International Congress
Motor Vehicles & Motors 2018
Kragujevac, Serbia
October 4th - 5th, 2018

Motor Vehicles & Motors

MVM2018-065

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EXPERIENCES RELATED TO THE INSPECTION OF MOTOR VEHICLES RUNNING ON NATURAL GAS IN THE REPUBLIC OF SERBIA

ABSTRACT: Natural gas and liquefied petroleum gas represent the most practical, realistic and easiest way to reduce pollution coming from road transportation. In practice, natural gas vehicles are as safe as any other vehicles (gasoline, diesel, liquefied petroleum gas, etc.) operating on the roads. However, safety incidents sometimes occur where a natural gas system, primarily storage cylinders, have failed. Recent incidents involving natural gas vehicles have shown that cylinders may explode through compliant with current UN ECE 110R regulation. In the paper are systematized regulations and technical requirements relating to the installation of devices and equipment on vehicles powered by natural gas. The main objective of the research is to present a good practice related to inspection of motor vehicles on natural gas. It was also shown the several options for the reconstruction of vehicles to drive on gas fuel, as well as logistics.

KEYWORDS: logistics, motor vehicles, natural gas, regulations

INTRODUCTION

In energy plan, oil as a conventional fuel is still a very important energy resource. On the other hand, constant increase in consumption of conventional energy generating products opens the door for all potential substitutes for oil.

Natural gas is a high-quality fuel for motor vehicles. Above all, available reserves equal the known oil reserves; negative influence upon environment is less than with fuels derived from oil, as well as the price. Due to that, natural gas as a motor fuel has been having a growing application in motor vehicles, which is further proved by the fact that there are over 26 million vehicles in the world powered by natural gas (1.86 million in Europe). As an example, we could mention the city of Porto whose budget for the current year includes the funds for purchasing 173 new buses powered by natural gas. Currently, in the Republic of Serbia, there are in traffic on the roads 878 natural gas vehicles (792 passenger and light duty vehicles, 58 buses and 28 medium and heavy duty trucks) [1].

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The growing number of vehicles powered by natural gas has required in parallel new regulations and rulebooks regulating this field to be adopted. Thus, environmental requirements for vehicles fueled by natural gas have been prescribed by ECE rulebooks 49 and 83; whereas the requirements related to the aspect of safety and functionality of installation of gas devices and equipment have been defined under regulations UN ECE 110R and UN ECE 115R. Laws and bylaws applicable in the Republic of Serbia for natural gas vehicles are: Road traffic safety law, Rulebook on the Classification of Motor Vehicles and Trailers and Technical Conditions for Vehicles in Road Traffic and vehicle testing rulebook on [2–6].

For the purpose of managing the process of logistic affairs, from production to periodical checks and maintenance of vehicles powered by natural gas, it is necessary to systemize the above mentioned regulations and rulebooks. That would also provide an answer to the question of how safe the vehicles powered by natural gas actually are.

NATURAL GAS AS FUEL FOR DRIVING AND MOBILE SYSTEMS

All gases are good fuels for Otto engines: the mixture is of high-quality and ready for full combustion, engine operation is economical, pollution is less, oil and engine life is longer etc. In terms of engine related criteria, natural gas may be used as the sole fuel for Otto or diesel engines (with certain engine reconstruction). In addition to that, it may be used in mixture with every kind of oil or proved alternative fuel (lower or higher alcohols, biogas, and other) [7].

In normal ambient conditions, natural gas has a low density of energy per unit of volume. Due to that, in case of application of natural gas as a motor fuel, it is necessary to have a certain treatment of natural gas in order to have a higher concentration of energy by unit of volume. Given that it is expected to have a wider radius of vehicle movement with one fuel tank topping, it is necessary to have operating pressures of around 200 bar which is the limit that standard bottles for technical gases may endure. The simplest way is to compress natural gas in high-pressure tanks (CNG–compressed natural gas). The second alternative for increasing the density of energy of natural gas inside tanks on vehicles is its extreme cooling down to (–162 °C), i.e. conversion to liquefied state (LNG–liquefied natural gas) and storing in cryogenic tanks.

Optimistic studies about natural gas are based on pure methane. Unfortunately, pure methane is nowhere to be found in nature. It is always in mixture with other impurities in concentration of various percentages. In order to use natural gas as fuel, it is necessary to filter it until it reaches more or less the established composition and quality. There are some national standards that regulate quality of natural gas as engine fuel: SAE J1616, DIN 51624 and 13 CCR § 2292.5 (California regulations). In parallel, there is an international standard ISO 15403, accepted also by the Republic of Serbia. The purpose of this standard is for producers, vehicle users, filling station operators and other logistics participants in the industry of (CNG) vehicles to get informed about quality of fuel for natural gas vehicles [7].

Natural gas has the following characteristics:

- It is non-toxic, non-carcinogenic, non-corrosive, however, it is suffocating, colorless and odorless due to which it is necessary to add certain odorizes and foul smells,
- Natural gas is lighter than air (density of methane is 0.68 $kg \cdot m^{-3}$ at 15 °C), and when leaking it leaks upwards, whereas for example propane (1.87 $kg \cdot m^{-3}$) and butane (2.44 $kg \cdot m^{-3}$) are heavier and leak downwards,
- Auto flammability temperature of (CNG) is in the scope of 480–650 °C, whereas in case of (LPG–liquefied petroleum gas) it is in the scope of 480–495 °C (methane 595 °C, propane 495 °C, butane 480 °C, gasoline 260–430 °C, whereas in diesel it is less than 260 °C),
- Flammability scope in volume percent of methane with air is 4.4–15%, in case of propane it is 2.4–9.3%, butane 1.8–8.8%, (gasoline 1.4–7.6% and diesel 0.6–7.5%),
- Natural gas is converted to liquid at ambient pressure at temperature of (–162 °C); and
- Critical point of methane is defined by temperature of (–82.7 °C), and pressure of 45.96 bar.

EXAMPLES OF SOLUTIONS FOR NATURAL GAS VEHICLE DESIGN

Natural gas as fuel of vehicle drive systems in road transport is applied in new vehicles with original natural gas engines or by converting existing engines so as to use gaseous fuels. In practice, there are the following options for conversion of vehicles so as to use (CNG) [8, 9]:

- Modification of gasoline engines so as to use CNG (Eng. dedicated fuel),
- Modification of gasoline engines so as to use CNG or gasoline (Eng. bi–fuel),
- Modification of diesel engines so as to use CNG (Eng. dedicated), spark plug ignition; and
- Conversion of diesel engines so as to have parallel function with CNG and diesel fuel (Eng. dual fuel).

The concept of vehicles with original factory produced engines designed for use of natural gas as fuel is the only one that can use all the natural advantages of this fuel [8, 9]. Modifications of old carburetor engines so as to use natural gas as fuel with use of cheap systems, such as those with injectors, do not contribute to reduction of emissions and improvement of safety, but quite the contrary, result in their increase and deterioration respectively.

Figure 1 shows the scheme of universal installation for CNG with sequential injection.

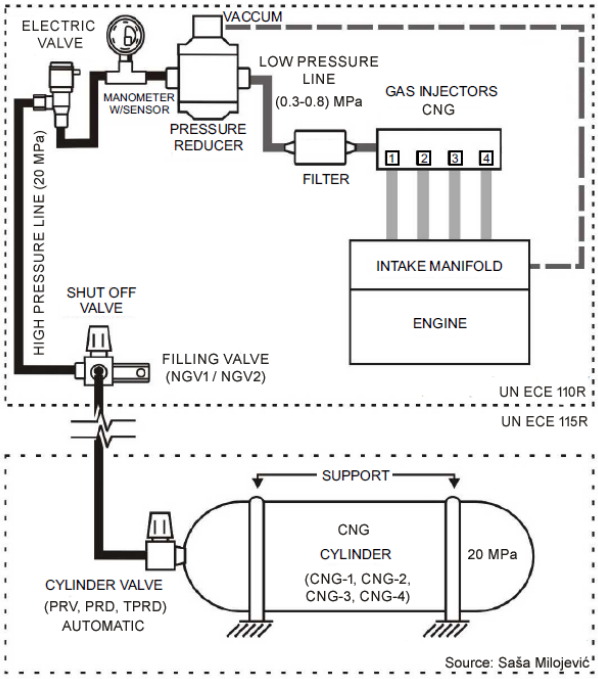


Figure 1 Parts of system for sequential injection of CNG to engine

Figure 2 shows position of the installed devices and equipment on the vehicle Volvo S80, with propulsion system on natural gas or biogas.

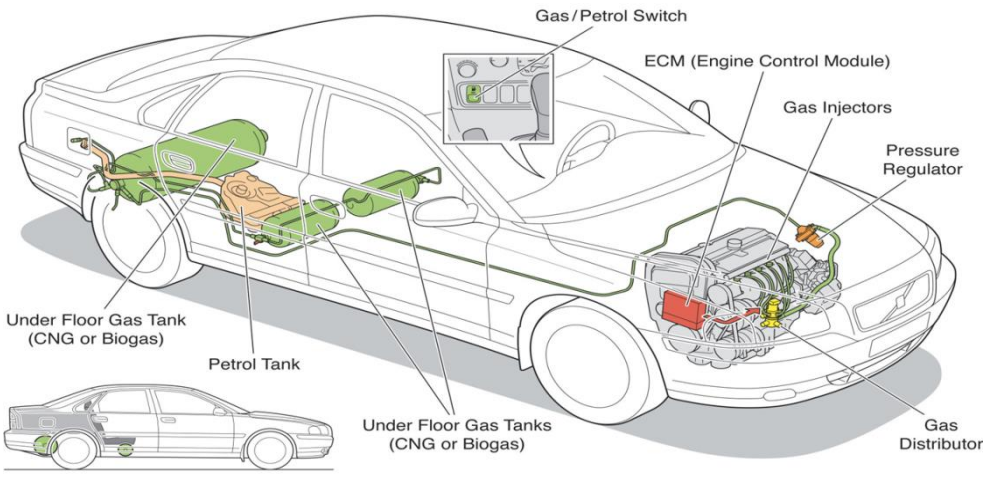


Figure 2 Bi–fuel systems (CNG or biogas) on passenger vehicle Volvo S80

Figure 3 shows parts of gas installation of a city low-floor bus on CNG. Bus propulsion system has been equipped with original, factory produced gas engine for CNG or LNG. The concept of engine that works on the principle of combustion of lean mixture meets the Euro IV regulation. With application of engines whose operation has been based on combustion of stoichiometric mixture of natural gas and air with recirculation of cooled combustion products and three-component catalyst, the reached level of toxic and hazardous combustion products from vehicle is within the limits prescribed by Euro VI [9-11].

According to author's experiences, the best option for reconstruction of existing city buses is the using of completely new propulsion system with dedicated (CNG) combustion. In the bus, need to be integrated modern automatic fire protection system [12]. Similar conditions apply if Hydrogen is used as a fuel [13].

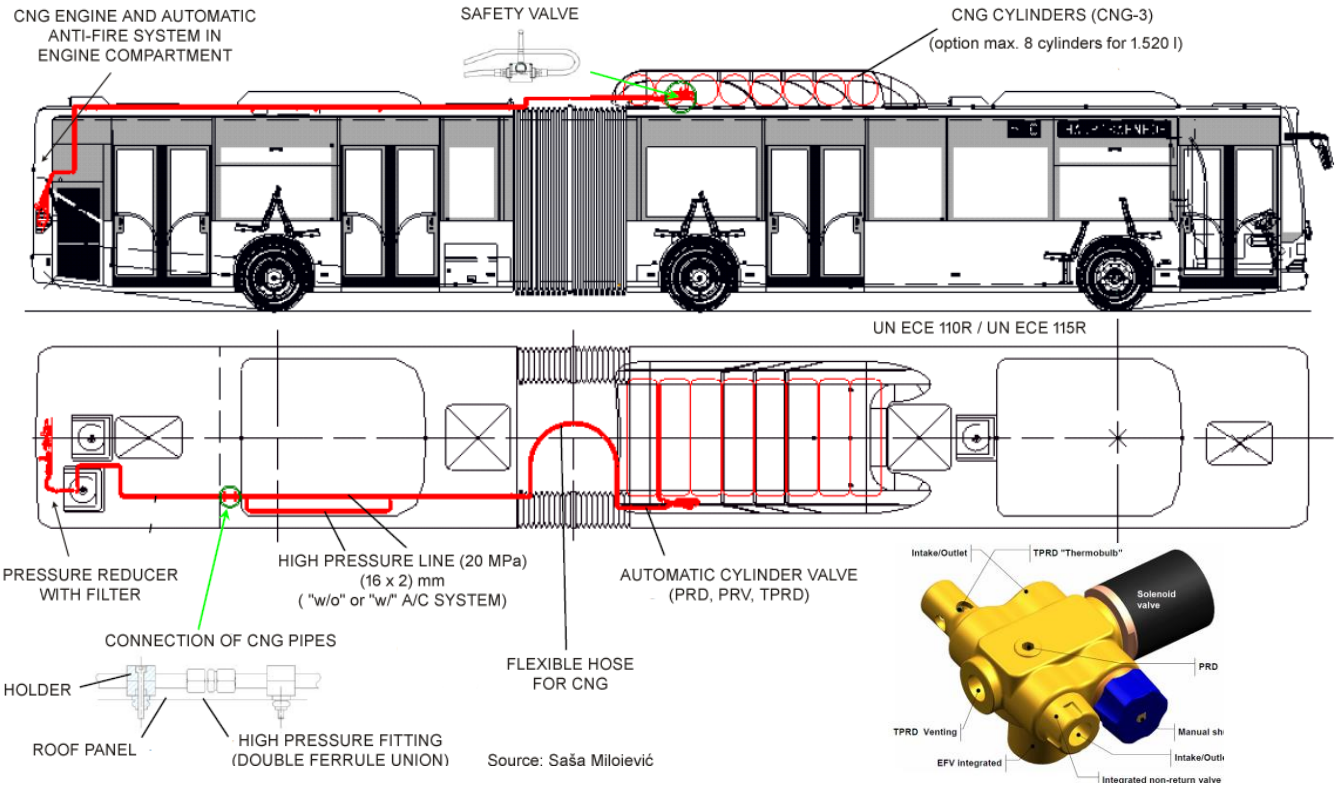


Figure 3 CNG installations on city low-floor bus

REGULATIONS REGULATING THE ISSUES RELATED TO VEHICLES POWERED BY NATURAL GAS

International regulations

Environmental requirements that should be met by CNG vehicles have been defined within ECE Rulebook no. 49 for freight carrying vehicles and buses, and within ECE Rulebook no. 83 for passenger vehicles.

From the aspect of safety and proper installation of gas equipment, the requirements to be met by CNG vehicles have been prescribed within two ECE regulations [5, 6]:

- UN ECE 110R – uniform homologation regulations:
  - Specific equipment of motor vehicles powered by CNG; and
  - Vehicles equipped with specific equipment for CNG in terms of installation of such equipment.

- UN ECE 115R – uniform homologation regulations:
  - Vehicles, previously homologated for basic fuel and subsequently equipped with specific equipment for LPG drive, in terms of installation of such equipment; and
  - Vehicles previously homologated for basic fuel and subsequently equipped with specific equipment for CNG drive, in terms of installation of such equipment.

National regulations

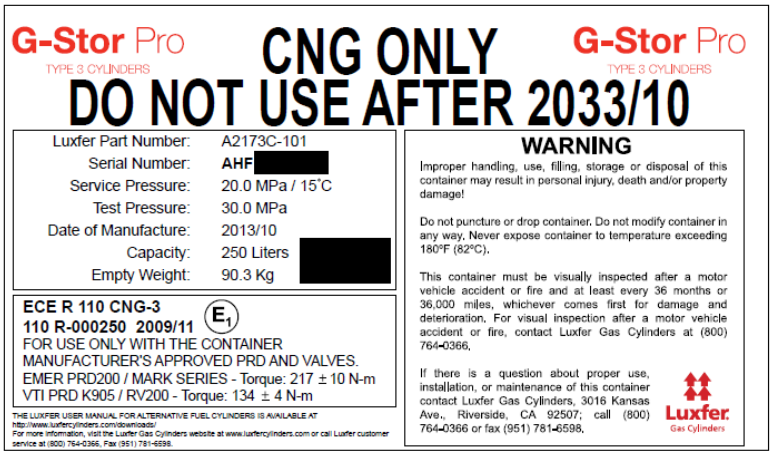
The following laws and by-laws apply to the vehicles in the Republic of Serbia [2–4]:

- Law on road traffic safety,
- Rulebook on the Classification of Motor Vehicles and Trailers and Technical Conditions for Vehicles in Road Traffic; and
- Vehicle testing regulations.

TECHNICAL REQUIREMENTS FOR INSTALLATION OF DEVICES AND EQUIPMENT OF NATURAL GAS VEHICLES

Cylinders for CNG must have the following data permanently inscribed in accordance with provisions of Rulebook UN ECE 110R, Figure 4:

- Name of manufacturer,
- Factory number,
- Month and year of production (inspection),
- Volume of empty cylinder in liters (l),
- Max. allowable pressure of cylinder filling (MPa/bar),
- Mark of gas to fill the cylinder – "CNG ONLY"; and
- Imprint of cylinder expiry date – "DO NOT USE AFTER XX/XXXX" where XX/XXXX indicates the month and year.



a)

b)

Figure 4 a) Cylinder identification and labels; b) Photography of sticker for CNG cylinder

The cylinders must be fitted to the basic vehicle structure according to the instructions of the manufacturer, i.e. technical requirements and must not be in direct contact with other metal parts, except in case of cylinders with special supports designed to be fitted to the metal structure. The technical requirements for cylinder fitting according to ECE Rulebook no. 115 annex 5 point 1.3 are listed in the table below 1 [6]:

Table 1 Technical requirements for cylinder fitting

Tank volume, l	Minimum dimensions of washers, mm	Minimum dimensions of fixing metal straps, mm	Minimum dimensions of screws, mm
Up to 85	30x1.5 or 25x2,5	20x3 or 30x1.5	8
85 – 100	30x1,5 or 25x2.5	30x3 or 20x3*	10 or 8*
100 – 150	50x2 or 30x3	50x6 or 50x3**	12 or 10**

Cylindrical tanks are fixed with at least to insulated straps, except in the following cases:

* in this case, three straps are necessary for fixing; and

** in this case four straps are necessary for fixing.

In case of cylinders installed below the vehicle floor, the cylinder must be fixed with at least three suitable straps. The screws used must be at least in the class 8.8.

As for the cylinders of volume over 150 l, it applies that the requirements of UN ECE 110R must be met. Rulebook UN ECE 110R prescribes that (CNG) cylinders must be fixed in appropriate way, so that they can (when full) endure deceleration in the moving direction of vehicle and in direction perpendicular to vehicle moving direction, depending on the vehicle category, as per Table 2. It also requires a certain resistance (absence of any deformation) of cylinder supports and also of the part of vehicle structure to which the cylinders have been fixed, which could also be proven by the following calculation [5, 10].

Table 2 Prescribed deceleration as per UN ECE 110R

CATEGORY OF VEHICLES	M1 or N1	M2 or N2	M3 or N3
Deceleration – in vehicle moving direction	20·g	10·g	6.6·g
Acceleration – in horizontal plane, perpendicular to vehicle moving direction	8·g		5·g

According to UN ECE 110R, the cylinder for (CNG) must be approved and equipped with the following components at the least which could be separate or combined [5]:

- Hand valve,
- Automatic valve of cylinder,
- Pressure relief device (PRD) or temperature activated pressure relief device (TPRD); and
- Excess flow valve (EFV).

The cylinder and valves may also be equipped with gas-tight housing with ventilation, if necessary. It is necessary to protect them from direct sun rays.

High-pressure gas pipes must not be soldered nor welded and instead have to be joined by fixing elements made of steel. High-pressure gas pipelines must be laid so as not to vibrate, not to have friction among parts especially in places where the pipes go through openings. The distance between two places of fixing, in case of high-pressure gas pipes below vehicles, may be at most 500 mm, whereas radiuses of pipe bending must be adjusted to material and dimensions of pipes.

Gas pipelines are installed in the driver and passenger's compartment, including the trunk, only if protected in a special way (impermeable housings, pipe-in-pipe etc.) provided that the protection must be resistant to mechanical damage, and its openings must be located on the external side of vehicles for ventilation purposes.

Before being connecting to the device (gas valve, pressure reducer, filter, manometer and other), gas pipe must have a compensation coil that enables expansion. The high-pressure gas pipelines must not have visible damage and the pipes that have fractures or have undergone mechanical damage due to corrosion process and other must be replaced immediately.

Low-pressure gas pipelines connecting the pressure reducer with device generating the mixture of fuel and air for engine must not be in contact with warmed up parts of exhaust system, i.e. with engine, but only with device for fuel supply to engine. Rubber lines must not be damaged nor cracked. Low-pressure gas lines are joined by collars. The junctures must be impermeable, collars must be self-blocking, and so there could be no uncontrolled loosening of joints.

Gas pressure reducer is bracket fixed on the interior part of car body, outside of driver and passenger's compartment, including the trunk and it must not be fixed to the parts of vehicle that get warmed up and must be distanced in a proper way from the parts of exhaust system and vehicle engine.

INSPECTION OF VEHICLES WITH INSTALLED DEVICES AND EQUIPMENT FOR NATURAL GAS POWERED VEHICLES

Necessary checks

Checking the compliance of devices and equipment with the approval type

Devices and equipment installed in the vehicles fueled by (CNG) must be type approved (homologated) according to UN ECE 110R, which is to be determined during this check-up.

Checking if meeting the requirements related to compliance of devices and equipment with the manner of combustable mixture preparation and technical implementation of installation

Checking if meeting the requirements related to compliance of devices and equipment with the manner of combustable mixture preparation

Devices and equipment must be installed in compliance with the instruction manual for installation made by the manufacturer of devices and equipment for natural gas vehicles, and if there is no such instruction; the minimum requirements of compliance are as follows:

- Devices and equipment with vacuum regulation system could be applied only in intake carburetor engines; and
- Engines with a plastic intake manifold and engines with multi point injection system (MPI) in vehicles produced after January 1st 2001 must have equipment with sequential injection of gas.

Checking if meeting the requirements in terms of technical implementation of installation

Devices and equipment of natural gas vehicles must be installed so as to be within limits of vehicles overall dimensions, not to reduce possibility, to be protected from mechanical damage that may occur in exploitation, and to be accessible for the purpose of checking their functionality and impermeability, and checking their identification marks. At the same time, it is mandatory that installation requirements have been met, as defined under regulation UN ECE 110R, which is to be determined during this inspection.

The following is to be checked:

- Meeting of requirements for installation of cylinder and its equipment,
- Meeting of requirements for gas lines (high-pressure and low-pressure lines),
- Meeting of requirements for gas pressure reducer; and
- Meeting of requirements for other devices (valves, fuel fill connector, manometers and pressure indicators, electrical installations, gas dosing devices etc.).

Inspection of tightness of gas installation is done by using a detector sensitive to methane, where each leak of gas to atmosphere is the reason for making a conclusion that the vehicle is not safe for further exploitation.

Inspection of vehicle mass

Installation of devices and equipment for natural gas fuels changes the vehicle mass, thus requiring during inspection to determine the mass of vehicle with installed device and equipment. Vehicle mass may be determined by calculation if you have available information about exact mass of basic vehicle, mass of installed device and equipment and mass of gas with tank filled by maximum allowed operating pressure in the tank. If the authorized organization, having checked the relevant technical documentation or in any other way, has any doubt about accuracy of these data, the mass must be measured. The calculation, i.e. data on grounds of which the mass of modified vehicle has been determined, must be indicated in the report on testing/inspection of vehicle. In case of testing a freight vehicle for the purpose of determining the value of increased mass of vehicle ready for driving, it is necessary to reduce the load bearing capacity of vehicle. In case of buses, if necessary, the total number of places for standing and seated passengers should be determined by calculation. For that purpose, depending on the bus body form, you should use the instructions defined by regulations UN ECE 36R and UN ECE 52R.

Periodical inspection

Cylinders are designed and manufactured for a limited design life, which is indicated on the cylinder label. Always check the label first to ensure that the cylinder has not exceeded its expiration date.

Regulation UN ECE 110R prescribes the time schedule of periodical inspections of CNG cylinders every 48 months, from starting the servicing. In doing so, it is visually checked if there are mechanical, abrasive or chemical damages. This regulation recommends checking during technical inspection if there is a gas leak [5].

In the Republic of Serbia, periodical inspections of vehicles with CNG devices and equipment are done every four years.

Periodical inspection of CNG cylinders

Inspection of CNG cylinders is done in accordance with procedure defined by standard ISO 19078, and/or in accordance with the national standards of the state in which the vehicle and CNG equipment have been exploited.

If using during a cylinder periodical inspection the hydraulic pressure test, it is mandatory to use specially treated water (with inhibitors, without chlorine etc.). Also, it is recommended to have the cylinders exposed to inspection as little as possible in terms of time, and never to have the cylinders with regular water (but to treated water instead). The reason for that is in the corrosive effect of water to material out of which the cylinders are made (mostly aluminum alloy).

Periodical inspections are a safety measure for timely detection of damages of cylinders and cylinder supports. Inspections must be conducted with use of special tools (measuring tools for measuring length and debt of cracks, battery lamps and other). There are two types of inspections: general inspection and, as already indicated in the previous section, inspection by an authorized organization in which case there is also a suitable certificate issued, Table 3.

Table 3 Overview of procedures for periodical inspections of CNG cylinders and equipment

TYPE OF INSPECTION	DESCRIPTION OF INSPECTION	PERIOD
General inspection	Inspection is conducted by a driver, a mechanic or a technician working in a workshop. It includes visual inspection of condition of cylinder and its supports, as well as of pipelines for the purpose of determining if they are in good condition and properly fixed.	Recommended to have it every three months (recommendation of manufacturers of CNG cylinders and equipment)
Inspection by authorized institutions and issuing of Certificates (Certificate and /or attestation of correct installation of CNG device and equipment)	Inspection is conducted by a professional/expert with authorization of the relevant institution.	Every four years from starting its service life in accordance with the national regulations.

Marking of CNG fueled vehicles

The vehicles of M2 and M3 class fueled by (CNG) must have stickers as a visible indication that they use this type of natural gas fuel. The form and dimension of stickers have been defined by standard UN ECE 110R. Stickers are to be place in the front, rear and on the door exterior on the right side of vehicle.

SAFETY MEASURES DURING CHECK–UP AND TECHNICAL INSPECTION OF CNG VEHICLES

Flammability limits of fuel and air mixture are often called explosiveness limits so as to warn about severity of possible incidents. Below the flammability limits, the mixture is too lean and over it too rich for combustion. The flammability limits are often called lower and upper limit of flammability/explosiveness.

Gas leaking from the system installed on a vehicle during the check-up and technical inspection of vehicle may create an explosive mixture in work environment due to which it is necessary to provide the following:

- Take the measures for the purpose of prevention of gas leaking from vehicle system,
- Keep the flame sources far from the place where there is a chance of forming a flammable mixture,
- Surface of heating elements inside the facility must not have the temperature over 400 °C, it is forbidden to use open flame, electrical or gas heaters; and
- It is necessary to adopt and regularly practice the measures of safety at work and fire protection of facilities, as well as professional training of staff, etc.

Given that in case of leaking from vehicle system, (CNG) leaks upwards it should be observed that explosive mixture is created in upper zones of the room. On the other hand, the position of the area with explosive concentration highly depends on the type of the roof structure of facility. In case of no flat roof, the increased concentration is usually in the highest parts). The position of setting the probes of gas automatic detection and alarm system also depends on the type of roof structure.

On grounds of applicable U.S. regulations for example ventilation systems in workshops for maintenance of CNG buses should enable 5–6 air changes per hour in the room. Also, it requires the air change dynamics of 425 $l \cdot min^{-1}$ per $1 \cdot m^2$ for the ventilated areas. Given that the requirements for workshops are similar in case of diesel buses (must have ventilation system with 4–6 air changes per hour), it is conclusive that it is not necessary to change the

ventilation system, in case of adaptation of existing facility so as to be used to work with CNG vehicles as well, thus there are no additional costs of maintenance. The relevant regulations also recommend to equip such facilities with so called roller doors that open faster than the standard ones so that in case of accidental gas leak it enables additional ventilation of facility in a natural way [14].

Electric equipment of facility for servicing CNG vehicles, such as switches, sockets, lighting devices, motors, should have a certain degree of explosion protection.

Contrary to the previously given instructions, e.g. when doing the LPG vehicle check-up and technical inspection, the facilities should be provided with as good as possible ventilation in the floor area of facility, especially in the zones where pits for repair or inspection of vehicles are, etc.

In general, the basic warnings which apply in cases of gas leakage accidents from vehicles and basic requirements and safety measures for facility are briefly listed in the Table 4 below.

Table 4 Warnings in case of gas leakage and preventive measures

TYPE OF GAS – FUEL	CNG	LPG
Warnings in case of gas leakage	Gas concentration is up!!	Gas concentration is down!!
Basic requirements and preventive safety measures for facility	– Good ventilation of ceiling-roof zone – Elimination of flame source above vehicle – Staff safety training for working with CNG vehicles	– Good ventilation of floor-pit zone – Elimination of flame source near floor – Staff safety training for working with LPG vehicles

General conditions and recommendations for working with cylinders and equipment for CNG

When handling the cylinders and equipment on vehicles fueled by CNG it is necessary to adhere to the following measures and instructions for the purpose of improving safety.

1. Ensure that all mounting blocks, brackets and other components are in good condition and properly secured. If any mountings are loose, re-tightened them by procedures specified by the fuel system manufacturer. If a mounting is damaged, need to be conducting a re-certification inspection.

2. Use suitable tools:
   - Use the tool recommended by manufacturer, if possible; and
   - Provide the relevant technical documentation of manufacturer before intervention.

3. Fuel system inspection includes checking all attached components, such as valves, tubing, end plugs, fittings and pressure-relief devices. During inspection, make sure that each device is securely attached. If any is loose, tighten it in accordance with the fuel system manufacturer's instructions:
   - Only trained staff may repair and inspect the cylinders and equipment for CNG; and
   - It is necessary to be familiar with functionality of parts of system for CNG on vehicles.

4. Eliminate potential flame sources:
   - No open flame or other heat sources; and
   - Disconnect electrical supply on vehicle; provide good grounding of facility for the purpose of preventing sparks and similar.

5. Never forget that parts of CNG system are under pressure:
   - Loosen the joints slowly due to discharge of gas under pressure, it is mandatory to tighten the joints with suitable torques according to recommendation of manufacturer (the torques are not the same for nuts when tightening the pipeline for the first time and in case when tightening the joint that was previously loosened).

6. Precautionary measures for potentially flammable mixture of natural gas and air:
   - Natural gas is flammable in air when the concentration is 4,4–15%,
   - It is forbidden to have service interventions, storing and transport of cylinders and equipment with potentially flammable mixture. Discharging of gas from cylinder is to be done according to instructions and technical documentation of manufacturer through a special connector; and
   - It is forbidden to connect to electric voltage any parts of device and equipment for CNG in which there is a potentially flammable mixture.

CONCLUSIONS

The issue that primarily refers to emission of particles resulted in reduced use of diesel buses and freight vehicles in downtown zones of cities in developed countries. It brought about intensive substituting of vehicles of public utility companies with vehicles powered by natural gas. As a consequence, there are over 26 million vehicles fueled by natural gas in the world today.

The growth of the number of vehicles fueled by natural gas has been followed in parallel by adopting new Regulations and Rulebooks regulating the issues in this field. From the aspect of safety and proper installation of natural gas equipment, the requirements to be met by vehicles fueled by CNG have been prescribed by two regulations: UN ECE 110R and UN ECE 115R. Thus, devices and equipment for vehicles fueled by gas must be installed in vehicles in accordance with requirements of applicable national and international regulations.

International and national regulations foresee periodical inspections of devices and equipment for vehicles fueled by natural gas. In the Republic of Serbia, there is a control check prescribed for the vehicles fueled by CNG that has to be conducted by an authorized institution every four years followed by a certificate being issued.

During checkups, technical inspections and servicing of CNG vehicles, the facilities should be provided with better ventilation in the zone of ceiling and roof, and it is mandatory to adhere to measures of safety at work for staff and fire protection for facilities.

ACKNOWLEDGMENTS

This paper is a result of the researches within the project TR35041 financed by the Ministry of Science and Technological development of the Republic of Serbia.

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