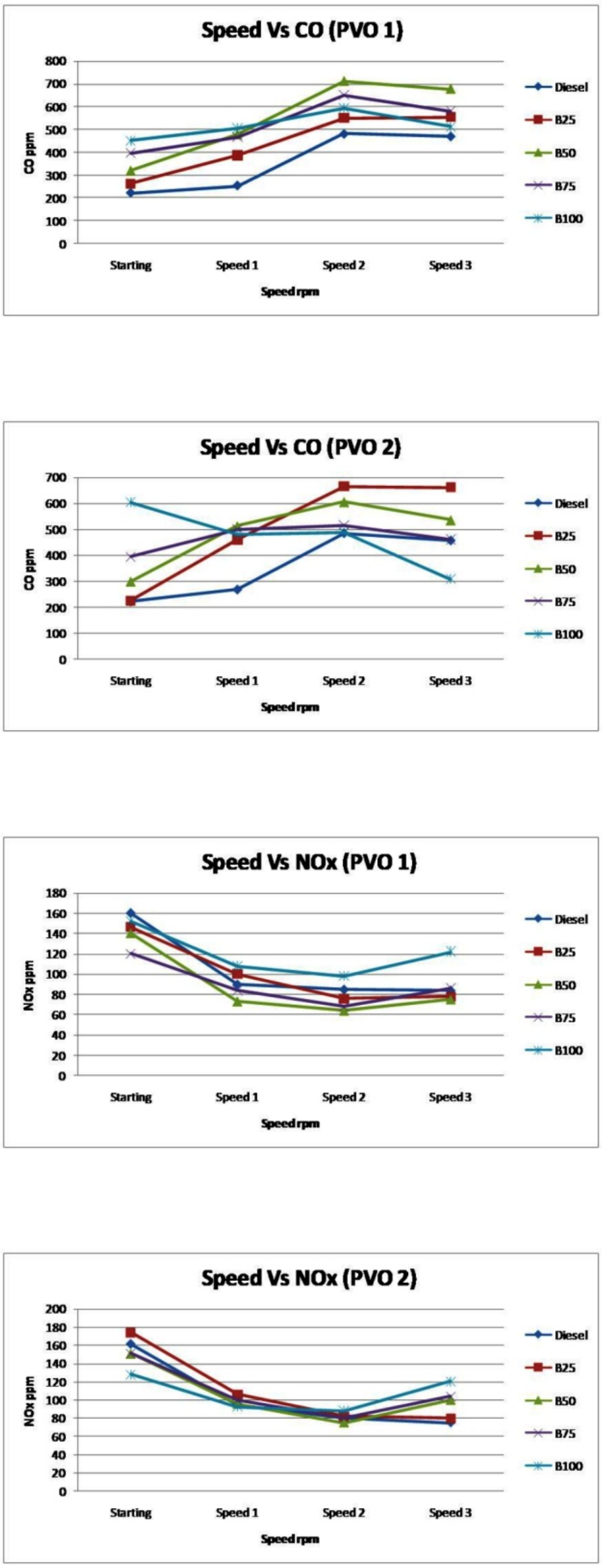

Fig. 3. Pure Vegetable Oil-Emission Strategy

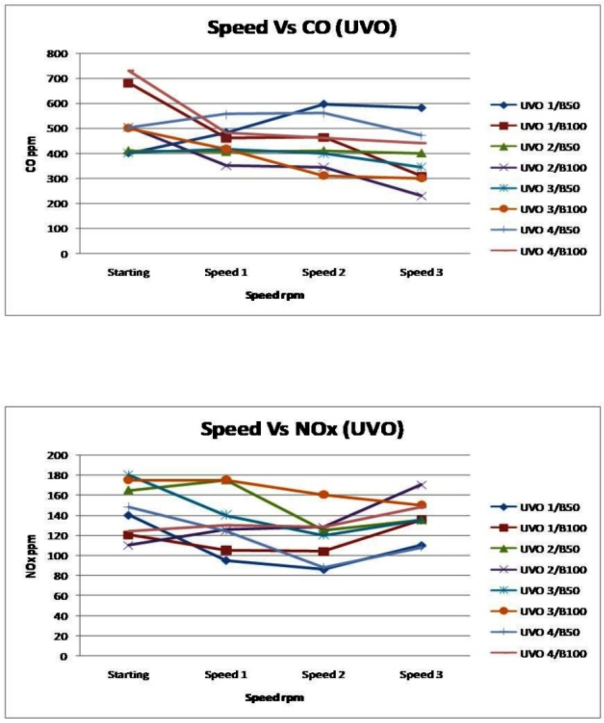

Fig. 4. Used Vegetable Oil – Emission Strategy

NO emissions with oil are also in the same range (60 – 180 ppm) as Diesel emissions. All NO emissions curves with oil have the same profile, both as a function of the oil proportion in the fuel, and of the engine speed. Whereas for Diesel fuel there is a constant decrease when the engine speed increases, with oil we observe a minimum in the emissions at intermediate speeds. At the same time, at low engine speed, the NO emissions decrease slightly when the percentage of oil increases in the blend, but the trend is reversed at high engine speed where oil-rich blends give higher emissions. This performance pattern is anticorrelated with the CO emissions pattern, so it is likely that the injection timing is also the reason for it. Differences are noted between the oils, as some of them, Pure Vegetable Oil1, Used Vegetable Oil3 and Used Vegetable Oil4 in particular, induce higher emissions when used pure than when blended. No explanation, such as differences in the composition, has been found to account for this effect.

B. Carbonyl compounds

Formaldehyde content in the exhaust gases has been measured only for three unblended used vegetable. The results of these measurements, shown in Table 1, illustrate the high variability of the emissions, where the formaldehyde concentrations at high engine speed can be lower, higher, or equivalent to the concentration at low engine speed. However, these concentrations are low compared to those reported when using ethanol/biodiesel/diesel blends [15], diesel fuel blended with biodiesel from waste cooking oil [16], or biodiesel and biodiesel/methanol blends. In these three studies, the formaldehyde concentrations in the exhaust gases are in the range 1-100 mg.m-3, much higher than in our study. We cannot regularly rule out experimental feasible art effects, in particular the solubilisation of formaldehyde inside the water in the water trap, because exhaust gases are diluted only after going through the trap.

Table 1 Formaldehyde concentration (μg.m-3) in the exhaust gases

Waste oil	Idling	1930 rpm
UV02	423	197
UV03	360	439
UV04	220	228

IV. CONCLUSION

Diesel fuel is inadequate, and hereafter, the various comparisons between the regulated and non regulated pollutants from diesel fuels, Pure Vegetable oil and Used Vegetable oil, pure or in blends with diesel fuel. Performance test was carried out on a vehicle fuelled with unesterified cooking oil, before or after use, performed at different engine speeds, spanning the typical driving conditions engine speed.

These tests have shown the use of oil as fuel does not modify significantly the emissions of regulated pollutants. The previous use of the oil, i.e. the ingredients that have been cooked in it, the length of time it has been used, the temperature cycles it has undergone, seems to be irrelevant parameters for estimating the emissions. With oils, smoke opacity is reduced and NOx emissions are comparable to those of diesel fuel and only CO emissions are a little increased. Formaldehyde emissions are also low, though because of the oxygen content of the oils, this compound should be investigated more closely. Our measurements tend to show that in spite of differences in the individual emission profiles, depending upon the previous use and/or the composition of the oil, B50 blends seem to be the more appropriate fuels for use in urban driving conditions, because of the reduced CO emissions at low engine speed.

Since tests on a single vehicle were performed in our study, it is not possible yet to generalize these findings, and a full-scale measurement campaign must be initiated, encompassing more vehicles with different engine types, preferably on normalized driving cycles. The influence of the tuning of the injection timing, not considered so far, should also be investigated at the same time, as it could lead to an abatement of the emissions. It will also be necessary to add to the measurement of the regulated pollutants and of aldehydes the determination of odorous compounds, which are a source of nuisance when using oil in the fuel.

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