Applied Energy 117 (2014) 134–141

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

An assessment of regulated emissions and CO_2 emissions from a European light-duty CNG-fueled vehicle in the context of Euro 6 emissions regulations

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HIGHLIGHTS

- Compressed natural gas is a promising fuel type for light-duty vehicles.
- Euro 5 and 6 emissions standards will reduce emissions to very low levels.
- A bi-fuel Euro 5 vehicle (CNG/gasoline) was tested on a chassis dynamometer.
- When operating on CNG the vehicle easily met Euro 6 limits.
- Carbon dioxide emissions were 24–25% lower when running on CNG.

ARTICLE INFO

Article history:
Received 26 February 2013
Received in revised form 28 October 2013
Accepted 4 December 2013
Available online 27 December 2013

Keywords:
Passenger car
Alternative fuel
Compressed natural gas
Exhaust emission
Euro 6

ABSTRACT

Natural gas is one of the most promising alternative fuels to meet the upcoming stringent Euro 6 emissions regulations in the European Union, as well as the planned reductions in CO_2 emissions. For spark-ignition engines, bi-fuel fuelling equipment is widely available and engine conversion technology for European automobiles is well established, thereby facilitating usage of natural gas in its compressed form (CNG). In light of the promising characteristics and increasing usage of natural gas as a vehicular fuel, this study investigates emissions from a passenger car featuring a spark-ignition engine capable of running on both CNG and standard gasoline. Results from emissions testing of the vehicle on a chassis dynamometer are presented and discussed in the context of the Euro 6 emissions requirements. The test vehicle featured a multipoint gas injection system and was an unmodified, commercially available European vehicle meeting the Euro 5 standard. The results indicated that when fueled with CNG, such a vehicle can comfortably meet Euro 6 emissions limits, with certain differences observed in the emissions according to the fuel type used. Furthermore, when running on CNG the vehicle was observed to emit considerably less carbon dioxide than when fueled with gasoline, with the reduction closely agreeing with the results of other studies.

1. Introduction

Worldwide population growth and industrialization have resulted in increases in demand for energy in the transportation sector, among other sectors. As a result, air pollution and anthropogenic greenhouse gas emissions have become key global problems. Various options are available to militate against these effects, one of which is making use of fuel types with more favorable emissions characteristics. The use of alternative fuels, mainly biodiesel, gasoline–alcohol blends, natural gas and liquefied gasolinium gas in vehicular applications has grown in recent years in European Union countries, the United States, Japan, India, Brazil and many other markets. Legislation is also in place to encourage or effectively force further adoption of these fuel types (e.g. [1]).

European Union requirements regarding vehicle emissions for passenger cars and light commercial vehicles were introduced in 2009 for type approval and in 2011 for all new types, specified as Euro 5, with further requirements (Euro 6) planned from 2014

Abbreviations: CH_4, methane; CARB, California Air Resources Board; CNG, compressed natural gas; CO, carbon monoxide; CO_2, carbon dioxide; CVS, constant volume sampling; EC, European commission; ECE, Economic Commission for Europe; ECU, electronic control unit; EU, European Union; EUDC, extra urban driving cycle; GHG, greenhouse gases; HC, hydrocarbons; mpg, miles per gallon; MPI, multipoint [fuel] injection; N_2O, nitrous oxide; NEDC, New European Driving Cycle; NMHC, non-methane hydrocarbons, HC–CH_4; NO_x, oxides of nitrogen; RON, research octane number; SI, spark ignition; TWC, three-way catalyst; UDC, urban driving cycle.

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0306-2619/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.apenergy.2013.12.003

onwards. These regulations set limits for emissions of HC, CO, and NO_x; CO_2 emissions are covered by separate legislation.

While harmful emissions are generally of relatively little direct consequence to a vehicle's owner/operator, CO_2 emissions are inherently linked to fuel consumption, which is of great importance to the owner. Two recent reports have further underlined the discrepancy between declared (i.e. type approval) CO_2 emissions and the real values actually observed during vehicle usage [2,3]. In light of ongoing discussion on these discrepancies, fuel types with well-established benefits regarding CO_2 emissions and regulated emissions are understandably of great interest to legislators. Such factors are less important to the average vehicle owner, but CNG has the added advantage of potentially lowering refueling costs for light-duty vehicles (compared to gasoline), based on data on pricing submitted by consumers and retailers [4,5]. Pricing data from the USA also indicates the potential for substantial reductions in refueling costs in that country, when running on CNG [6]. It is in this context that usage of natural gas as an automotive fuel seems bound to increase over the next few years – indeed, demand for natural gas for use in European road vehicles is projected to double between 2015 and 2020 [7]. A recent techno–economic analysis of a broad range of fuel types revealed CNG to outperform gasoline in terms of fuel economy, with a vehicle purchase cost that was close to that of a gasoline vehicle [8].

As things stand, it appears likely that fossil fuels will remain the chief source of energy in the transportation sector for the foreseeable future, but the aforementioned factors indicate pressure to move towards increased usage of alternative fuels. Since energy density is an important factor for automotive fuels, gases are inherently at a disadvantage compared to liquid fuels (e.g. gasoline, bioethanol, and diesel), but this unfavorable characteristic can be partially offset by compression of natural gas, creating compressed natural gas (CNG). In light of these factors, CNG is currently the best alternative to conventional transport fuels. Various basic physical and technical parameters of CNG make it a very good fuel for turbocharged SI engines (discussed in Section 2). While the energy content of the fuel is somewhat lower, as an automotive fuel CNG generally has favorable drivability characteristics and has proven relatively popular with consumers in multiple markets. By the end of 2011 the global NGV fleet numbered more than 15 million vehicles, with around 2.5 million vehicles coming into use in 2011 alone [9].

Separate (but qualitatively similar) legislative moves taking place in the EU and the USA can also be considered to be drivers of increased interest in (and usage of) CNG as an automotive fuel. In the EU, the commission's proposal to enforce a fleet average CO_2 emissions limit of 95 g/km over the NEDC by 2020, together with ongoing discussions over aiming for a fleet average figure of 70 g/km by 2025. In the US, the target requiring carmakers to increase fuel economy in new vehicles sold between 2011 and 2025 to finally reach 54.5 mpg as CAFÉ (corporate average fuel economy) by 2025. The proposed CAFÉ rule grants incentives to plug-in electric and hybrid vehicles, with the final rule adding CNG-powered vehicles to the list.

Natural gas is mainly obtained from gas wells or is driven off as a by-product during production of crude oil. The gas typically contains 80–99% methane, together with some higher hydrocarbons and impurities [10]. A product broadly equivalent to natural gas can also be produced biogenically (termed 'biomethane'). Natural gas for automotive spark ignited engines continues to receive considerable attention in the literature (e.g. [11–13]).

When compared to usage of gasoline as a vehicular fuel, CNG exhibits significant potential for the reduction of both gaseous emissions [10,14–19], and solid emissions [8,10,17,18,20,21]. Carbon dioxide emissions from a vehicle fueled with methane are typically some 25% lower than the CO_2 emissions from a similar vehicle fuelled with gasoline [7], helped by the fact that the carbon

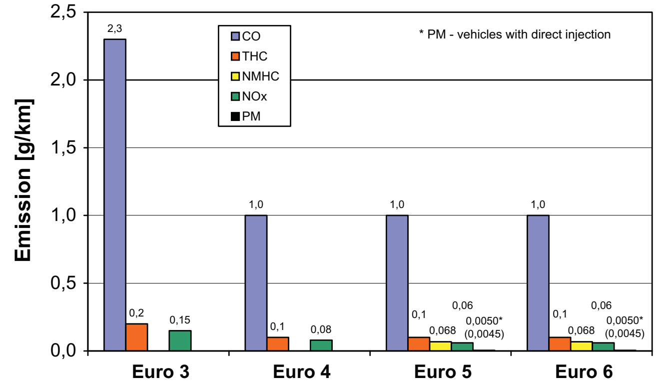

Fig. 1. Progress in European emission regulations for passenger cars fitted with spark ignition engines.

to hydrogen ratio of methane is low – approximately 52% lower than that of gasoline. Usage of biomethane can dramatically reduce fuel life-cycle greenhouse gas emissions, compared to gasoline, particularly when employed in tandem with other technologies such as hybridization [22]. EU legislation admits the possibility of life-cycle greenhouse gas reductions as high as 86% [1]. California Air Resources Board (CARB) legislation makes reference to a list of the standard CO_2-equivalent emissions from the quantity of fuel which contains one megajoule of energy, with all types of CNG listed faring substantially better than gasoline [23]. It is also worth highlighting that EU legislation already in force [1] negates the CO_2 emissions produced from combustion of biofuels (including biogas) in its fuel life-cycle assessments. Given the potential for synergistic effects between efforts to reduce emissions of harmful pollutants and CO_2 [8], research on emissions resulting from usage of CO_2 is a priority.

The aim of this study was to assess and compare the emissions performance of a Euro 5 vehicle operating on gasoline and CNG, for comparison to the planned Euro 6 limits, shown in Fig. 1. CO_2 emissions were also measured and analyzed. Furthermore, instantaneous concentrations of regulated compounds and CO_2 were measured undiluted at the vehicle's tailpipe, in order to gain further insight into emissions phenomena affected by the fuel type in use (i.e. CNG or gasoline).

2. CNG technology for light-duty vehicles

Natural gas is already widely used in bi-fuel light-duty vehicles (LDV) and light-commercial-vehicles (LCV) as an alternative to gasoline. The physicochemical properties of CNG are important in all discussions in this area and Table 1 presents typical characteristic properties. At this stage of development, vehicle and engine config-

Table 1
Typical values of key properties of natural gas from an automotive viewpoint (Bielaczyc [14]).

Property (units /conditions)	Value
Carbon to hydrogen ratio	0.25–0.33
Relative density (kg/dm^3 at 15 °C/1 bar)	0.72–0.81
Boiling point (°C/1 bar)	−162
Flashpoint (°C)	540–650
Octane number (RON/MON)	120–130
Methane number	80–99
Stoichiometric air/fuel ratio by mass	17.2
Lower heating value (MJ/kg)	38–50
Methane concentration (volumetric %)	80–99
Ethane concentration (volumetric %)	2.7–4.6
Nitrogen concentration (volumetric %)	0.1–15
Carbon dioxide concentration (volumetric %)	1–5
Sulfur concentration (ppm, mass)	<5
Wobbe index (MJ/m^3)	41–58