EMISSIONS FROM A EURO V TRUCK FUELED BY DIESEL, BIODIESEL BLENDS, NEAT BIODIESEL AND VEGETABLE OIL

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Abstract

The substitution of conventional fuels (gasoline, diesel) by renewable biofuels including biodiesel and vegetable oil is considered as a potential solution not only for satisfying the fuel demand but also for reducing emissions. In this study, a Euro V truck fueled with a low sulphur diesel fuel, a neat biodiesel (B100), biodiesel blends (B7 and B10), a mixture of 7% biodiesel, 3% vegetable oil and 90% diesel (B7+3) and a straight vegetable oil was tested on chassis dynamometer under the European stationary cycle. During the test, emissions in the exhaust gas were collected and measured following the standard methods. Besides the regulated emissions, particle number and size distribution, which were sampled by volatile particle remover system compliant with the PMP requirement, as well as soot concentration, were also considered. Results show the effects of the tested fuels on the engine characteristics as well as the emissions.

Keywords: Biodiesel, Diesel exhaust gas emissions, Particle number, Particle size distribution, Vegetable oil

Introduction

The scarce and rapidly depleting conventional petroleum resources have promoted research for alternative fuels for internal combustion engines. The substitution of conventional fuels (gasoline, diesel) by renewable biofuels including biodiesel and vegetable oil is considered as a potential solution not only for satisfying the fuel demand but also for reducing emissions. Biodiesel is referred to as the mono-alkyl esters of long-chain fatty acids derived from renewable lipid sources [1] such as oil seeds (oils from rapeseeds, soybeans, palm kernels, etc), animal fats and waste cooking oils. Regardless of the feedstock used, the chemical process to produce biodiesel is essentially the same that is called transesterification. Biodiesel can be blended with fossil diesel for use on compression ignition engines. Biodiesel can also be used in its pure form (B100), but may require certain engine modifications to avoid maintenance and performance problems.

The U.S. Environmental Protection Agency reviewed of published biodiesel emissions data for heavy-duty engines and summarized the effects of biodiesel on pollutant emissions [2]. However, they also concluded that these effects varied depending on fuel properties and engine technologies. Currently in Europe, diesel fuel blended up to 5% biodiesel by volume (B5) is used as a commercial fuel. Increasing percentage of biodiesel in blends has been considered in many studies. This paper studies the influences of neat biodiesel, biodiesel blends and vegetable oil on emissions from a Euro V truck. Especially, not only the regulated emissions but also the particle number, which will be regulated in the near future, and size distribution are all presented. The experimental work was carried out at the

Institute of Internal Combustion Engines and Thermodynamics, Graz University of Technology, Austria.

Measurement Setup

Experimental Apparatus

The truck was tested on a heavy duty chassis dynamometer (Figure 1). The dynamometer is a thyristor-controlled direct current machine, which can be driven as generator (brake operation) and motor (motoring operation). Exhaust gas of the tested vehicle was transferred to a full flow Constant Volume Sampling (CVS) system. At the end of the CVS tunnel, the secondary dilution stage was used to further dilute the sample gas in order to reduce the temperature for particle mass (PM) sampling. The PM mass was collected on a pair of 70 mm diameter Teflon-coated filter papers and measured by gravimetrical method. The Micro Soot sensor AVL 483, which has a principle based on the photo-acoustic method, was installed to measure soot concentration. A Volatile Particle Remover (VPR) system, which has been developed at Graz University of Technology and compliant with Particle Measurement Programme (PMP) working group, was used to sample and condition the sample gas for particle number (PN) measurement. Flowing through the VPR system, sample gas was heated and diluted by clean compressed air in order to remove volatile particles and to reduce particle concentration under the threshold of the particle counter, so that solid particles could be counted. The outlet of the VPR system was split

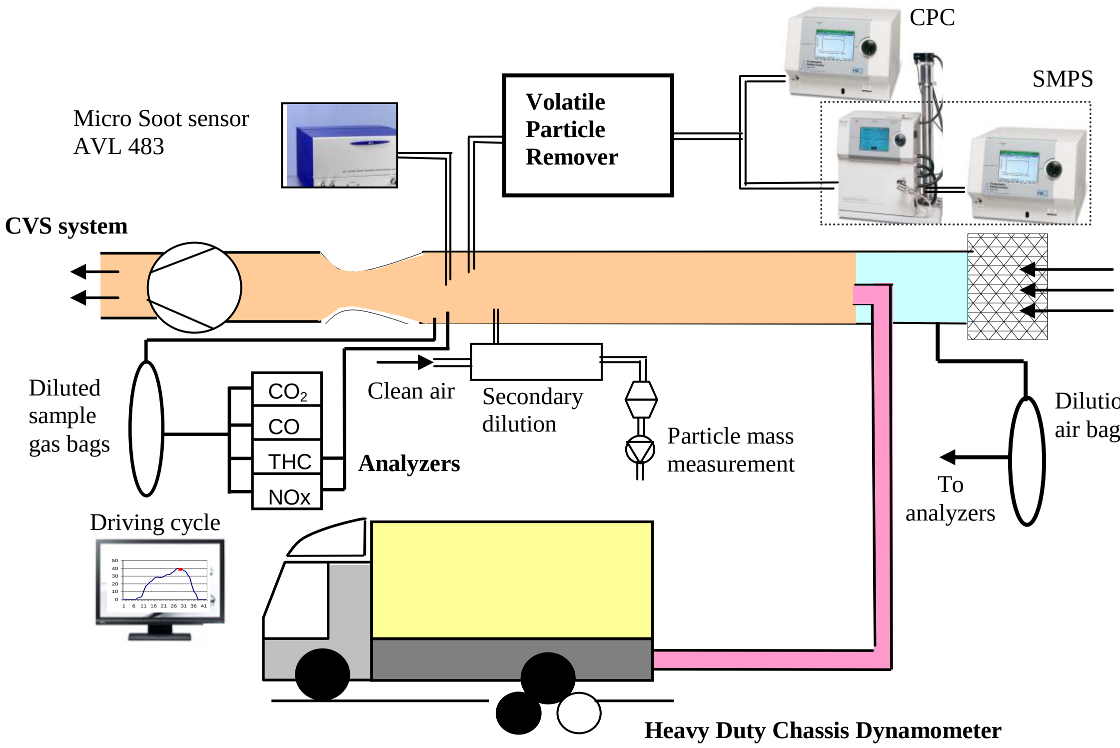

Figure 1. Layout of the measurement setup

into two paths: one connected to the Condensation Particle Counter model 3775 (CPC 3775) for particle number measurement and the other connected to the Scanning Mobility Particle Sizer (SMPS), that comprised the Differential Mobility Analyzer 3081 (DMA 3081) and the CPC 3010, for particle size distribution measurement. The cutoff point of the CPC 3775 is at 4nm and that of the CPC 3010 is at 10nm. Additionally, a soot sensor AVL

483 was used to detect soot concentration. All the sampling points were placed at the same position as of the PM mass measurement. Specification of the tested truck is given in Table 1.

Table 1. Specification of the Tested Truck

Model Year	2007
Emission Standard	Euro V
Cylinder Displacement (l)	10.5
Rated Power/Engine Speed (kW/rpm)	324/1900
Injection System	Common rail
Emission Control	Selective Catalytic Reduction (SCR)

Testing Procedure

The truck was driven following the European Stationary Cycle (ESC) which comprises 13 modes (Figure 2). The engine power was calculated from the power of brake and the power losses for transmissions and auxiliaries [3]. The fuel consumption was evaluated by using the carbon balance method which bases on the fact that the amount of carbon atoms before and after combustion is equal. According to the regulation [4], the duration of each mode of the ESC cycle is 2 minutes with an exception for idling mode which lasts 4 minutes. The sampling time for PM mass measurement per mode is even less but at least 4 seconds per 0.01 weighting factor. Such a short time is not sufficient to sample for particle mass, number and size distribution measurements at each mode. In this study, therefore, the sampling time for each mode was extended to be sufficient for these measurements.

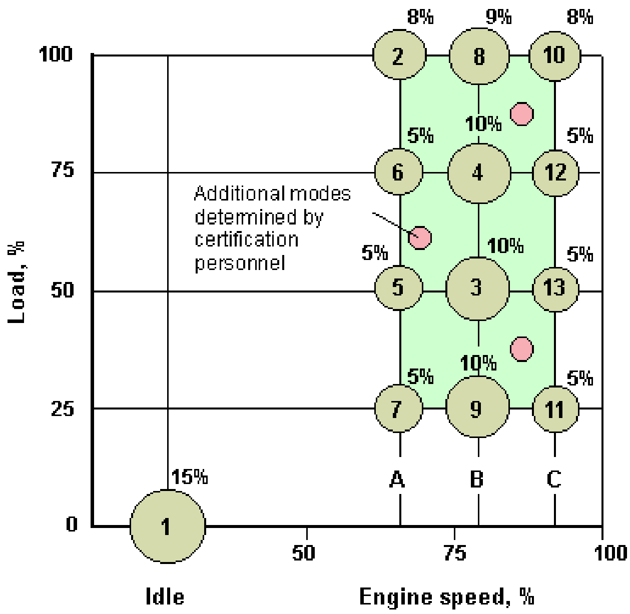

Figure 2. European stationary cycle (ESC)

The engine speeds A, B and C were calculated and had the values of 1200rpm, 1500rpm and 1800rpm, respectively.

Tested Fuels

There were 6 tested fuels including a fossil diesel fuel, a neat biodiesel B100, biodiesel blends B7 and B10 (7% and 10% biodiesel in volume, respectively), a straight vegetable oil fuel and a mixture called B7+3 (7% biodiesel, 3% vegetable oil and 90% diesel in volume). The diesel, which had very low sulphur content, was used as the base fuel. The neat biodiesel is rapeseed oil methyl ester and the vegetable oil is rapeseed oil. The neat biodiesel B100 was compliant with EN14214. The main properties of these fuels are shown in Table 2.

Table 2. Some Main Properties of the Tested Fuels

Fuel properties	Unit	Diesel	B7	B10	B7+3	B100	Vegetable oil
Heating Value	kJ/kg	42960	42563	42393	42383	37292	37192
C Component	% (mass/mass)	84.7	84.15	83.92	83.92	76.9	77
H Component	% (mass/mass)	14.4	14.23	14.15	14.15	11.9	12
O Component	% (mass/mass)	0	0.756	1.08	1.92	10.8	10.8
S Component	ppm (mass/mass)	3.5	-	-	<3.5	<1	<1
Phosphor Component	ppm (mass/mass)	1.3	1.615	1.75	-	5.8	3
Cetane Number	-	53.8	-	-	-	58.4	46.4
Density at 15°C	g/cm^3	0.8357	0.839	0.841	-	0.885	0.9202
Viscosity at 40°C	mm^2/s	2.51	2.661	2.726	-	4.67	34.85

Results and Discussions

Comparison of Engine Power and Fuel Consumption

A comparison of engine power and fuel consumption are made at full load condition at 1200rpm, 1500rpm and 1800rpm (Figure 3 and Figure 4).

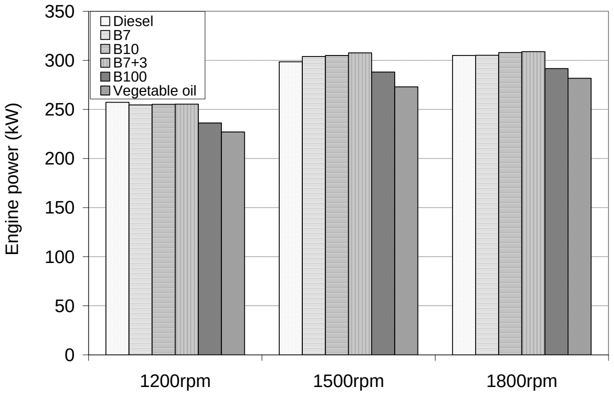

Figure 3. Engine power at full load points

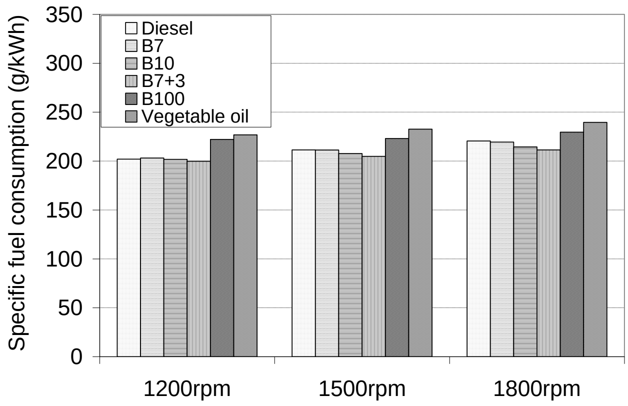

Figure 4. Specific fuel consumption at full load points

It shows that there is nearly no change in power and fuel consumption when using B7 but slight improvement with B10 and B7+3 as compared to diesel. A little higher oxygen content in the B10 and B7+3 may improve the combustion. For the B100 and vegetable oil, the significant decrease in power and increase in fuel consumption can be seen. The highest change occurs at 1200rpm, engine power decreases by about 8.2% and 11.8%, fuel consumption increases by 10.0% and 12.3% with B100 and vegetable oil fueling, respectively, relative to diesel fueling. These results may come from the lower heating values of the B100 and vegetable oil which are 13.2% and 13.4% less than the value of the diesel (see Table 2). However, the changes in engine power and fuel consumption are less than the changes in heating value, which would be an expected result. The B100 has a higher cetane number than the diesel, which may slightly increase combustion efficiency. Moreover, the combustion with higher oxygen content in the B100 and vegetable oil can be more complete than that with the diesel. These lead to a power recovery that compensates for the loss with the B100 and vegetable oil due to their lower heating values.

Comparison of Regulated Gaseous Emissions over the ESC Cycle

Oxides of Nitrogen (NO_x) Emissions

Reduction in NO_x is one of the challenges for present-day diesel engines. Unfortunately, the higher NO_x concentration when using biodiesel fuels was obtained in several previous publications [2],[5]. Here as compared to the diesel, the increase in NO_x can be obviously seen with 10.2%, 9.4%, 37.7% and 9.1% higher for the B7, B10, B100 and vegetable oil, respectively (Figure 5). NO_x emissions formed in an engine are highly dependent on combustion temperature, along with the concentration of oxygen present in combustion products. Biodiesel's rich oxygen content is an important factor in high NO_x formation levels because of the ability to increase flame temperature due to more fuel burned and reduction in the heat dissipation by radiation as a consequence of the low amount of soot emitted [6]. Furthermore, the fuel oxygen may provide additional oxygen for NO_x formation. It is not clear whether the higher cetane number of biodiesel which advances the combustion timing by shortening the ignition delay is a reason of increasing NO_x. On the one hand, advanced combustion timing may cause a higher mean temperature peak resulting in high NO_x; on the other hand, shorter ignition delay decreases premixed combustion which usually decreases NO_x. Moreover, the tested truck applies a SCR for NO_x reduction, so that the variation of NO_x may strongly depend on the behaviour of the control system. One surprising result for the B7+3, the NO_x produced is 5.0% less than for the diesel fuel.

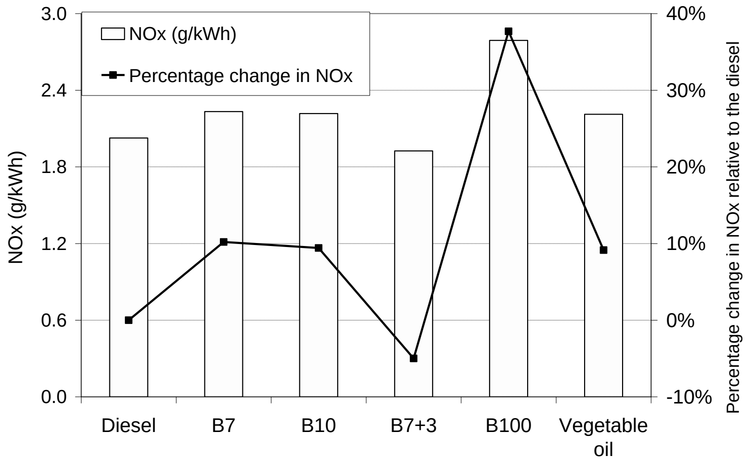

Figure 5. NO_x emissions over the ESC cycle

Hydrocarbons (HC) and Carbon Monoxide (CO) Emissions

The significant decrease in HC and CO emissions with the biodiesel and vegetable oil are also apparent (Figure 6 and Figure 7). With respect to the diesel, HC emission with the B7, B10, B7+3, B100 and vegetable oil reduces by 18.1%, 10.5%, 19.8%, 52.8% and 54.2%, and CO emission reduces by 4.1%, 11.2%, 15%, 43.7% and 29.2%, respectively. These reductions have several reasons. The higher oxygen content in these fuels enhances the complete and clean combustion that decreases HC and CO emissions. For the biodiesel and biodiesel blends, the higher cetane number could shorten the ignition delay resulting in more proper combustion and consequently reducing HC and CO. Furthermore, regarding to the HC measurement method, the sampling line is usually heated up to 190°C to avoid hydrocarbon condensation; however, biodiesel, and vegetable oil especially, are less volatile so that this temperature may not be enough to evaporate all components, leading some hydrocarbon losses by condensation.

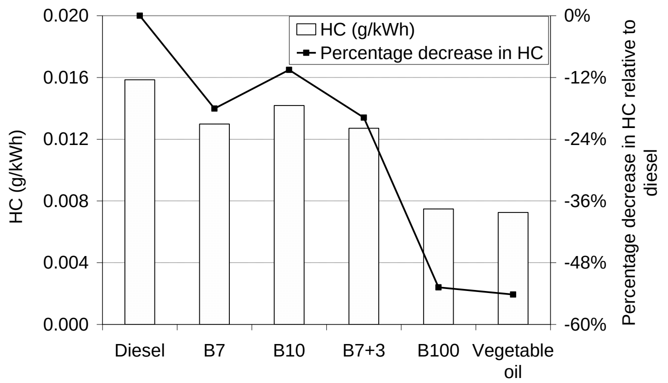

Figure 6. HC over the ESC cycle

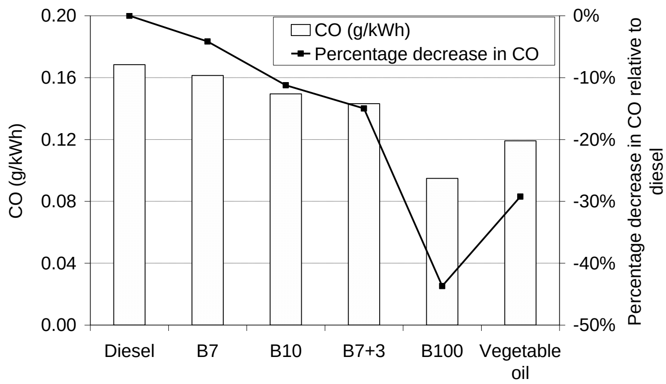

Figure 7. CO over the ESC cycle

Comparison of Particle Emissions over the ESC Cycle

Particle Mass and Soot

Particle mass over cycle was calculated from particle mass at each mode which was collected on filters and weighted after conditioning in a chamber. The soot was instantaneously measured by the soot sensor and then integrated to determine soot concentration over cycle. Reductions in PM and soot can be observed for the biodiesel, biodiesel blends and vegetable oil (Figure 8 and Figure 9). Compared to the diesel fuel, PM emission with the B7, B10, B7+3, B100 and vegetable oil reduces by 19%, 18%, 28%, 60% and 62% and soot reduces by 14.1%, 13.7%, 18.4%, 77.3% and 65.4%, respectively. The reduction in PM and soot is expected and it can be explained by some reasons. The oxygen content with 10.8% by weight in the biodiesel and vegetable oil enables more complete combustion even in regions of the combustion chamber with fuel-rich diffusion flames, and promotes the oxidation of the already formed soot. The high oxygen content in the fuels also reduces the demand of air for stoichiometric condition, lowering the probability of fuel-rich regions in the nonuniform fuel/air mixture. The aromatic content, which is widely known to contribute to particulate formation, of the biodiesel and vegetable oil is generally less than of the diesel, which may lead to the lower soot and PM emissions.

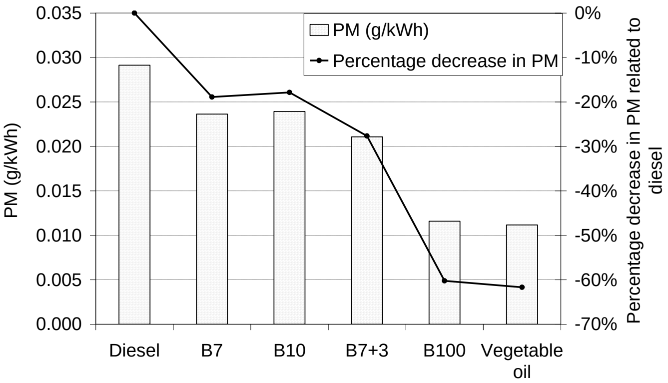

Figure 8. PM over the ESC cycle

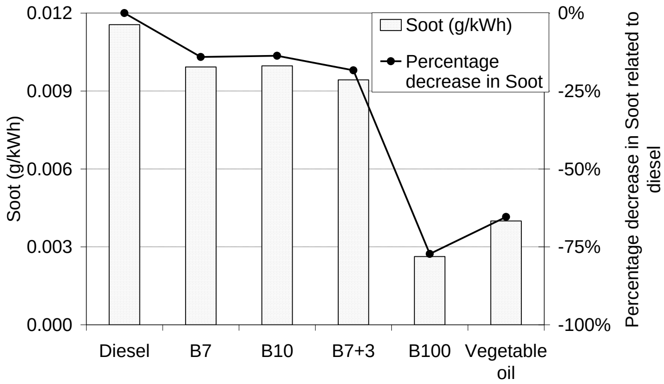

Figure 9. Soot over the ESC cycle

Particle Number and Size Distribution

Compared to the diesel, the PN with the B7, B10, B7+3 and B100 reduces by 32.2%, 29.7%, 25.2% and 38.4% over the ESC cycle (Figure 10). On the contrary, vegetable oil fueling produces a much higher PN that increases by up to 391% over the cycle with respect to diesel fueling. These changes are also pointed out by the size distributions at the modes (mode 3 for example, Figure 11). The particle number with vegetable oil is scaled on secondary axis due to its very high value.

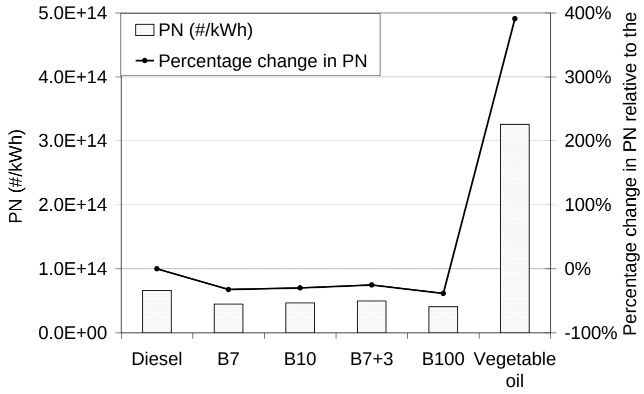

Figure 10. Particle number over the ESC cycle

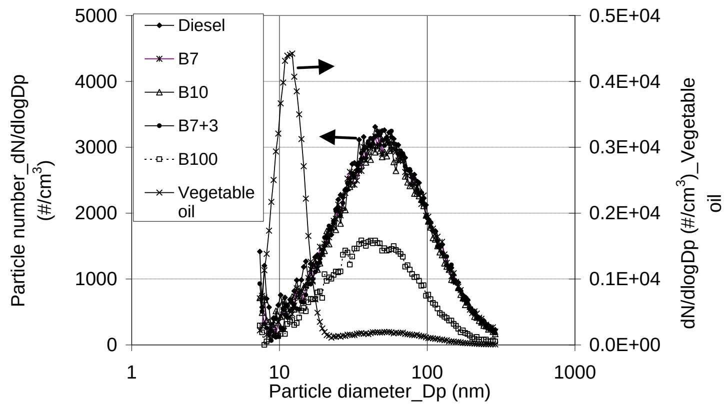

Figure 11. Particle size distribution at mode 3 of the ESC cycle

The size distributions are similar for the diesel, B7, B10 and B7+3 but lower for the B100 over the diameter range. Especially with the vegetable oil, bimodal distribution is observed with a domination of <23nm particles (nuclei particles) and numbers in this range are much higher as compared to the diesel and other fuels, whereas the numbers in size range from 30 to 500 nm (accumulated particles) are lower relative to the diesel but a little higher than the B100 which is consistent with the particle mass and soot results mentioned above. The much higher particle number in nucleation mode with vegetable oil fueling may be caused by the significant difference in fuel properties from the diesel (e.g. length and structure of hydrocarbon chains, viscosity, density, etc.).

Conclusions

Effects of the neat biodiesel, biodiesel blends and vegetable oil on the Euro V truck emission characteristics are analyzed and ascertained. It shows the potential of using biodiesel blends up to 10% biodiesel in volume with the benefits but a little increase in NO_x emissions. Using the mixture B7+3 might solve this disadvantage. There are penalties in engine power, fuel consumption and NO_x emissions when fueling the engine with the B100 and vegetable oil. However, the significant reduction in other regulated emissions can be obtained. For the vegetable oil, much higher particle number in nucleation mode is produced which needs to be considered.

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