Application Natural Gas on City Buses and Their Introduction in the Traffic

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Abstract: Compressed Natural Gas (CNG) as an alternative fuel has many advantages: lower cost, more complete combustion, lower emissions, lower noise and longer engine life. CNG technology has been developed for decades and now is available for commercial use in motor vehicles. Natural gas causing about 25% lower CO_2 emissions compared to the same amount of energy diesel fuel, due to the lower carbon content (H/C = 4), and thus contributes significantly to reducing global warming. This enables bus body builders to make natural gas buses comply with the challenging and voluntary Enhanced Environment friendly Vehicle (EEV) emission standard, without using extensive filter technology and expensive additives.

This paper analyzes the technical features of a city bus powered with compressed natural gas, as well as environmental, economic and security aspects of these buses for passenger transport in major cities. In the paper, also is presented the solutions for the reconstruction of diesel powered local bus into dedicated natural gas vehicle.

Keywords: CNG Cylinder, Emission, Natural gas buses, Logistics.

1. Introduction

There are already more than 22 million natural gas vehicles (NGV's) worldwide (1.76 million in Europe). In the last five years, sales of cars powered by natural gas have tripled in Europe, while they have increased six-fold in Spain in the same period. Between 2009 and 2014 in Italy there was an increase of 31% in the number of NGV's (15% in Germany). Also, CNG buses and trucks have a significant role in the continent: they consume 73.5% of methane applied to vehicles, while in the rest of the world the average is 40.5% [1]. Figure 1 shows the predictions of the Landscape Power trains in the future [2].

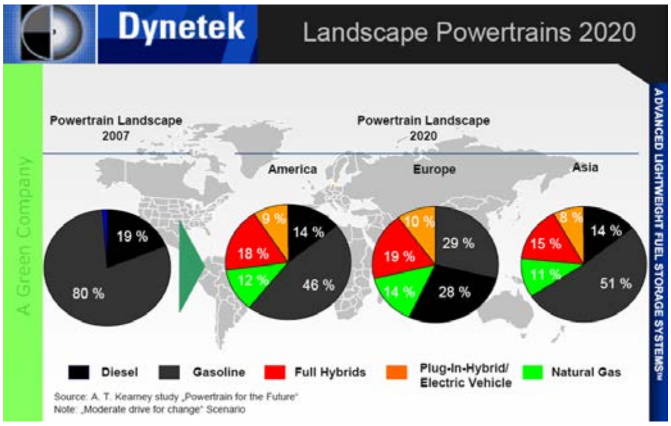

Figure 1. Landscape Power trains and Natural Gas rate [2]

Transit buses are one of the most cost–effective forms of mass transit, and the foundation of public transportation in the developing world. Diesel engines have been the traditional power source for public buses and heavy trucks due to their durability, robustness, reliability, high fuel efficiency and high torque. Because transit buses operate in heavily congested areas under stop and-go traffic patterns, continuous acceleration and deceleration increases the production of particulate matter (PM), typical of high load during vehicle acceleration periods. Critical public health situations related to exposure to high concentrations of exhaust emission and legislation, have pushed local authorities to take actions favoring low–emitting vehicles and in some extreme cases, banning the use of vintage diesel buses. As example, Euro VI emission for heavy duty (HD) vehicles was introduced in January 2014. The new limit for heavy duty vehicles for Nitrogen oxides (NOx) is 0.4 $g \cdot kWh^{-1}$. For PM new limit is 0.01 $g \cdot kWh^{-1}$. Both values represent a reduction of 80% and 50% in comparison with earlier Euro V regulation, respectively [3].

2. The technology for CNG fueled buses

At the Mercedes-Benz bus plant in Mannheim, series production of low-floor urban line service buses begins in mid-1994. The gaseous emissions of the M 447 hG engine – based on the proven OM 447 h six–cylinder diesel engine, redeveloped for natural gas combustion and fitted with a three-way catalytic converter with closed–loop lambda control – are more than 50% lower than the EU exhaust emissions limits which apply as of 1st October 1996 (Euro 2) [4].

Today, the new M936G natural gas engine model exists first in the new Mercedes–Benz Econic truck with Euro VI which is designed especially for the needs of municipal utilities. The theoretical CO_2 advantage of the fuel natural gas over diesel of 25 % was realized. The complete system of engine and exhaust after–treatment is robust and favorable in terms operating costs. Therefore, a lambda–1 concept was combined with exhaust gas recirculation (EGR) which allows for the use of three-way catalyst (TWC) and best efficiencies. Additionally the noise level over the complete operating map stays below the diesel engine [5].

MAN Truck & Bus has many years of experience when it comes to natural gas buses: as early as 1972, MAN buses fitted with natural gas engines transported athletes and visitors at the Olympic Games to venues in Munich and the surrounding area. Twenty years on, the MAN SL 202 with CNG drive premiered and in 2003, MAN delivered the first natural gas buses with EEV technology to its customers. Meanwhile, MAN has hundred over in excess of 5,000 natural gas buses and bus chassis featuring natural gas engine [6].

Regarding to the combustion process, CNG engine can be characterized as stoichiometric or lean-burn. Lean-burn HD engines became popular during the first generation of CNG engines due to their higher fuel efficiency and lower heat rejection compared to stoichiometric engines (lambda–1). Lean-burn CNG engines provide comparable power and torque as compared to conventional diesel engines. The engine-out emission levels from a lean–burn CNG engine without any after treatment system are low enough to outperform a conventional diesel engine in terms of PM and NOx.

For achieving the US2010, Euro V and VI emission limits for HD engines, manufacturers explored the possibility of combining stoichiometric combustion with a TWC. The main problem of stoichiometric combustion for HD applications is the high in–cylinder gas temperatures during combustion, which leads to high production of NOx and the excessive amount of heat that must be removed. In addition to higher thermal stress, lower brake efficiency is expected due to the required low compression ratio.

In the Republic of Serbia take in mind the experience of leading manufacturers of buses, the design engineers in domestics Production Company from Kragujevac city have successfully implemented a prototype of fully low floor city bus with CNG drive on the originally produced chassis. With this unique ECO–bus, were transported competitors at the 25th Universiade Belgrade 2009 [7].

The prototype bus is implemented with the original gas engine with C Gas Plus lean-burn technology, according to Euro IV emissions legislations. The serial production continued with the package contains the Cummins Westport Inc. (CWI) 2007 ISL G spark ignited, natural gas engine. These engines are designed to meet the proposed 2010 U.S. Environmental Protection Agency (EPA) and California Air Resources Board (CARB) emission standards at launch in mid-2007 [7,8].

The 8.9 L 2007 ISL G engines will use stoichiometric combustion with Cooled Exhaust Gas Recirculation (CEGR) technology to enable a three way catalyst after treatment method, leveraging Cummins proven EGR technology to create a high–performance natural gas engine. The use of cooled EGR (in place of large amounts of excess air used in lean burn technology) lowers combustion temperatures and knock tendency. Use stoichiometric combustion with CEGR technology also improves power density and fuel economy compared to lean and alone stoichiometric technologies. Compared to previous CWI lean burn natural gas engines, ISL G torque at low speed is improved over 30% and fuel economy is improved by up to 5% [8].

It is clean that CNG engines present an attractive alternative to diesel engines for urban buses because they have been shown to offer lower PM and NOx emissions in terms of grams per distance traveled and in terms of grams per unit energy produced.

According to previous experiences we are also started new project for production of articulated low floor city buses, powered by CNG engine MAN in combinations with the automatic gearbox Voith. MAN natural gas engine are just as powerful as their diesel counterparts: a powerful drive, dynamic acceleration and superior driving. With its innovative catalytic converter technology, emission values are far below Euro V and EEV standards, Fig. 2. MAN CNG technology represents CO_2 – neutral series technology when operated with biogas. The MAN E28 series (E2876 LUH03) horizontal six cylinder natural gas engines are fitted with turbochargers, intercoolers and TWC converters [6].

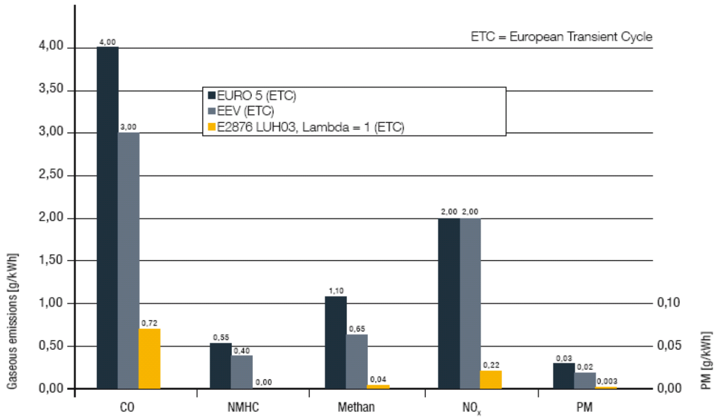

Figure 2. MAN diesel and CNG Engine Exhaust Emissions by Comparison [6]

3. The instruction for buses safety projecting and servicing

Before discussing the design features that are recommended for CNG buses, it is important to understand what makes this fuel different from gasoline or diesel. The items below summarize the basic differences between the properties of gaseous and liquid fuels that influence the chassis design changes:

- Natural gas is lighter-than-air and in gaseous form at atmospheric conditions. This property allows this fuel to quickly rise and disperse in the unlikely event of a leak. Although lighter-than-air fuels have safety advantages, roofs and ceilings of these facilities must be designed without any unventilated "pockets" in the ceiling space that could trap gas. Liquid fuels such as gasoline and diesel will form a pool of liquid with a vapor layer above. Liquid fuels remain in a concentrated form after a leak, causing on-going safety and environmental concerns.
- Natural Gas has a very selective and narrow range of flammability—that is, the mixture of gas in air that will support combustion (between 5% and 15% natural gas in air by volume—ratios outside of this range will not support combustion). In other words, with less than 5% Natural Gas in air the mixture is too lean and will not burn, and with greater than 15%, the mixture is too rich and will not burn. Maintenance facilities must be designed to quickly and automatically remove the risk caused by a leak, using ventilation to dilute then exhaust any leaked gas. As indicated above, liquid fuel leaks will pool and therefore will remain in flammable or explosive mixtures until the leak is manually contained and cleaned up [9].
- CNG and Hydrogen (H_2) both have an ignition temperature of around 480 to 650 °C, whereas Gasoline is approximately 260 °C to 430 °C and diesel is less than 260 °C. This relatively high ignition temperature for CNG and H_2 is an additional safety feature of these fuels. To ensure a safe environment in the maintenance garage, the surface temperature of equipment that could contact a gas leak is usually limited to 400 °C [9].

According to previous descriptions, ventilation systems in the garages for CNG fueled buses must be designed that typically provides between 5 and 6 Air Changes per Hour (ACH) (the requirement is for 425 $L \cdot min^{-1}$ per $1 \cdot m^2$ of ventilated area). The conclusion is that this is no additional airflow requirement and cost, according to existing diesel facilities designed for a baseline ventilation rate of 4 to 6 ACH [9].

Figure 3 shows the parts of the CNG fuel line from gas cylinders trade mark DTK to the engine, applied to domestic bus MB–S. All parts of the installations are designed according to regulation UN ECE R 110 and the same labels are marked on the material.

On the bus roof is mounted Gas Rack with four cylinders mark DTK "V294", with a total water capacity of 1.176 L. The weight of one tank was about 92.4 kg (0.308 kg·L^{-1}). The composite DyneCell® cylinders are particularly lightweight cylinders for the storage of CNG. They consist of a thin-walled, seamless aluminium internal vessel whose entire surface is wrapped with a high–strength carbon fiber reinforcement (Type CNG–3, fully wrapped metal liner, according to ECE R 110 and ISO 11439) [2,10].

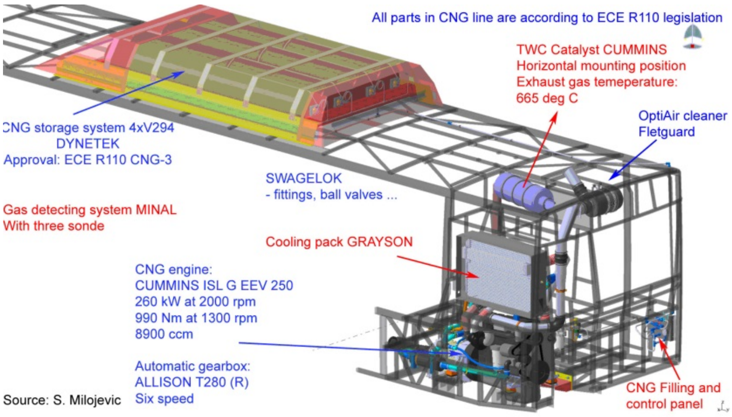

Figure 3. The design of CNG line applied on the bus MB-S [7]

By using cylinders type CNG–3, achieved the better bus performances in accordance with lower weight and has up to 8 seats more for passengers. Also the consequences are the lower number of failures and regular vehicle services, the friction on the wheels of the front axle is less for about 30%, and gas consumptions is lower for about 0.5 to 1·kg/(100 km). As a comparison, for the same driving radius with one CNG filling, if used gas cylinders type CNG–2, bus had about 40% more weight [2].

In the MB–S bus used CNG tanks have been tested under a pressure of 30 MPa and for fire protection all cylinders fitted with Pressure Relief Devices (PRD). Cylinders are equipped with electric shut–off valves to stop and open the CNG flow in fuel line. In the valve is integrated thermal switch that quickly respond to increasing temperatures. That is so called Temperature triggered Pressure Relief Device (TPRD) [2,7,10].

According to requirements for vehicles of categories M3 and N3, (resistance to destruction of the roof structure during deceleration of (6.6·g) in the longitudinal and (5·g) in transverse direction), we calculated and accepted the mounting of CNG cylinders assembly to carry through the auxiliary "U" profiles, Fig. 4 [10,11].

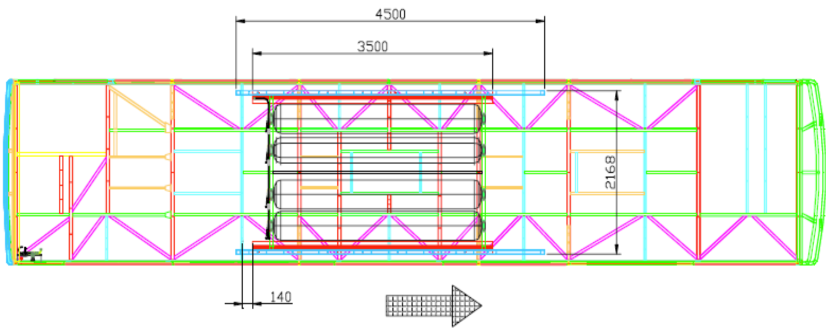

Figure 4. CNG Cylinders Rack position on the bus roof [11]

The mounted cylinders consist of an aluminium liner which is fully wrapped with a carbon fiber and epoxy reinforced laminate, Fig. 5. This material is selected for the following reasons and benefits [2]:

- No permeation: Taking into consideration the zero emission discussion, the absolute impermeability to gas of the aluminium core is a particular advantage in other words; no gas can permeate through the aluminium wall of the liner

– High impact resistance: The aluminium liner guarantees high impact resistance, as the aluminium structure stabilizes the carbon–fiber reinforcement in case of impact, which means that the fibers are neither dented nor broken. Protection in the form of polyurethane caps is not necessary
– Very light weight: As a result of the thin–walled design of the aluminium liner and the extreme strength of the carbon fibers, it is possible to achieve an exceptionally low weight/volume ratio of approx. 0.4 $kg{\cdot}L^{-1}$ for 250 bar applications. This leads to a very high storage density related to the external geometrical volume of the cylinders
– Easy mounting: The neck of the aluminium core can be manufactured so that various lengths are possible. This means that a neck mounting can be provided which enables the cylinder to be installed in the vehicle easier and cheaper
– Fast filling: Further benefits of the aluminium liner include the high heat–conductivity of the aluminium, which means that heat can be dispersed much faster than it is the case with fully wrapped plastic cylinders, especially during rapid filling, when a very high gas temperature occurs. These results in a considerably higher filling level, in other words the mass of gas and therefore the range of the vehicle are greater.

The nominal service pressure is 20 MPa at an ambient temperature of 15 °C. Settled temperatures of gases in cylinders may vary from –40 °C to a high of 65 °C. The temperature of the cylinder materials may vary from –40 °C to 85 °C [2].

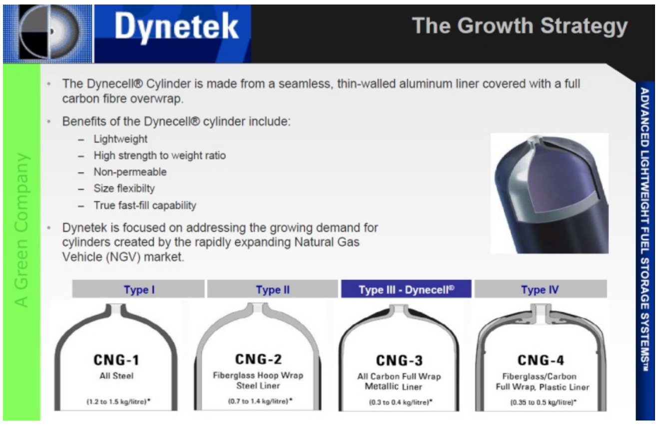

Figure 5. The Benefits of the Dynecell® cylinders DTK [2]

The cylinders have a maximum Service Life of 15 to 20 years from the final manufacturing inspection date, depending on the number of filling cycles per year specified in the relevant standard for the country where the cylinder is operated. When the Service Life is reached, the cylinders must be removed from using. If cylinders are filled more than (1000 x Service Life in years) before the expiration date is reached the cylinders must also be removed from using [2].

Cylinders require an external re–inspection for defects in the composite wrap at certain intervals after installation or upon reinstallation. Inspection shall always be in accordance with the relevant standards and regulations of the country where the cylinder is operated. According to ECE R110 Rev. 1, for natural gas cylinders this inspection shall be performed at least every 48 months after the date the vehicle enters into service [2,10]. Inspection shall be in accordance with procedures outlined in ISO 19078, and/or also according to the relevant national standard of the country where the cylinder is operated.

4. Gas market supply and CNG buses filling

Today almost 85 countries from all five continents use NGV's. There are more than 26 thousand filling stations spread throughout 2,900 cities worldwide (4 thousand in Europe). In the Republic of Serbia in this moment exist only 10 CNG filling stations and 878 NGV's (58 buses and 28 trucks) [1].

In typical NGV/CNG refueling stations, owners do not have to rely on the arrival of trucks for the fuel supply since it is constantly provided by the pipeline. It is possible for some users to refill their NGV/CNG cars at home because there are dispensers that take natural gas directly from the domestic distribution network.

The security of the CNG supply is very important requirement to continue the introductions of NGV’s in city transport in the Serbian cities. The South Stream project is aimed at strengthening the European energy security. The new gas pipeline system meeting the latest environmental and engineering requirements will significantly raise the energy supply security of the entire European continent, too.

According to previous, to secure natural gas supply to the transporters and another, like the bridge before gas networking (applicable for any territories), is better to use the Containers for CNG Bulk transport with semitrailers, Fig. 6 [2]. The use of mobile natural gas pipelines on trucks or trailers makes NGV/CNG available where there are no physical pipelines either because of long distances or because of the scale of the demand.

Figure 6. The 250 bar Modules with Cylinders DTK for CNG Bulk Transport [2]

Analyzed DTK Containers for Gas Transport are approved according to ADR as MEGC, with main characteristics listed below [2]:

– Extremely High Storage Capacity due to Light-Weight Composite Cylinders
– Low Weight, Less Wear and Friction and Lower Costs for Maintenance and Repair
– Handling by Crane or Forklift
– Lifetime up to 40 years
– Standard 250 bar Service Pressure
– Vertical or Horizontal Assembly with Neck or Belly Mounting.

The comparison between composite type CNG–3 cylinders DTK and steel cylinders with dimensions and filling characteristics–capacities, are presented in Tab. 1 [2].

Table 1. ISO 20 ft and 40 ft Container Options DTK [2]

CYLINDERS	Composite Type-3 20 ft Container 250 bar	Composite Type-3 40 ft Container 250 bar	Jumbo Vessels 40 ft Semitrailer 250 bar 250 bar
A. Cylinder Material	AL 6061 liner + Carbon Fiber in Epoxy Resin		Steel 34CrMo4
Standard	TPED / ADR		
Number of Cylinders	76	152	9
Outside diameter	406 mm		559 mm
Cylinder capacity	234 L		2,358 L
Cylinder Weight	84 kg		2,660 kg
Test pressure	375 bar		300 bar
Total cylinder volume	17,784 L	35,568 L	21,400 L
B. Weights			
Total cylinder weight	6,384 kg	12,768 kg	23,940 kg
Total CNG, kg *	4,222	8,444	4,471
Total CNG weight/Total Cylinder Weight Full	0.66	0.66	0.18

**depending on actual density of CNG used and filling conditions!*

TPED –Transportable Pressure Equipment Directive, ADR – European Agreement concerning the International Carriage of Dangerous Goods by Road

4. Cost analysis – Example Kragujevac city

Public transport in Kragujevac city operates with 50 buses and average 280 km/ (per day), every 315 working days per year. Taking into account all parameters, we obtain the following conclusions about a year operation with 50 buses operated on diesel fuel and CNG, Tab. 2 [7]:

Table 2. Cost analysis (city bus with diesel or CNG propulsion system)

	Diesel	CNG	Saving
Fuel prices in RS	1.2 €/(L)	0.45 €/(kg*) 0.75 €/(kg**)	
Average fuel consumption	40 L/(100 km) measured	33 kg/(100 km) measured	
Fuel consumption per year	1,764,000 L	1,455,300 kg	
Fuel cost per year	2,116,800 € Saving 50%	645,885 €* 1,091,475 €**	1,470,915 €* 1,025,325 €**

**The case with proper filling station, **the case with public filling station*

Investments for replacing diesel engine with new power pack: CNG engine, gearbox and CNG system on the bus are about 55,000 €/(bus). The new Euro VI CNG bus costs 180,000 €/(bus). Costs for CNG filling station, with capacity of 1,800 $m^3 \cdot h^{-1}$ (including two compressors), and additional infrastructure are about 450,000 € (Profitable for one year). Return of total investments are for 3–4 years.

5. Conclusions

There are already more than 22 million natural gas vehicles (NGV's) worldwide. In the last five years, sales of cars powered by natural gas have tripled in Europe.

When deciding to introduce CNG buses, one must evaluate the appropriate CNG engine technology. To achieve US2010 or Euro VI emissions performance stoichiometric CNG engines with TWC is required. If use CNG drive, the emissions of PM and NOx, can be reduced up to 70% and 30% respectively, when compared to conventional diesel buses without after treatment.

By installing the CNG Cylinders and rest CNG fuel equipment on the bus according to UN ECE Regulation No. 110, was achieved great progress from the aspect of vehicle safety in traffic.

The introduction or expansion of NGV's will require investment in natural gas fueling infrastructure.

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