

Effect of the Addition of Biomass Gasification Gas on the PM Emission of a Diesel Engine

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ABSTRACT

In order to reduce the pollutant emissions (NO_x and PM) of diesel engines, the addition of small gaseous fuel amounts or dual mode operation have been proved as potential techniques. This paper is focused on a detailed characterization of the particles emitted from a single cylinder diesel engine when part of the diesel fuel (5 to 20% by energy) is replaced by a gaseous fuel (producer gas, mainly composed by H₂, CO, CH₄ and inert compounds) coming from biomass steam gasification. The engine was run at constant speed and torque and different EGR rates. Particle samples were collected by means of fiber glass filters placed in a dilution mini-tunnel. Simultaneously, during tests, part of the exhaust gas was conducted to an SMPS to determine the particle size distribution. The filters were analyzed by using two different techniques: Thermogravimetric analysis (TGA) to obtain the volatile organic fraction (VOF) and the soot concentration, and Soxhlet extraction/High Performances Liquid Chromatography (HPLC) to speciate PAHs (Polycyclic Aromatic Hydrocarbons).

Results show a significant decrease in the PM mass and concentration when increasing the gaseous fuel addition. Such reduction is caused by the replacement of a carbon-rich fuel with a high potential to produce particles (diesel fuel) and by chemical effects (higher OH concentration due to the H₂ presence, which promotes soot oxidation). Moreover, the addition of producer gas allows higher EGR rates (to reduce NO_x) while keeping low PM emissions. The PM volatile fraction was increased for higher diesel fuel replacements. The PAHs content was very low (the lighter ones being the most significant) and it decreases when replacing diesel fuel by producer gas.

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INTRODUCTION

Due to the high thermal efficiency when compared with spark ignition engines, the demand of compression ignition engines (diesel engines) has considerably increased in the last years, mainly in the transportation sector [1]. However, diesel engines emit harmful pollutants including nitrogen oxides (NO_x) and particulate matter (PM), the latter mainly composed by carbonaceous agglomerates known as soot and adsorbed/condensed hydrocarbons on its surface. In the case of PM (with a significant carcinogenic potential), not only the specific emission (g/kWh) but also the particle size distribution and its composition are important. In fact, the smaller particles have a higher probability to be inhaled and deposited in the respiratory tract, causing respiratory diseases as well as inflammation and damage to the lungs [2]. Although acceptable NO_x-PM trade off in diesel engines is typically achieved by using both internal (Exhaust Gas Recirculation (EGR), injection strategy) and external (Diesel Particulate Filter (DPF), Lean NO_x traps) methods, the addition of some compounds such as hydrogen and reforming gas [3] has been proved to reduce PM without significantly affecting NO_x emissions. Moreover, dual-mode

diesel engines (which typically use a small liquid fuel injection at the end of the compression stroke to ignite the gaseous fuel) have been also checked in the last years as an attractive alternative for reducing emissions, natural gas being the fuel typically used [4, 5, 6]. In the last case, some renewable gaseous fuels such as biogas [7, 8, 9], syngas (composed by H₂ and CO) [10-11] or producer gas (H₂, CO, CH₄ and other inert compounds) [12, 13, 14], have also been tested (with additional advantages such as the reduction of CO₂ emissions, the use of autochthonous fuels and the removal of wastes). For both applications (addition of a small quantity of gaseous fuel or dual-mode), hydrogen, carbon monoxide and methane use to be the main components of the gaseous fuel.

Methane exhibits the highest resistance to the knock phenomenon due to its auto-ignition temperature, making it appropriate for engines with high compression ratios [15]. In addition, the carbon content of methane is also relatively low compared to that of conventional diesel fuel, resulting in a significant decrease in pollutant emissions [16]. The main problem derived from its use (pure, biogas or natural gas) is the

comes from the high methane content in the exhaust gas (with a very significant greenhouse effect) due to the incomplete combustion of the initial methane [6, 7, 8]. Thus, particular requirements are imposed on the catalyst for methane combustion. They must resist thermal and mechanical shocks and exhibit high activity, which is not trivial due to the high stability of methane [17]. Hydrogen has a low lean-flammability limit which allows stable combustion at highly dilute conditions and therefore working at very low relative fuel/air ratios [18]. Moreover, the wider flammability region could allow ultra-lean operation and very low NO_x emissions. Carbon monoxide also presents a high resistance to the knock phenomenon due to its high methane number and auto-ignition temperature. It also allows operating at very low relative fuel/air ratios. CO emissions derived from its incomplete combustion are the main disadvantage, although these emissions can be removed through the widely used Diesel Oxidation Catalyst (DOC).

Although the separate effect of H₂ and CH₄ addition on diesel engines performances and emissions has been previously studied, the most of them do not analyze the PM composition and size distribution. Moreover, the combined use of H₂, CO and CH₄ needs further investigation. Regarding the latter aspect, some works using diesel/biodiesel reforming gas (mainly composed by H₂ and CO), H₂ or LPG prove a very significant soot decrease when substituting the diesel fuel [2,19-20], the potential of H₂ being more relevant than that of methane. However, the gaseous fuel used was very different to that of the gasification gas, the effect of EGR and the PAHs speciation not being usually studied. Thus, this work is focused on a complete characterization of PM emissions (mass, size distribution and composition) when part of the diesel fuel is replaced by a renewable gas coming from biomass gasification (producer gas). This application is especially interesting in the case of developing countries (by a partial diesel fuel substitution), in which the growing demand of fossil fuels has become an important challenge, and mainly for small capacity power generation systems.

METHODOLOGY

Engine Test Bench

The testing bench (Figure 1) consists of an AVL 501 single-cylinder diesel engine, connected to a Piller 225.26B dynamometric brake. The geometrical and functional characteristics of the engine (Table 1) answer those of heavy-duty vehicles. The bench is characterized by the possibility of controlling individually the complementary systems, such as the intake, EGR and the common-rail injection systems. The gaseous fuel was introduced in the engine at the inlet pipe, just before the EGR connection, at a slightly higher pressure than the inlet pressure in order to ensure the correct gas flow.

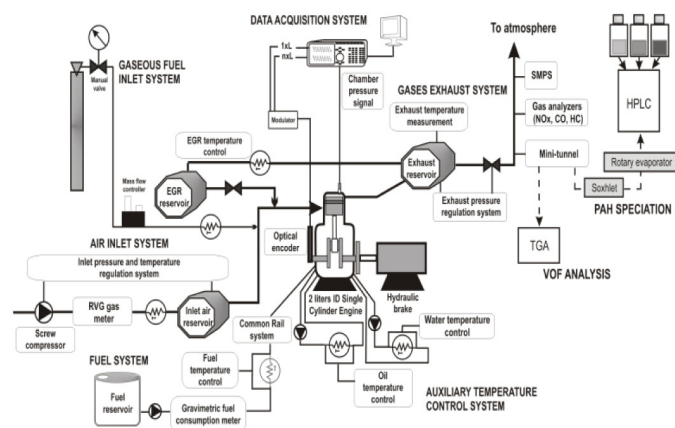


Figure 1. Scheme of the testing bench.

During tests, the engine was run at 1500 rpm and 90 Nm (BMEP = 5.72 bar), keeping constant the intake air temperature (35 °C), injection pressure (1200 bar) and EGR temperature (80 °C). These operating conditions can be typical of stationary diesel engines coupled to the electricity network (constant speed and almost full load operation). The start of injection angle was 12 deg before TDC. Parametric studies were carried out changing the EGR volumetric rate (0, 7.5 and 15%) and the diesel fuel replacement (0, 5, 10, 15 and 20% by energy).

Table 1. Engine technical characteristics.

Geometrical data	Cylinder diameter	130 mm
	Connecting rod length	275 mm
	Cylinder volume	1999 cm ³
	Swept volume	135.23 cm ³
	Compression ratio	15.78:1
	Piston free height	1.75 mm
	Bowl diameter (D)	74 mm
	Aspect ratio (D/h)	2.96
Distribution data	No. of intake valves	2
	No. of exhaust valves	2
	Intake valve diameter	43 mm
	Exhaust valve diameter	39 mm
	Inlet valve opening	15° BTDC
	Inlet valve closing	50° ABDC
	Exhaust valve opening	72° BBDC
	Exhaust valve closing	16° ATDC

Tested Fuels

A Spanish commercial diesel fuel, distributed by CEPESA, was used as reference fuel. Following the current European regulation, this diesel fuel contains a 5.8 %v/v of FAME. The main properties (measured in our laboratory following standard methods, estimated from the fuel composition or provided by CEPESA), are listed in Table 2. A gaseous fuel simulating the composition of producer gas coming from steam gasification of dealcoholised marc of grape has been used [21], this solid fuel