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Assessment of on-road emissions of four Euro V diesel and CNG waste collection trucks for supporting air-quality improvement initiatives in the city of Milan

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ABSTRACT

This paper summarizes the results of an extensive experimental study aiming to evaluate the performance and pollutant emissions of diesel and CNG waste collection trucks under realistic and controlled operating conditions in order to support a fleet renewal initiative in the city of Milan. Four vehicles (1 diesel and 3 CNG) were tested in two phases using a portable emission measurement system. The first phase included real world operation in the city of Milan while the second involved controlled conditions in a closed track. Emissions recorded from the diesel truck were on average 2.4 kg/km for CO_2, 0.21 g/km for HC, 7.4 g/km for CO, 32.3 g/km for NO_x and 46.4 mg/km for PM. For the CNG the values were 3.6 kg/km for CO_2, 2.19 g/km for HC, 15.8 g/km for CO, 4.38 g/km for NO_x and 11.4 mg/km for PM. CNG vehicles presented an important advantage with regards to NO_x and PM emissions but lack the efficiency of their diesel counterparts when it comes to CO, HC and particularly greenhouse gas emissions. This tradeoff needs to be carefully analyzed prior to deciding if a fleet should be shifted towards either technology. In addition it was shown that existing emission factors, used in Europe for environmental assessment studies, reflect well the operation for CNG but were not so accurate when it came to the diesel engine truck particularly for CO_2 and NO_x. With regard to NO_x, it was also shown that the limits imposed by current emission standards are not necessarily reflected in real world operation, under which the diesel vehicle presented almost 4 times higher emissions. Regarding CO_2, appropriate use of PEMS data and vehicle information allows for accurate emission monitoring through computer simulation.

1. Introduction

Heavy duty vehicles (HDV) constitute a very important vehicle category of the road transport sector, operated in a wide series of activities, from passenger and freight transport to very unique applications. Thus there is high variability with regard to HDV characteristics, types and possible uses. Only the rigid goods vehicles licensed in Great Britain can be classified into 25 different categories (Hill et al., 2011). Their increasing numbers and usage result in significant contribution to gaseous pollutant, particulate matter and greenhouse gas (GhG) emissions, particularly in urban environments, despite the fact that important progress has been made in lowering emissions and fuel consumption from heavy duty internal combustion engines. Indicatively, the number of HDVs registered in the Lombardy region in Italy increased by 3.7% during the 1998–2004 period adding about 4000 vehicles to the existing fleet (Caserini et al., 2008).

New stringent emission standards for heavy duty engines (Euro VI) are being introduced in Europe and the European Commission (EC) is fully engaged in defining the related implementing measures. Off-cycle emissions and real-world/in-use emissions represent two major issues among those being currently addressed in the regulation development process. In addition particular emphasis is being given to GhG emissions globally. US EPA recently issued the draft regulation regarding GhG standards and fuel efficiency standards for medium and heavy duty engines and vehicles (US-EPA, 2011), while in Europe EC is currently working on a HDV CO_2 emission monitoring scheme to be implemented in the near future. In both cases a series of tools will be employed such as vehicle simulation and measurements of real world emissions.

In a previous study (Pastorello et al., 2011) authors attempted to estimate the contribution of HDV in the road transport generated pollutant and GhG emissions of the Milan area. Particular emphasis was given in the future evolution of the garbage collection and street cleaning vehicle fleet, composed of about 1200 vehicles operating almost throughout the day. Waste collection trucks are at one extreme of the operating condition range for heavy duty engines. The very low average speeds and the frequent stops represent difficult conditions to cope with from the emission reduction perspective. In addition one of the main conclusions of the study was the lack of solid experimental data on such unusual vehicle types and operating

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conditions that would allow more accurate emission calculations and environmental impact assessment. This kind of information is necessary for providing guidance in future planning and decision making of large organizations such as the municipality of Milan.

In an effort to provide insight on the optimal future planning and renewal of the Milan waste collection vehicle fleet, the Joint Research Centre of the European Commission, in collaboration with the Azienda Milanese Servizi Ambientali (AMSA), initiated an on-road emission testing campaign. The aim of this extensive experimental study, performed both under real and controlled operating conditions was to identify the actual emission levels of various waste collection vehicles, compare two different engine technologies (diesel and natural gas fuelled engines) and assess the environmental efficiency of various candidate trucks. In addition following the mandatory procurement requirements for energy efficiency criteria set by European legislation the study aimed also to identify and assess the energy efficiency of the candidate vehicle models.

Similar studies comparing mainly city buses have been performed in the past (Turrio-Baldassarri et al., 2004; Lopez et al., 2009; Ryan and Caulfield, 2010; Genovese et al., 2011), but limited literature is available, such as (Walkowicz et al., 2005; Lopez et al., 2010) regarding waste collection vehicles.

This paper summarizes the results of the aforementioned experimental activity. For this study a total of 4 different Euro V waste collection trucks were investigated regarding their emissions, one representing the conventional trucks used up to that time by AMSA for the purpose and 3 new compressed natural gas (CNG) fuelled ones. Tests were performed during normal work shifts in the city of Milan, Italy and on a race track following a specific driving pattern. The vehicles had been equipped with portable emission measurement systems (PEMS) and the emission was monitored and recorded second-by-second. The PEMS data retrieved from the diesel vehicle were used for the development of a vehicle model in order to simulate alternative operating conditions and garbage collection routes in the future and test the potential application of HDV simulation with respect to CO_2 emission monitoring. The methodology and the results are presented below.

2. Experimental

The experimental work was divided into two phases. During phase 1, two waste collection trucks, one equipped with a Euro V diesel engine and the second equipped with a Euro V CNG engine, were equipped with PEMS and their exhaust emissions were measured during normal work conditions in the city of Milan. During phase 2, two waste collection trucks, both equipped with a Euro V CNG engine but produced by different manufacturers, were equipped with PEMS and tested on a track according to a driving/operating cycle simulating the typical conditions observed during the first phase.

2.1. Test vehicles

During the study 4 waste compactor trucks were investigated. Although the trucks were produced by different manufacturers they had similar superstructure and mass. The main vehicle characteristics are summarized in Table 1.

In order to compact waste, each vehicle was equipped with a sweep-and-slide system that digs in the waste and compresses it against a moving wall. The wall will move towards the front of the vehicle as the operator moves it with a manual control. The blade of the compactor is operated by the same engine used to move the vehicle.

2.2. Fuels

The fuels used for the tests were a diesel–biodiesel blend with 25% v/v biodiesel content (B25) and compressed natural gas (CNG).

Table 1
Test vehicle characteristics.

	Vehicle 1	Vehicle 2	Vehicle 3	Vehicle 4
Used for phase	1	1	2	2
Emission standard	Euro V			
Combustion type	Compression ignition	Otto		
Fuel	75% diesel fuel 10 ppm + 25% rapeseed methylester (RME)	CNG		
Aftertreatment	DOC	Three way catalyst		
Displacement (cc)	9500	7790	7790	6900
Cylinders (no.)	6 in-line			
Mass (kg)	16,000	15,900	15,900	16,000

Although B25 is not standardized yet on a European level, it is a strategic decision of the AMSA organization to fuel all conventional vehicles with this fuel to support biofuel application and raise environmental awareness. Therefore during this study this B25 fuel was considered as the reference fuel for all analyses.

All fuels were provided by the internal AMSA's fuel service. All the fuels are purchased by AMSA by means of open tenders and must comply with the fuel specifications currently in force. Therefore, the fuels used for this experimental activity can be considered as representative of standard commercial quality. The diesel and biodiesel blending components complied with EN590 and EN14214 standards for diesel and biodiesel fuel characteristics respectively.

2.3. Emission measurement equipment

Exhaust emissions were measured by means of a portable emission measurement system (PEMS). The system consists of a set of analyzers and an exhaust flow meter used to measure the exhaust mass flow. In respect to this, the system used in this project employs a mass flow meter (EFMs) equipped with differential pressure devices and thermocouples which measure the exhaust temperature. The relationship between the differential pressure, the temperature and the exhaust mass flow is based on the Bernoulli principle. Such technique, also known as "averaging Pitot", was proven to be reliable over time and accurate enough during the large number of testing hours. For these HD vehicle application a 51 mm flow tube diameter was used; the EFM accuracy over a typical test cycle is better than ±3.0%, with a resolution of 0.003 m^3/min and an exhaust temperature range that goes from ambient to 550 °C. The flow meter was installed at the outlet of the tailpipe using modified cycle racks to secure the device to the vehicle body. Table 2 summarizes the main characteristics of the PEMS used in terms of measurement technique, ranges and accuracy for the different analyzers.

The PEMS was complemented by other instruments used to monitor the ambient conditions and the position/speed of the vehicle. In the first case a weather station was used to measure relative humidity and air temperature while the speed of the vehicle was measured and recorded by means of a GPS system. The PEMS was connected to a power supply consisting of battery pack ensuring about

Table 2
Main characteristics of the PEMS system.

	Method	Range	Accuracy
CO_2	NDIR	0–20%	±0.1% or ±3% of reading
CO	NDIR	0–8%	50 ppm/±3% of reading
THC	HFID	0–100 ppm	5 ppm/±2% of reading
		0–1000 ppm	5 ppm/±2% of reading
		0–10,000 ppm	25 ppm/±2% of reading
NO	NDUV	0–2500 ppm	15 ppm/±3% of reading
NO_2	NDUV	0–500 ppm	10 ppm/±3% of reading