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Particle size distributions from a city bus fuelled with ethanol–biodiesel–diesel fuel blends

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HIGHLIGHTS

- Under transient vehicle driving oxygenated fuel blends affect particle distributions.
- Accelerations and decelerations with fuel consumption produced bimodal distributions.
- Under idle and decelerations, nuclei and accumulation modes were comparable.
- Under accelerations, nuclei mode was negligible compared to accumulation mode.
- Particle concentration decreased when oxygenated fuel blends were used.

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ABSTRACT

The use of oxygenated fuels has potential to reduce the greenhouse gases and the regulated pollutant emissions from diesel engines. Apart from particulate matter and NO_x emissions, the study of particle concentration and its size distribution emitted by diesel engines is gaining attention due to the harmful effects on the environment and human health. In this work, particle size distributions (PSDs) from the exhaust gas of a city bus working in real driving conditions have been measured using three different fuel blends: petroleum diesel used as reference fuel, a binary fuel blend of 7.7% v/v ethanol on diesel fuel (denoted as ED) and a ternary fuel blend (denoted as EBD) of ethanol, biodiesel and diesel fuels with 10% v/v of ethanol on a binary B30 fuel blend (30% v/v of soybean biodiesel on pure diesel fuel). For measuring the PSD, a city bus was equipped with a rotating disk diluter coupled to a dilution air thermal conditioner. The diluted gas was driven to a TSI Engine Exhaust Particle Sizer spectrometer. The main objective of this work was to evaluate the effect of the fuel on the main statistical parameters of PSD (geometric mean diameter and total concentration) during acceleration transitions in real vehicle driving operation. Compared to diesel fuel, the results showed a great reduction of particle concentration when both fuel blends were used, although the relative differences depended on the transition studied.

1. Introduction

The concern about urban air quality increases as the number of vehicles grows. Many local governments have proposed limiting vehicular traffic in urban areas by promoting the use of city buses for public transport. However, further initiatives are necessary to reduce their emissions, mainly particulate matter (PM) and nitrogen oxides (NO_x) emissions. The use of renewable and oxygenated fuels is an interesting alternative for reducing these emissions and improving urban air quality [1]. Biodiesel and ethanol have a great potential for fuel blending in diesel engines due to the significant reduction in smoke opacity and PM emissions as a consequence of the presence of oxygen functional groups and the absence of aromatic and sulphur compounds in its composition clearly contribute to the reduction in PM [2].

Biodiesel shows similar properties to conventional diesel fuels, but ethanol presents more challenges when used in diesel engines. Ethanol has low cetane number, low lubricity and a limited miscibility with diesel fuel [3]. Thus additives must be used to ensure the stability of fuel blends. The need to modify the fuel tank and the supplying nozzles restricts its use to captive fleets [4,5]. Despite these disadvantages, its 35% oxygen content, which is three times the oxygen content of biodiesel, makes ethanol very attractive as a diesel fuel blending agent in order to reduce PM [6].

Since biodiesel molecules have a polar end with affinity for ethanol, which is also polar in nature, biodiesel can be used as a stabilizing agent for ethanol–diesel fuel blends. In addition, its high cetane number and good lubricating properties offset reductions in those properties due to ethanol. The number of studies on emissions in compression ignition engines fuelled with these ternary

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blends is recently increasing. As it occurred with binary blends, the authors report a general decrease in PM emissions when ethanol–biodiesel–diesel fuel blends are used as fuel [7–11].

The fuel effect on emissions is often studied using either an engine test bench (under steady-state and/or transient conditions) or vehicle tests on chassis dynamometers following a defined driving cycle. In both cases the vehicle motion is simulated and therefore the emissions measured constitute an approximation of the emissions from actual vehicle operation in real driving conditions [12]. The correlation between pollutant emissions derived from chassis dynamometer tests and those derived from real driving conditions depends on the ability of the cycle used on chassis dynamometers to reproduce the real driving conditions in the vehicle [13,14].

Vehicles tested under current certification driving cycles are clearly operated far from real driving conditions. This fact has led researchers to test under real traffic conditions with Portable Emissions Measurement Systems (PEMSs) [15]. Analysis of the data collected during these tests constitutes a challenge due to the huge amount of data and its high dispersion. In many cases, representing the studied parameter with respect to time or distance travelled is not useful. Consequently, some authors divide the driving cycle into several sequences defined by the running vehicle conditions (acceleration, deceleration, idle, cruise, high speed) [16,17]. However, each transient sequence could be affected by its preceding one depending on the fuel used [18].

The main objective of this work was to analyze the effect of three different fuels on particle size distributions during real driving conditions of a city bus. The fuels studied were: commercial diesel fuel (without blended biodiesel) used as reference, a binary ethanol–diesel fuel blend (denoted as ED) with additives to ensure its stability and a ternary ethanol–biodiesel–diesel fuel blend (denoted as EBD). In order to study if a preceding event could affect emissions, two of the most common transitions which occur during real vehicle driving were studied: accelerations coming from idle (Idle + A) and accelerations coming from deceleration with fuel consumption (DwF + A). These sequences belong to the route followed by a city bus working under real traffic conditions in Seville, Spain.

2. Experimental facilities

2.1. Test vehicle

The vehicle tested was a EURO II Renault city bus, 12,700 kg weight. It is equipped with a 6-cylinder, 7790 cm^3, turbocharged, direct injection, heavy-duty IVECO diesel engine (186 kW rated power at 2050 min^{-1} and 1100 N m rated torque at 1000 min^{-1}) without exhaust gas recirculation (EGR). The injection system, hydraulic-mechanically controlled, includes an in-line injection pump. In this vehicle, the engine is coupled to an automatic VOITH transmission. The vehicle is equipped with neither diesel oxidation catalyst (DOC) nor diesel particle filter (DPF). This model of vehicle constitutes the 64% of a fleet composed by 202 diesel buses.

2.2. Test fuels

A low sulphur diesel fuel (without biodiesel) was used as reference fuel. The ethanol–diesel fuel blend (ED) contents 7.7% v/v ethanol blended with diesel fuel, using a stabilizing additive (0.62%) named O2D05 and provided by O_2 Diesel corporation [19]. The composition of this additive is: 75% of a stabilizer blend (37.5% of surfactants and 37.5% of co-solvent) and 25% of a cetane improver (2-ethylhexyl nitrate). Finally, a ternary ethanol–biodiesel–diesel fuel blend (EBD) was tested with 10% v/v of ethanol on a binary B30 blend (30% v/v of soybean biodiesel on pure diesel fuel). As biodiesel can be used as a stabilizing agent, no additive was added to EBD fuel blend. Both oxygenated fuels were supplied by Abengoa Bioenergy Corporation. The ethanol content of the tested blends was determined from the results of a previous study [3,20]. The main properties of the tested fuels are presented in Table 1.

Table 1
Fuel properties.

	Diesel fuel	ED	EBD
Density at 15 °C (kg/m^3)	835	831	843
Kinematic viscosity at 40 °C (cSt)	2.72	2.41	2.61
High heating value (MJ/kg)	45.54	43.82	43.15
Low heating value (MJ/kg)	42.61	40.86	40.31
% C (by weight)	86.13	83.63	81.07
% H (by weight)	13.87	13.82	13.26
% O (by weight)	0	2.55	5.67
% H_2O (ppm)	57	243	343
% S (ppm)	34	31	–
Stoichiometric fuel–air ratio	1/14.67	1/14.25	1/13.63
Molecular weight MW (g/mol)	211.7	167.5	179.53

2.3. Test facilities

The bus was instrumented with a HORIBA OBS 1300 analyzer and a TSI Engine Exhaust Particle Sizer (EEPS™) spectrometer model 3090 as shown in Fig. 1a. The OBS analyzer includes sensors for relative fuel–air ratio and ambient conditions (temperature, pressure and humidity), and it was located next to a Data logger PC OBS-1000 for recording instantaneous vehicle parameters. Vehicle velocity was determined using a global positioning system (GPS). The sampling frequency used by the OBS was 1 Hz. The EEPS was used to measure the particle size distributions in transient conditions. The particle size measuring range is 5.6–560 nm with a resolution of 16 channels per decade. The sampling frequency of EEPS is 10 Hz. The EEPS was coupled to a Matter Engineering rotating disk diluter model MD19-2E, as primary dilutor, and to an air supply-thermal conditioner model ASET15-1 with an evaporating tube, as secondary dilutor. This two-stage dilution system is accepted by the Particle Measurement Programme (PMP), which evaluates different systems for determination of particle number concentration emitted by on-road vehicles [21,22], since European standards Euro 5 and Euro 6 introduce the measurement of non-volatile particles with diameter >23 nm [23]. Partial dilution factors and evaporating tube temperature were defined from previous research [24]. Total dilution factor ($DF_{Tot} = 217.5$) was determined taking into account diffusion and thermophoretic losses ($Ld + t$). The scheme of the experimental setup used for determination of particle size distributions and vehicle parameters is shown in Fig. 1b.

The synchronisation of the signal profiles recorded by each of the experimental facilities (due to their different timing) was achieved using a procedure presented by Arregle et al. [25]. The total particle concentration was synchronized with respect to the relative fuel air ratio signal, measured by the OBS, during accelerations starting from idle. This procedure was also used to check the synchronisation of the signals at some other times during the cycle.

3. Experimental procedure

The route followed by the city bus was around 13 km long (Line 34 of Seville public transport buses) which is approximately one hour in time. It includes some stretches of medium speed (~50 km/h). The altitude profile is almost constant during the entire route (~10 m over the sea level). The route has 38 stops for passengers, uniformly distributed along the itinerary and it also