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SAFETY ENGINEERING & MANAGEMENT –
SCIENCE, INDUSTRY, EDUCATION (SEM-SIE 2023)

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SAFETY ENGINEERING & MANAGEMENT
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Conference Co-organisers:
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CONDITIONS FOR SAFE APPLICATION OF LIQUEFIED NATURAL GAS IN HEAVY-DUTY GARBAGE TRUCKS

Abstract: *When using alternative fuels in mobile systems, it is important to know that truck transport and shipping, as examples of transport modes, require a higher fuel energy density in the reservoirs. The physical and chemical properties of liquefied natural gas as an alternative fuel present some advantages (higher energy density, range of flammability, etc.). This paper systematizes the possibilities for the application of liquefied natural gas in mobile systems for transportation for longer distances.*

Keywords: emission, natural gas, safe transport, vehicles

INTRODUCTION

The increased amount of energy demand produces a large amount of greenhouse gases, specifically carbon dioxide emissions by the burning of fossil fuels, which ultimately causes global warming (Gil-Lopez & Verdu-Vazquez, 2021; Gnap & Dočkalik, 2021; Jhawar, 2022; Marotta et al., 2015).

In order to meet the proposed targets of the Paris Climate Agreement, multiple strategies are available to reduce emissions from transport. New technologies have been developed and applied to vehicles and their propulsion systems for higher fuel economy and lower raw emissions of toxic gasses (Livaniou & Papadopoulos, 2022; Milojević et al., 2023; Skrúcaný et al., 2018).

In countries such as Serbia (with a large river port, many tourist centres and the transportation of goods by trucks due to the connection with international companies, etc.), the demand for alternative fuels that are suitable for long distance applications is expected to remain high. Natural gas is a high-quality fuel available for propulsion systems. Currently, in Serbia, there are 878 natural gas-powered vehicles on the roads (792 passenger and light duty vehicles, 58 buses, and 28 medium and heavy-duty trucks). The fuel cost savings for owners of natural gas vehicles are higher, due to the difference between the cost of a cubic meter of natural gas and a litre of traditional fuels – petrol and diesel (Milojević, 2017).

The growing number of vehicles powered by natural gas required that new regulations and rulebooks regulating this field be adopted. The requirements related to the aspect of safety and functionality of installation of gas devices and equipment have been defined under the regulations UN ECE 110R and UN ECE 115R. Laws and by-laws applicable in Serbia for natural gas vehicles are the Law on Road Traffic Safety, the Rulebook on the Classification of Motor Vehicles and Trailers and Technical Conditions for Vehicles in Road Traffic, and Vehicle Testing Rulebook (Milojević et al., 2016).

LIQUEFIED NATURAL GAS AS FUEL IN HEAVY-DUTY VEHICLES

Liquefied natural gas (LNG) is predominantly 92-98% methane that has been liquefied by condensation at cryogenic temperatures. At atmospheric pressure, the condensation temperature of natural gas is about -162 °C. In the process of natural gas liquefication, its volume decreases approximately 600 times (Jhawar, 2022).

Another way to increase the energy of stored natural gas in vehicles is under higher pressure of 20 MPa onboard in cylinders as CNG (compressed natural gas), (Jurkovič et al., 2020; Lähde et al., 2021). In Serbia, natural gas was used for the first time in serially produced MAZ-BIK buses for the purpose of public transportation in Kragujevac, about which numerous studies were published (Milojević et al., 2018; Skrúcaný et al., 2019).

The autonomy equivalence of one litre of diesel oil is 5 litres of CNG, meaning that, concerning heavy vehicles, CNG is mainly recommended for urban fleets, with daily refuelling by night. LNG, by its liquid state, is the natural gas with a higher energy density, needing only a volume of 1.8 litres to give the same autonomy as one litre of diesel fuel. This significant characteristic opens the way for the medium- and long-distance road transport using LNG (Jurkovič et al., 2020; Zhao et al. 2021; Pavlović et al., 2021).

Gas engine power supply system

Natural gas as fuel for 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.

Figure 1 shows the main components that are added to vehicles when an LNG conversion kit is installed. Diesel blend system makes it possible to convert diesel engines to dual-fuel operation by substituting cleaner and cheaper LNG for some of the diesel fuel that would normally be injected into the engine. In principle, this system is suitable for all diesel engines.

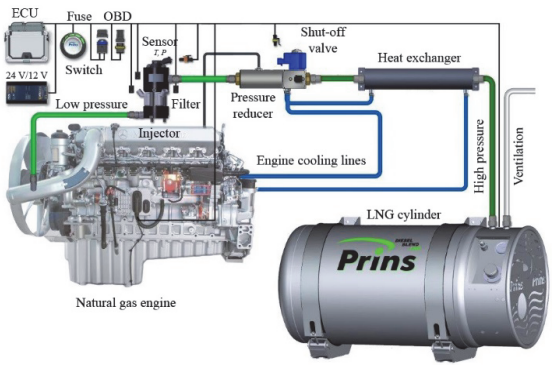

Figure 1. *Components for LNG diesel blend dual-fuel system*

Figure 2 shows the position of the installed devices and equipment on a heavy-duty truck, with a natural gas (LNG) propulsion system.

LNG fuel tanks are made of aluminium alloy and covered with polyurethane foam thermal insulation with a thickness of about 50 mm. Such tanks not only maintain a low temperature (–162 °C), but also withstand overpressure up to 0.2 MPa.

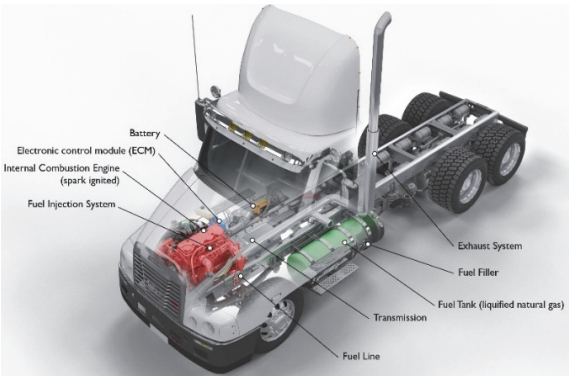

Figure 2. *Fuel system of an LNG truck*

Heavy-duty LNG vehicles work much like petrol-powered vehicles with a spark-ignited internal combustion engine. The natural gas is super-cooled and cryogenically stored in liquid form, usually in a tank on the side of the truck. LNG is typically a more expensive option than CNG and is most often used in heavy-duty vehicles to meet longer range requirements. Because it is a liquid, the energy density of LNG is greater than CNG, so more fuel can be stored on board the vehicle.

The main disadvantage of CNG power is the increased curb weight of the vehicle, which reduces its carrying capacity by the same amount.

The main disadvantage of LNG is the volatility of the gas and, as a result, its periodic venting into the atmosphere. This problem manifests itself only during long-term downtime of vehicles, and with its constant use, there are no gas losses.

REGULATIONS RELATED TO THE VEHICLES POWERED BY GAS

International Regulations

From the aspect of safety and proper installation of gas equipment, the requirements to be met by CNG and LNG vehicles have been prescribed within two ECE regulations (United Nations Economic Commission for Europe, 2011):

a) Regulation No. 110 (UN ECE 110R) – Uniform provisions concerning the approval of:

- specific components of motor vehicles using CNG and/or LNG in their propulsion system;
- Vehicles with regard to the installation of specific components of an approved type for the use of CNG and/or LNG in their propulsion system.

b) Regulation No. 115 (UN ECE 115R) – Uniform provisions concerning the approval of:

- specific retrofit systems to be installed in motor vehicles for the use of LPG in propulsion system;
- specific CNG retrofit systems to be installed in motor vehicles for the use of CNG in their propulsion system.

National Regulations

The following laws and by-laws apply to the vehicles in Serbia:

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

SAFE INSTALLATION OF LNG EQUIPMENT IN VEHICLES

On each tank, the manufacturer shall provide clear permanent markings not less than 6 mm high. Marking shall be made either by labels attached by adhesive or plates attached by welds. Each tank shall be marked as follows:

a) Mandatory information:

- “LNG ONLY”;
- manufacturer’s identification;
- tank identification (applicable part number and a serial number unique for every cylinder);
- working pressure and temperature;
- regulation number, along with tank type and certification registration number;
- the pressure relief devices or valves, qualified for use with the tank or the means for obtaining information on qualified fire protection systems;
- when labels are used, all tanks shall have a unique identification number stamped on an exposed metal surface to permit tracing in the event that the label is destroyed.

b) Non-mandatory information. On a separate label(s) the following non-mandatory information may be provided:

- gas temperature range;
- nominal water capacity of the tank to two significant numbers;
- date of original pressure test (month and year).

The markings shall be placed in the listed sequence but the specific arrangement may be varied to match the space available. An acceptable example of mandatory information is given in Table 1.

Table 1. *Example of mandatory information on an LNG tank plate*

LNG ONLY
Manufacturer/part number/serial number
1.6 MPa (16 bar) / (-162 °C)
ECE R 110 LNG (registration No. …)
Use only manufacturer approved pressure relief device

The LNG tanks shall be type approved, also with provisions on components fitted to the LNG tank. A system shall be provided for preventing the fuel tank from being overfilled.

The LNG tank shall be equipped at least with the following components, which may be either separate or combined (special care shall be taken to prevent LNG trapping):

- pressure relief valve;
- manual valve;
- automatic valve;
- excess flow device;
- the tank may be equipped with a gas-tight housing, if necessary.

The other LNG system components shown below shall be type approved:

- LNG heat exchanger – vaporizer;
- LNG filling receptacle;
- pressure control regulator;
- LNG pressure and/or temperature sensor/indicator;
- natural gas detector;
- automatic valve, check valve, the pressure relief valve, excess flow valve, manual valve and non-return valve;
- fuel pump and electronic control unit.

Installation of the LNG tanks

Every LNG tank shall be tested at a minimum pressure of 1.3 times (the working pressure plus 0.1 MPa). The tank shall be permanently installed in the vehicle and shall not be installed in the engine compartment. The tank shall be installed such that there is no metal-to-metal contact, with the exception of the fixing points of the tank(s). When the vehicle is ready for use, the fuel tank shall not be less than 200 mm above the road surface (Figure 2).

The fuel tank(s) shall be mounted and fixed so that the following accelerations can be absorbed (without damage occurring) when the tank(s) is full (Table 2).

Table 2. *Prescribed accelerations of the LNG tank*

Categories of Vehicles	M1 and N1	M2 and N2	M3 and N3
Accelerations in the direction of travel	$20 \cdot g$	$10 \cdot g$	$6.6 \cdot g$
Accelerations horizontally perpendicular to the direction of travel	$8 \cdot g$	$5 \cdot g$	

A calculation method can be used instead of practical testing if its equivalence can be demonstrated by the applicant for approval to the satisfaction of the Technical Service.

LNG component type approval mark

Figure 3 shows an example of approval mark affixed on the LNG component.

Figure 3. *Example of approval mark affixed on the LNG component caption*

The above approval mark affixed to the LNG component shows that this component has been approved in Italy (E 3), pursuant to Regulation No. 110 under approval number 042439 (United Nations Economic Commission for Europe, 2011). The first two digits of the approval number indicate that the approval was granted in accordance with the requirements of Regulation No. 110 as amended by the 04 series of amendments. The letter "L" indicates that the product is suitable for use with LNG. The letter "M" indicates that the product is suitable in moderate temperatures. The letter "C" indicates that the product is suitable in cold temperatures.

TECHNICAL INSPECTION OF LNG-POWERED VEHICLES

"Periodical technical inspection" means a periodical administrative uniform procedure by which the authorized technical inspection centres responsible for conducting the inspection tests declare, after carrying out the required verifications, that the wheeled vehicle submitted conforms to the requirements.

"International Technical Inspection Certificate" means a certificate about the first registration after manufacture and the periodical technical inspections of wheeled vehicles in compliance with the provisions.

"Wheeled vehicle" means motor vehicles of categories M_1, M_2, M_3, N_1, N_2, and N_3, as specified in Consolidated Resolution on the Construction of Vehicles (RE.3) (TRANS/WP.29/78/Rev.6, as amended), used in international transport.

Wheeled vehicles used in international transports shall satisfy the requirements set out below when they are fitted with LPG, LNG, or CNG engines according to UN Regulations Nos. 67, 110, 115, or 143 (Table 3).

Table 3. *Periodicity of technical inspection*

Categories of Vehicles	Maximum inspection intervals
✓ Passenger-carrying motor vehicles: M_1, except taxis and ambulances ✓ Goods vehicles: N_1	Four years after the first entry into service of the first registration and every two years thereafter
✓ [Taxis and ambulances] ✓ Passenger-carrying motor vehicles: M_2 above 3.500 kg and M_3 ✓ Goods vehicles: N_2 and N_3	One year after the first registration (or if the vehicle is not required to be registered, date of first use) and annually thereafter

"Verification" means the proof of compliance with the requirements set out in Table 4 through tests and checks carried out using techniques and equipment currently available, and without the use of tools to dismantle or remove any part of the vehicle.

For the purpose concerning the uniform conditions for periodical technical inspections of wheeled vehicles and the reciprocal recognition of such inspections, the items to be inspected are related to safety requirements of motor vehicles using CNG, LPG, and LNG in their propulsion system (Table 4).

The method of inspection shall be the minimum requirement. Where a method of inspection is given as visual, it means that in addition to looking at the items, the inspector can also handle them, evaluate noise, etc.

"Inappropriate repair or modification" means a repair or modification that adversely affects the road safety of the vehicle.

Recommendations for the main reasons for rejection are also given in the annex. The three criteria for assessment of defects are defined as follows:

- "Minor defects" (MiD) are technical defects that have no significant effect on the safety of the vehicle and other minor non-compliances. The vehicle does not have to be re-examined as it can reasonably be expected that the detected defects will be rectified without delay;
- "Major defects" (MaD) are defects that may prejudice the safety of the vehicle and/or put other road users at risk and other more significant non-compliances. Further use of the vehicle on the road without repair of the detected defects is not allowed although it still may be driven to a place for repair and afterwards to a specified location for the repair to be checked;
- "Dangerous defects" (DD) are defects that constitute a direct and immediate risk to road safety such that the vehicle should not be used on the road under any circumstances.

Table 4. *Minimum inspection requirements*

Item Method and Main reasons for rejection	Defect assessment		
	MiD	MaD	DD
Legal requirements; visual inspection; documentation Installation is not approved according to UN Reg. Nos. 67, 110, 115, or 143, etc.		X	
Fuel control command; visual inspection or by operation Operation not possible		X	
Not clear marking that may confuse the driver		X	
Ventilation housing and its ventilation pipes Visual inspection with the vehicle, on a hoist when appropriate Not adequately secured with risk of detachment, gas leakage or fire			X
Components missing, damaged, corroded, or not appropriated		X	
Blocked ventilation pipes			X
Other components of gas filling system: valves, pipes, injectors, etc. Visual inspection Discharge valves with blocked discharge holes			X
Pipes without an appropriate protection		X	
Electronic control unit Visual inspection Warning device malfunctioning			X
Warning device shows system malfunction			X
Leakage; Inspection and use of leak detecting devices Presence of gas			X
Marking; Visual control Marking and data plate or component marking not in accordance with the requirements		X	

CONCLUSION

In the future, more intensive use of environmentally cleaner alternative fuels is expected. In this regard, the paper presented the logistics of using liquefied natural gas as a fuel in garbage trucks.

The following three conclusions were made after the presented discussion:

1. Natural gas is a high-quality fuel for propulsion systems. Available reserves equal the known oil reserves; the negative influence upon the environment is lower than that of fuels derived from oil, as is the price. Therefore, natural gas as a fuel has been increasingly used in motor vehicles.
2. The advantage of using and storing natural gas in a liquid state in tanks on motor vehicles is reflected in the fact that in the process of natural gas liquefaction, its volume decreases by approximately 600 times. Consequently, using liquefied natural gas as fuel, it is possible to cover approximately the same distance in kilometres with a single filling of the tank as with diesel-powered vehicles.
3. From the aspect of safety and proper installation of gas equipment, the requirements to be met by CNG and LNG vehicles have been prescribed within ECE Regulation No. 110 (UN ECE 110R).

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