MODERN LPG/CNG FUEL SYSTEMS, WTW AND GHG ANALYSES FOR GASEOUS FUELS

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Abstract

Gaseous fuel engines utilizing LPG or CNG constitute a significant part of ecological vehicle engine options. Achievement of the desired ecological effect can be accomplished by various engine configurations and different air-fuel mixture control systems. The paper summarizes the basic types of CNG/LPG fueling systems (mixing devices, injection of gaseous or liquid LPG) and their applications. Individual types of air-fuel mixture control (stoichiometric or $\lambda >> 1$ mixtures) are described, and performance and emissions compared to operation on conventional fuels. Well-to-wheel (WTW) and greenhouse gas emissions (GHG) analyses for LPG and future energy use estimates are presented. The presented results of the LPG engine measuring show spark ignition engine with injection of liquid LPG like high-quality variation of the car drive with favorable operating consumption and with ecological effects for environment.

Key words

gas fuel, mixture forming, power reducing, injection of liquid LPG, WTW analyse

INTRODUCTION

Liquified petroleum gas (LPG) and compressed natural gas (CNG) have higher octane number than gasoline. It allows engines running on LPG/CNG to have higher compression ratios, and thus higher energy efficiencies, than gasoline engines. But gaseous Light-Duty Vehicles (LDVs), which are mostly retrofitted gasoline cars, do not exploit this advantage and do not have optimal engine efficiency. LPG/CNG heavy-duty engines have lower compression ratios than heavy-duty diesel engines.

Gaseous at barometric temperature and pressure, LPG is stored as a liquid under pressure. It is needed over 1.5 times the weight of the tank and almost twice the space for equivalent amount of energy in gasoline. The LPG tank can be filled only to 80% of its capacity, to leave sufficient space for expansion of the fuel. CNG is stored as a gas under pressure. This fuel has worse conditions for storing and then for roadway range.

Atmospheric (non-turbocharged) engines with an external mixture formation (outside of the cylinder) exhibit a reduction in the mean indicated pressure p_i and thus a reduction in the effective pressure p_e, compared to the original gasoline engine. This is a result of different properties of the fuels, and the fact that gaseous fuel takes up more volume than liquid fuel, effectively reducing the mass of the intake air charge in the cylinder.

In the case of LPG, a more suitable solution is multi-point injection of liquid LPG into the intake channels in the cylinder head or into the intake manifold near the head. Using this option, the temperature of the charge at the end of the intake is lower, due to the evaporation of LPG. This lower temperature then allows for a higher mass of the charge. The calculation accounts for the change in fuel, but not for the effects of the accessories. The volumetric efficiency of a gasoline engine will be, in real world, higher than that of a LPG engine. The power loss associated with operation on LPG/CNG is, in reality, even higher.

Depending on the customer requirements or the engine application, the engine can be configured for operation solely on LPG/CNG (buses, forklifts), or, more frequently, as a dual-fuel versions (automobiles), with user-selectable switching between gas and gasoline operation. In the forklift applications, only operation on LPG or CNG is intended, and the engine is designed as a single-fuel.

BASIC GASEOUS FUEL SYSTEMS AND EQUIPMENT

I. External air-fuel mixture formation in a mixing device. This is the simplest solution in the domain of passenger automobiles, currently also often used in motorized carts and non-vehicular applications. The air-fuel mixture is drawn by the intake vacuum. The mixing device is in the intake system before the throttle plate. A disadvantage of this solution is a pressure drop at the point of mixture entrance into the engine, caused by the mixer construction (reduction of the diameter). The mixing devices are of many different designs; the basic classification is according to the gas inlet:

   a) a single-body gas inlet tube in the center of the device
   b) a gas inlet along the perimeter of the mixing device, formed by two parts

   In the mixing device, the desired amount of gas is measured by a slider driven by a step motor controlled by a separate control unit, or by controlling the cross-section by a set screw. In the first case, an alteration of the engine ECU, or utilization of an external ECU, is required. In the second case, no special ECU is necessary, and the control is implemented by a single switch, which controls the appropriate electromagnetic valves.

II. External mixture formation using a throttle-body injection. It is utilized primarily in some types of bus gaseous engines. There is no pressure drop at the engine inlet with this type of system.

III. External mixture formation using multi-point gaseous injection into the intake manifold just prior to the intake ports in the engine head. Individual injectors are mounted separately into the manifold, or are grouped in a single element (rail) distinct from the intake manifold. The gas is then delivered from the injectors to the individual injectors via rubber hoses. The pressure regulator is set differently than in the first type. Injectors can be controlled either by a modified original gasoline engine control unit, or by an additional gaseous fuel control unit, without the need to change the original ECU.

IV. In the case of LPG, external mixture formation using multi-point injection of liquid LPG into the intake before the intake ports in the cylinder head. The main advantage of this type is the elimination of problems associated with impurities in the gas and its subsequent evaporation. The installation of the system is more complicated. Performance should be similar to the original gasoline engine. This type is used mainly in automobiles, and less in carts or forklifts. The most complex aspect is the appropriate choice of the injector design and placement, in order to prevent the formation of frost on the injector body during various operating conditions. The frost can result in a total freezing of the injector, erratic running of the engine, and introduction of ice fragments into the cylinder charge. The solution of this problem lies in the proper placement of the injector, for example, all the way into the cylinder head, so that the injector can be properly heated even during fast evaporation of the fuel. In case of interest of engine manufacturers, the cylinder head can be constructed with the installation of liquid LPG injectors in mind.

TECHNICAL SOLUTIONS OF THE LOW EMISSION GAS ENGINES USING GAS FUELS

By using the LPG/CNG as a fuel for spark ignition engines, an ecological effect (i.e. very low exhaust emissions) can be achieved only by providing the engine with the proper adjustment - in practice; it can be done in two ways [2]:

A) Stechiometric operation (with the co-efficient of the excess of air $\lambda = 1$) at all operating conditions and a three-way catalyst. Most often, this option is featured in conversions of gasoline engines. In order for the optimal parameters to be achieved, the operation of the engine needs to be verified on a test stand, or the conversion needs to be performed by a specialized shop. Conversion of a compression ignition engine is more complicated and requires experience and modification of the engine head (i.e., incorporation of spark plugs), and can be accomplished only at specialized facilities.

B) Very lean mixture operation, with the excess air coefficient of λ = 1,45 - 1,55 at full load. This option is most likely to be used in diesel engine conversions. It requires appropriate design of the fuel system, including a fuel pump, intake air charge cooling, ignition system and its settings, air-fuel mixture control, and, in some cases, installation of an oxidation catalyst and modifications of the combustion chamber. The limiting element here are the anti-knock properties of LPG/CNG, which necessitate, in case of diesel engines, a reduction of the compression ratio.

GASEOUS EMISSIONS RESULTING FROM LPG/CNG OMBUSTION

Complete combustion of propane and butane or natural gas yields water vapor and carbon dioxide, which are, along with atmospheric nitrogen, the primary components of the exhaust gases of an gas engine. In realistic conditions, nitrogen oxides (NO_x), carbon monoxide (CO), sulfur oxides (SO_x), and various organic compounds are also produced.

The presence of sulfur dioxide (SO_2) in the combustion gases is caused by sulfur compounds in the liquified hydrocarbon gases. Their quantity depends on the origin and processing of the gas. The regulatory limit for total sulfur content of the fuel gas is 50, 100 or 200 mg sulfur per kg of fuel, depending on the product type. Stechiometric combustion of a fuel with sulfur content of 200 mg/kg corresponds to the concentration of SO_2 in dry flue gases of 16 mg/m^3.

The concentration of nitrogen oxides (NO_x) is the sum of concentration of nitric oxide (NO) and nitrogen dioxide (NO_2). NO_x is formed from atmospheric nitrogen at high temperatures and pressures. The first degree of oxidation produces NO, which is then oxidized by atmospheric oxygen or ozone to NO_2. The concentration of NO_x in the combustion gases are dependent primarily on the design and operating parameters of the combustion device.

The concentration of carbon monoxide (CO) in the combustion gases is related primarily to the operating parameters of the combustion device, namely the amount of excess air utilized, the uniformity of the air-fuel mixture, and the combustion gas cooling system.

The results (for example from measurement in KVM laboratory) speak explicitly in the favour of the LPG and CNG. The important thing in this case is also different ratio C/H against gasoline and diesel fuel.

RESULTS OF WTW, GHG ANALYSES

When observing the overall activity of the utilization of energy of the fuel for vehicle propulsion, it is appropriate to consider the consumption of energy in the entire chain from the primary resources (fossil as well as renewable) to the mechanical energy delivered to the wheels of the vehicle. This category includes not only the energy utilized in the automobile, but also energy expended in the mining or production of the primary energy carrier, during manufacturing of the fuel, and also for the transportation and distribution of the fuel. The evaluation of the effects on the environment also includes monitoring of the production of carbon dioxide, which can take part on the global climatic changes, and the production of gaseous pollutants (CO, HC and NO_x). The energy transformation chain, termed „Well to Wheels“ (WTW) analysis, can be divided into two parts. The first part, „Well to Tank“ (WTT), encompasses the path to the chemical energy in the fuel reservoir of the vehicle. The second part, „Tank to Wheels“ (TTW), considers the path from this chemical energy in the tank to the mechanical energy delivered to the wheels.

Both parts can be evaluated according to the energy relative to the mechanical energy delivered to the wheels, or relative to the distance traveled by the automobile under pre-determined conditions, such as the EHK R83 emissions test cycle. This test simulates both city and highway driving. This method for evaluating the total (WTW) energy use and total carbon dioxide production for different fuels and different automobile drivetrain types will further be demonstrated for the following drivetrains of a passenger automobile utilizing year 2005 technology and technology expected in the year 2010.

The following table [5] shows the WTW energy and greenhouse gas emissions per 100 km for a five-passenger automobile with the following parameters: weight class 1250 kg, front area cross-section of 2,1 m^2, maximum speed 180 $km.h^{-1}$, acceleration 0 – 100 $km.h^{-1}$ of 13 s. The estimates and details for 2010 are given in Figure 1 [6].

COMPARISON OF DIFFERENT FUELS IN TERMS OF WTW ENERGY, ITS INDIVIDUAL PARTS, AND PRODUCTION OF CO_2 EQUIVALENT FOR YEARS 2005 AND 2010

Table 1

	Year 2005				Year 2010	
	Energy (kWh)			Eqiv. CO_2 (kg)	Energy (kWh)	Eqiv. CO_2 (kg)
	TTW	WTT	WTW	GHG	WTW	GHG
Petrol PISI	59,6	8,3	67,9	18,5	60	16,4
Petrol DISI	55,7	7,6	63,3	17,2	59,4	16,2
Ethanol DISI	55,7	101,2	156,9	10,4	147	9,7
CNG PISI	61	11,7	72,7	15,7	64	13,9
Diesel DICI	50,1	7,9	58	15,8	55,3	15,1
FAME DICI	50,1	56,3	106,4	9	101,8	8,6
DME DICI	50,1	38,9	90	19,8	85	18,7
LPG (imports from remote gas fields) PISI	62,2	7,2	69,4	16,6	58,9	14,1

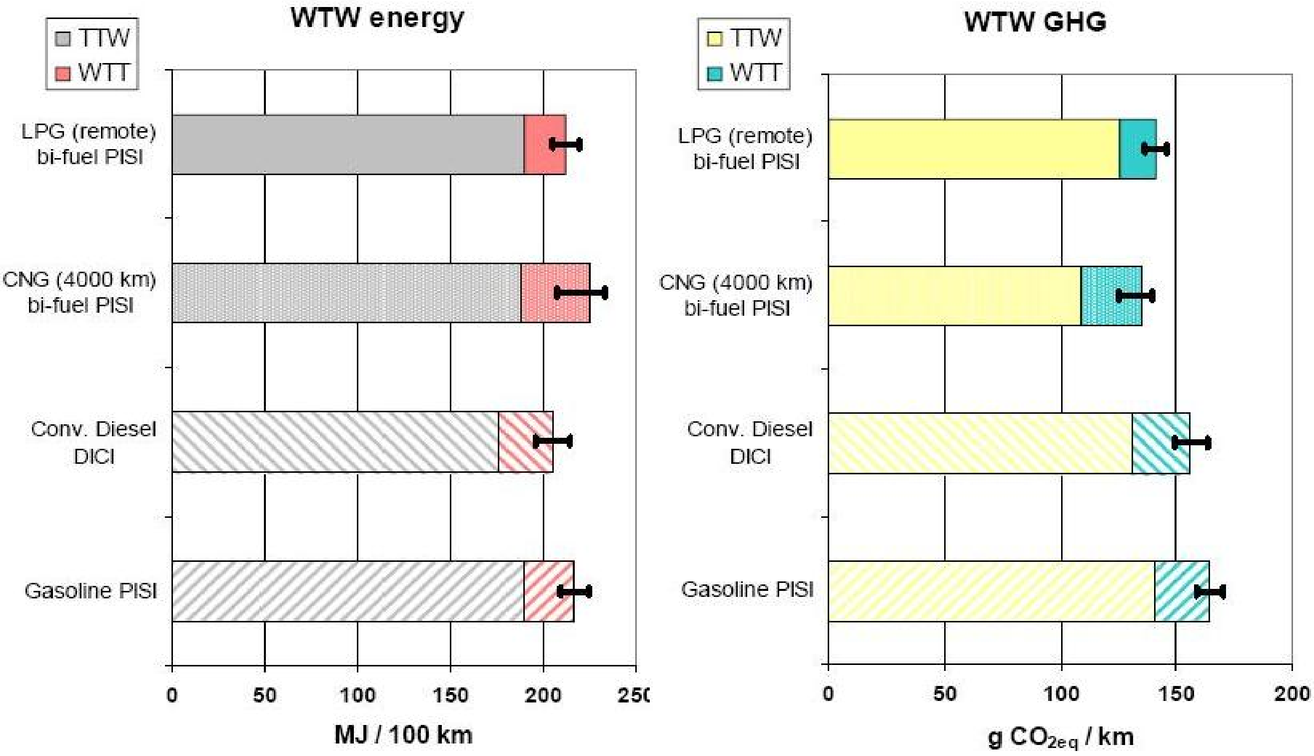

Fig. 1. *Comparison of classic and gaseous fuels in terms of estimates of WTW energy consumption and production of CO_2 equivalent for year 2010 [6], [7]*

CONCLUSIONS

Lately, LPG, in terms of automobiles, is less spoken about; compressed natural gas, CNG, is a more popular topic. The era of LPG vehicles is certainly not ending: the opposite is the case. There are an estimated 200 000 LPG vehicles in the Czech Republic, with 20 000 new conversions annually [8]. Due to the automobile manufacturers seldom offering LPG vehicles (Renault, Volvo), conversions of new vehicles to gaseous fuels by official dealers or their suppliers are more common in Europe. The advantage of authorized conversions of new vehicles is that warranty on the vehicles is maintained even after conversion.

There is a high number of manufacturers and suppliers of proven, quality LPG/CNG fueling systems and accessories. Development in the area of engine control units is expected, with movement towards the utilization of one integrated unit for both fuels. This would lead to the improvement in the quality of the engine control and air-fuel mixture composition control, which would then be a benefit to the performance and emissions characteristics of the vehicle. Gaseous fuel systems are following the original fueling systems, notably for spark ignition engines (development from mixer to gaseous and liquid fuel injection). On the table is, for example, direct injection of LPG into cylinders, although given the necessity of the modifications to the core engine, complexity of the installation, and technical requirements of the conversions, this option is not a simple and universal solution. Currently, sequential multi-point injection of gaseous fuels seems to be the best trade-off between price and performance. Fuel quality should not be underestimated, just like with traditional liquid fuels.

Operation of automobiles on LPG/CNG contributes to the reduction of air pollution by the exhaust emissions, while having similar energy requirements per km driven as the traditional fuels (gasoline, diesel fuel). Therefore, LPG and in next years also CNG as a fuels has a large significance in the passenger automobile category, despite still being considered, and utilized as, alternative fuels. It can be expected that gaseous fuels can, in general, be a successful partial replacement for petroleum based fuels.

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