

TECHNICAL REQUIREMENTS AND METHODS OF TESTING RETROFIT LPG SYSTEMS FOR MOTOR VEHICLES IN ACCORDANCE WITH THE UN / ECE 115 REGULATION

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Abstract

The UN / ECE 115 Regulation concerns technical requirements and methods of measurements for retrofit LPG systems to be installed in the motor vehicles already in operation

In Poland, the 115 Regulation was adopted in 2004 but has not been observed. Regulation 115 is used in other countries, which created the need for tests.

ITS has been conducted tests according to R115 since 2006. The technical requirements imposed by 115 Regulation include emission test, OBD testing, testing of maximum power at the wheels and testing the methods of the system elements installation in the vehicle. The article presents the requirements of the Regulation and the conclusions of the tests conducted at ITS on over 100 vehicles equipped with LPG systems. The paper presents: vehicle equipped with LPG systems tested at ITS as part of the statutory ITS work, time of switching over from running on petrol to LPG fuel during the driving test following a cold engine start, onset of the emission during the EUDC test following a cold start in respect to the value of the total emission in the emission test in accordance with the Regulation 83.05 during the first 780 seconds of the driving test, registered signals controlling the operation of the petrol and LPG injectors operation in the engine of a spark ignition and direct petrol injection, operating in the gas mode with a periodical switch over of the supply type, an example of determining power criterion for the family of vehicles.

Keywords: *air pollution, environmental protection, LPG*

1. Introduction

Condition for the introduction in service of the new bi-fuel and dual fuel vehicles, fuelled with petrol and LPG are laid down in the type-approval regulation. Such a vehicle has to undergo the emission tests, noise tests, and the examination of the installation LPG components, in accordance with the detailed procedures contained in the UN / ECE Regulations or EU Directives. The scope of tests is determined in Europe by the EU 2007/46 Framework Directive. Therefore the manufacturer of the bi-fuel vehicle powered by gas fuel is obliged to have it subjected to a typical type approval tests as far as appropriate regulations require. It is a factor contributing to maintaining good quality of components, optimising the methods of installation and assuring the safety as well as reliability of operation characteristic to the new vehicles.

The vehicles manufactures have not been interested in production of the vehicles powered by LPG. This gap has been filled by the independent manufacturers of the gas systems through which the growth of the market of the systems adapting vehicles to run on the gas fuels encompasses the market of used, and not, new cars. For this reason the vehicles type-approved as bi-fuel represent in Europe a small margin of the cars powered by LPG.

To ensure an acceptable safety level of the operation of the LPG systems installed in the vehicles being operated, the individual countries have introduced internal regulations.

In Poland the regulations concerning technical requirements for the vehicles adopted to run on LPG are contained in the Annex 9 to a Decree of the Infrastructure Minister issued on 31 December 2002 (J. of L. nr 32 pos. 262). There is also a system of registering the adapted vehicles based on the type-approval certificates for the methods of the installation, granted to the

distributors upon the Decree of the Infrastructure Minister issued on 24 December 2003 (J. of L. nr 232 pos. 2333).

The market of the LPG powered vehicles has been growing under the catchy slogan of beneficial influence of the LPG system use on the emission from the exhausts system, but the tests carried out at ITS on two selected low emission vehicles EURO 2 and EURO 3 did not support that claim. As part of the research project the selected LPG systems have been subjected to tests, on the chassis dynamometer, of the emission from the exhaust system. The system has been installed in the vehicles under workshop conditions. The results have shown that the installation of the LPG systems carried out under workshop conditions negatively affects the emission of the limited components of the exhausts, such as carbon monoxide (CO), hydrocarbons (CH) and nitrogen oxides (NO_x) [2, 3].



Fig. 1. Vehicle equipped with LPG systems tested at ITS as part of the statutory ITS work

The comparison tests of the emission properties of the vehicles adapted to run on the LPG fuel conducted by other laboratories confirm the results obtained at ITS. The conclusions from the tests have become a basis to demand from the systems manufacturers to improve the emission properties. The UN / ECE 115 Regulation [1], has become a proposal for unifying the technical requirements as well as testing methods, whose first version was introduced on 30 October 2003. Since then, it has been systematically modified. At present the Appendix 4 is in force since its introduction on 19 August 2010.

In Poland the regulation has been quoted in the Government Statement on 10 February 2004 (J. of L. nr 112, pos. 1185). The application of the Regulation 115 in Poland has been limited by the absence of the executory regulations. Thus it is possible to conduct tests and issue the certificates of type approval according to the Regulation 115, while the type approval certificate has at present no use in Poland.

The subject of the Regulation 115 is type approval of the retrofit LPG or CNG fuel system in the vehicles and combustion engines regarding the emission of the limited exhausts components, OBD testing, testing maximum power, carbon dioxide emission and verification of the installation methods in view of the vehicle operation safety.

Due to varied specifics of the tests of the objects covered by the Regulation 115 this article will discuss only its part concerning tests of the vehicles equipped with combustion engines with the spark ignition powered by petrol and adapted to run on LPG fuel.

2. The UN / ECE 115 Regulations

The Regulation 115 refers only to vehicles originally powered by petrol, homologated as new with the emission level starting from EURO 3. It does not cover the vehicles homologated in other type approval systems e.g. the American one.

The type approval, according to the Regulation 115 serves to determine the properties of the complete gas supply system, installed in the vehicle or vehicles subject to tests. A set of system components forming the approved LPG installation kit is determined based on the conducted tests.

Based on the data of the vehicle being tested the „family of vehicles” is created, which determines the scope of the use of the given system in the group of vehicles meeting the criteria of being recognised as the member of the family of vehicles.

The Regulation concerns the modification of the vehicles, to supply them with the gas fuel, carried out by the entities independent of the vehicle manufacturer without the need to obtain consent from the manufacturer of the object subject to adaptation.

The Regulation does not determine the procedures of inspecting those vehicles in their operation or the procedures of registering the vehicles adapted to run on gas fuels.

2.1. Classification of the LPG systems

The Regulation 115 differentiates the gas supply systems as master-slave and independent ones. The essence of the master-slave system is the use of the petrol injection control system adopted by the vehicle manufacturer, to control the LPG injection, and thus optimised to supply a given engine with petrol. The independent systems in turn meter the gas fuel based on their own control algorithms acting independently of the vehicle engine controller.

The Regulation 115 differentiates the requirements depending on the type of the system significantly facilitating the compliance with the requirements for the master-slave systems. The second distinction valid before the entry into force of the Amendment 3 consists of splitting the gas supply systems into “intrusive” and “non-intrusive”, it means systems that do not introduce any changes into the air and petrol supply system. The LPG injection systems are regarded as “non-intrusive” ones.

3. The scope of the requirements

The Regulation 115 contains requirement concerning:

- emission of the gas pollutants from the exhaust system,
- requirements for the OBD system operating during supplying the vehicle’s engine with the gas fuel,
- power output of the engine running on LPG,
- method of installing components of the gas system in the vehicle,
- the contents of the system installation instruction and the instruction for the user.

3.1. Testing the emission

According to the Regulation 115 it is mandatory to conduct tests of the gas pollutants emission from the exhaust system, such as: carbon monoxide (CO), hydrocarbons (CH) and nitrogen oxides (NO_x). The tests are conducted on the chassis dynamometer. Prior to the test the vehicle is conditioned in the chamber at a temperature between 20 and 30°C. The measurements of the emission are taken according to the procedure from Regulation 83 (type test I, emission test following the engine cold start). Checking the emission is done for the engine supplied with three reference fuels: petrol and two reference gas fuels defined as a mixture of „A” and mixture „B”, which differ with the proportion of propane and butane.

The measured emission of the limited exhausts components should meet the type approval requirements in accordance with the vehicle type-approval issued, i.e. for the emissions level defined in the vehicle’s type approval when running on petrol and each of both reference gas fuels. The measurement is taken three times for each fuel, unless the results obtained, meet the criteria of reducing the number of the measurements.

The LPG supply system is switched to the „gas mode” prior to the test, which means that during the emission tests the engine is started using petrol and then in the conditions set out by the system manufacturer, is being switched by the gas system controller to running on LPG fuel. Thus the measuring of the emission in the gas mode encompasses engine operation supplied with petrol and then following the switch over, running on the gas fuel.

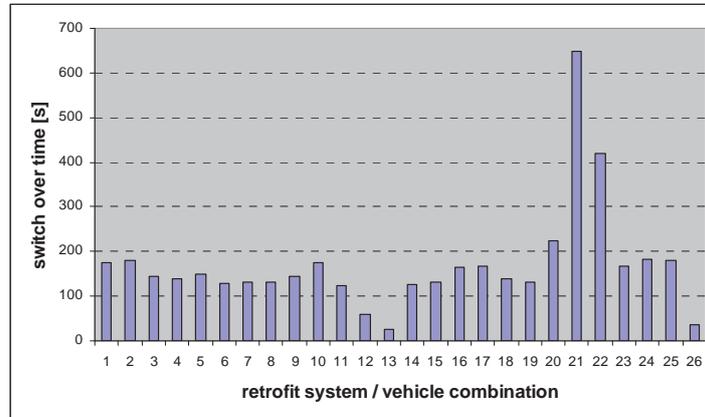


Fig. 1. Time of switching over from running on petrol to LPG fuel during the driving test following a cold engine start

The Fig. 1 presents the results of the registered switching over time to run on the gas fuel of the vehicles tested at ITS as part of the type approval in accordance with Regulation 115 with the Appendix 3. Typical time for operating on petrol was estimated at 150 seconds. During those first 150 seconds of operation, following the cold start, the tested vehicle emits about 90% of the emission of hydrocarbons, 80% carbon monoxides and about 35% of the emission of nitrogen oxides in respect to the emission during the test lasting in total 1180 seconds (Fig. 2).

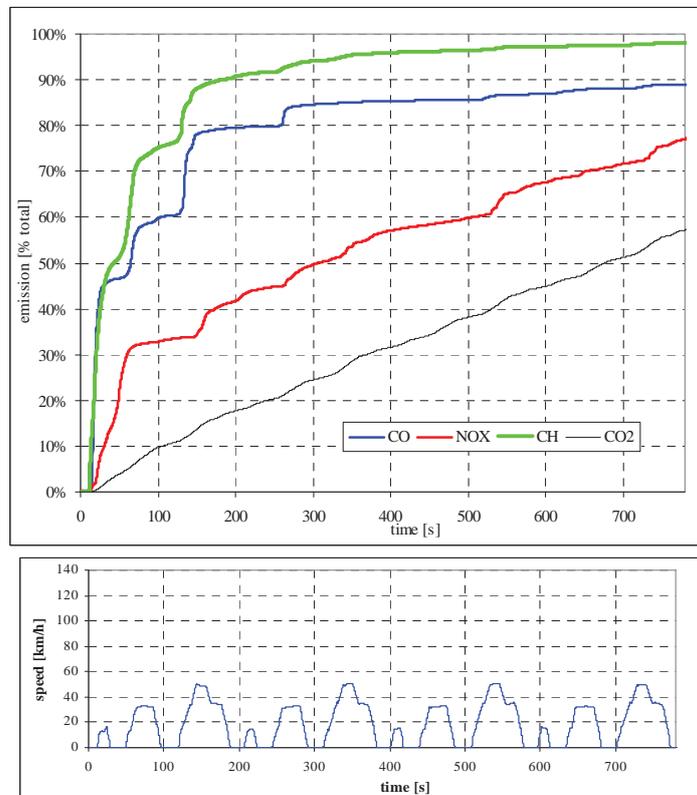


Fig.2. Onset of the emission during the EUDC test following a cold start in respect to the value of the total emission in the emission test in accordance with the Regulation 83.05 during the first 780 seconds of the driving test

In some infrequent cases the switching over took place significantly later, and even after more than 600 seconds, which means that switching over took place during a fourth, elementary cycle of the urban driving. In that case the engine, for over 50% of time of operating in the gas mode, was supplied with petrol. This created a significant assistance in conforming to the emission requirements, especially if the emission during the test from the vehicle running on petrol is considerably lower than the admissible value. In such circumstances the delay in switching over to running on LPG in the gas mode favours meeting the emission regulations of the Regulation 115, even if after switching over to run on the gas fuel the emission is many time higher than on petrol in the analogical conditions of the engine operation.

The Amendment 4 to the Regulation 115 introduced limitations to the operating time for running on petrol for the vehicles EURO 3 and EURO 4 to 90 seconds and up to 60 seconds for the EURO 5. Such formulated provision, on one hand de facto made it impossible to meet the emission requirements in the gas mode while running on petrol, and on the other introduced unjustified restrictions in respect to gas systems powering engines of direct petrol injection.

As far as the design is concerned the systems adapting the direct petrol injection engines to the gas fuel do not differ from the popularly used master-slave injection systems. The problem for this group of engines is cooling of the petrol injectors located in hot engine components, which if deprived of the flow of the cooling them fuel, gets damaged after short time of operation.

For this reason, during the operation in the gas mode, it is necessary to maintain the flow of petrol through the injectors. Because of the fact that the Regulation 115 does not take into consideration the possibility of the engine being supplied simultaneously with two fuels (petrol and LPG fuel), it is admissible to switch the supply from petrol to gas fuel for the whole engine. This is why in the already existing systems adapting the direct petrol injection engines to run on gas fuel, the controller of the LPG supply system controls the injecting of the gas fuel into the inlet manifold and periodically switches over to supplying with petrol all or successively selected cylinders. During the type approval process, the total time of running on petrol in the gas mode is determined based on registering the course of the electrical signals in the circuits controlling opening of the injectors. Fig. 3 depicts mode of controlling injectors in the tested engine operating in the gas mode, which periodically is supplied with petrol.

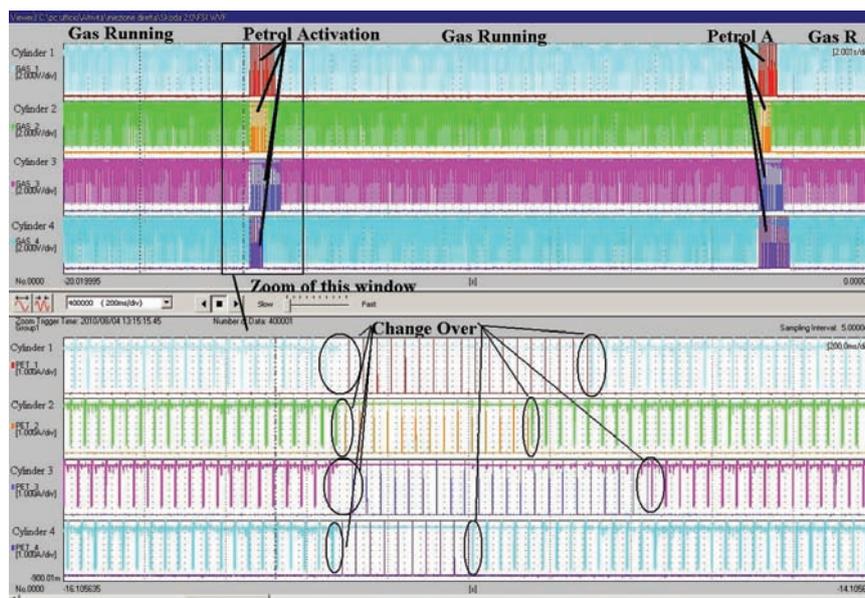


Fig.3. Registered signals controlling the operation of the petrol and LPG injectors operation in the engine of a spark ignition and direct petrol injection, operating in the gas mode with a periodical switch over of the supply type

In the currently operated vehicles with this type of system, the time of running on petrol in the

gas mode ensuring the adequate protection of the petrol injectors considerably exceeds quoted in the Regulation 115 threshold values (90 or 60 seconds). Therefore in case of adapting the engines with the direct petrol injection it is recommended to introduce an exception from the above requirement taking into account the specifics of this group of engines. It is important as the current use of direct petrol injection systems is common and the number of applications for homologation concerning this group of vehicles is expected to grow.

3.2. Testing OBD of the LPG fuel supply system

The Regulation 115 makes a distinction between the requirements concerning the OBD systems for the independent systems and master-slave ones. For the independent ones it makes a reference to the Appendix 11 of the Regulation 83, and thus poses demands on a par with the type approval. This means that the gas system controller has to perform procedures enabling the detection of the pollutants emission increase from the exhaust system based on the analysis of the signals from the sensors monitoring engine, in a similar fashion as the petrol supply system. The author of this article is not aware of any gas systems dedicated to installation in the used vehicles, which can meet the presented requirements [4].

For the master-slave system, the Regulation 115 defines separate requirements concerning OBD system of the LPG supply system, which are limited to checking if the original OBD system operates following the installation of the gas system while supplying the engine with petrol and gas fuel. Then next is checking the monitoring of the gas installation circuits continuity and systems reaction to installing faulty element of the gas system.

Soft requirements contained in the Regulation 115 in respect to the master-slave systems stem from the assumption that control functions of the ignition order, effectiveness of the catalytic convertor and damages to the lambda probe are dealt with by the factory system controlling petrol injection independently of the type of fuel, the engine runs on.

3.3. Testing engine power output

The Regulation 115 demands, for the maximum power output of the engine running on gas fuel, not to exceed by more than 5% the power of the engine running on petrol. The results of the comparison test conducted for the master-slave systems indicate rather decrease of the maximum power of the engine running on LPG by 1 to 7% in respect to the power obtained using petrol.

4. Family of vehicles

The scope for the application of the type approval certificate is defined by the list of vehicles in which it is possible to install the system under the certificate obtained. The basis of creating such a list represent data of the vehicles subjected to tests and verification criteria of the vehicle types for which the type-approval has been granted.

The Regulation 115 defines the following criteria of recognising the vehicle as a member of the family:

- the same vehicle manufacturer,
- emission level,
- engine maximum power output or the engine maximum power per single cylinder,
- process of supplying fuel and combustion,
- type of the system to reduce pollutants emission.

4.1. Criterion of the vehicle manufacturer

The family may include vehicles from the same manufacturer. The Regulation does not provide

the definition of the vehicle manufacturer which causes, that individual type approval bodies may vary as far as the interpretation of this provision is concerned, which in turn is visible in the analysis of the type approval certificates issued.

In Poland, as a manufacturer, is regarded a firm quoted in the complete vehicle type approval certificate. Thus Dacia and Renault or respectively Opel and Daewoo/Chevrolet do not meet that condition, despite the existence of capital connections. But the Daimler manufacturer encompasses such makes as Mercedes Benz, Smart and Maybach.

4.2. Emission level criterion

The emission category is understood as the emission level determined during the type approval process of a new vehicle powered by petrol. If the vehicle being tested according to the Regulation 115 was homologated as EURO 3, then the family covers only EURO 3 vehicles. If the vehicle tested has been homologated as EURO 4, then the family members can only be EURO 4 vehicles and those listed in the earlier series of the UN / ECE 83 Regulation, i.e. EURO 3. And by analogy, if the tested vehicles belonged to EURO 5, then the members of the family can include vehicles EURO 4 and EURO 3.

4.3. Power output criterion

There are LPG systems with the central metering unit for the whole engine and those equipped with individual devices metering separately for each cylinder.

In case of the LPG systems with the central metering unit for the whole engine the main criterion is power output. The condition for belonging to a given family is for a maximum engine power of a given vehicle to fall between 70% and 115% of the engine power of the tested vehicle. In order to widen the possibility for forming the family it is possible to run test on two cars (so called parent vehicles) and based on that widen the family by the vehicles, whose maximum power falls between the 70% of the engine power of the parent vehicle of a lower maximum engine power and 115% of the engine power of the parent vehicle of a higher maximum engine power.

In case of the system equipped with individual devices metering separately for each cylinder, the family criterion is maximum engine power per 1 cylinder. If the tests were conducted on one car, then the condition to belong to a given family is for a maximum engine power per one cylinder to fall between 70% and 115% of the power per cylinder of the tested vehicle. In case of testing two cars the power output range is from 70% maximum engine power of the parent vehicle of a lower power per cylinder, to 115% power per cylinder of the second tested parent vehicle. The Table 1 presents methods of determining power output criterion for the example of the vehicle family.

Tab. 1. An example of determining power criterion for the family of vehicles

Parameter	Unit	Vehicle tested	
Object of tests	[-]	X	Y
Engine power output	[kW]	77	147
Number of cylinders	[-]	4	4
Power per cylinder (P)	[kW/cyl]	19.25	36.75
70%P	[kW/cyl]	13.475	-
115%P	[kW/cyl]	-	42.2625
Power range per cylinder	[kW/cyl]	13.475 do 42.2625 kW/cylinder	

To obtain a possibility to widen the scope of type approval to an entire family of vehicles by a given manufacturer it is necessary usually to run a test with two parent vehicles. However, in case of testing one parent vehicle, larger possibility of creating family of vehicles exist for the

system equipped with individual devices metering separately for each cylinder.

4.4. Fuel supplying process and combustion process

The family of vehicles covers vehicles with the engines equipped with petrol injection system - direct or indirect and single or multi-point. Thus the engines of a direct injection form a different family than the engines with a petrol injection into the inlet manifold.

4.5. Pollutants emission reduction system

Regulation 115 divides the emission reduction systems into those equipped with: oxidising catalytic converter, multifunction catalytic converter, air injection and the exhaust gas recirculation system (EGR). If the vehicle subject to tests was not equipped with air injection and EGR, then the family of vehicles can be extended onto the vehicles which have those devices. The exception is the vehicles with the master-slave type of systems installed. In their case there is an exception from the rule made by extending homologation independently of whether there is or there is not an air injection system and EGR used. Because 100% of the homologated LPG systems meet the requirements of the master-slave system, then this exception is becoming a rule.

4.6. Extending the type-approval onto the vehicles of a different manufacturer

To belong to the family, can qualify vehicles produced by other manufacturer, if it can be proved that, they are equipped with the same type of engine and fuel supply system of the same injection configuration. This is a provision often used for extending the type approval, e.g. in the VW/Audi/Seat/Skoda group.

4.7. LPG supply system of a homologated type

The LPG supply system homologated in accordance with Regulation 115 has to contain certain elements affecting the system operation, such as: pressure regulator, gas fuel injector and controller. This set can be extended by other elements of the same manufacturer. This means, that as part of one type approval, there are elements that differ in design and not all of them have to be laboratory tested following their installation in the vehicle.

For example, the pressure regulators used, work on the engines of a maximum engine power defined by the manufacturer. This data is not being verified due to an absence of requirements as well as recognised methods of testing, enabling to corroborate the manufacturer provided data. This has particular significance, if the pressure regulator is tested on the four cylinder vehicle, and type approval is extended on to the eight cylinder engines, thus engines of a maximum power considerably exceeding the tested vehicle's engine.

The remaining elements such as, gas fuel tanks with the fittings, do not have any significance on the method of supplying the engine with the gas fuel and can be declared in unlimited numbers as part of the set being homologated, adhering to the installation conditions.

5. Conclusions

The scope for the application of the Regulation 115 is limited to EURO 3, EURO 4 and EURO 5 vehicles, homologated as new vehicles within the EU system. There is a significant percentage of older vehicles in operation, not complying with the EURO 3 requirements. There are also vehicles homologated according to the American standards and individually imported from the markets outside Europe, for which determining the emission level in accordance with the European regulations is difficult or impossible. If one assumes that it is allowed to have a system installed in any vehicle, as is the case now, then the application of the Regulation 115 in Poland

requires maintaining an alternative system, apart from that relying on the Regulation 115, of admitting, to be registered, of the vehicles adapted to run on the gas fuel.

The Regulation 115 poses before the car powered by a gas fuel, the requirements considerably easier to be met than the type approval regulations pose for the bi-fuel car type-approved as new. Type approval of the bi-fuel car in accordance with the Regulation 83 or appropriate Directive covers vehicles of a certain body shape, equipped with one type of engine. One type approval certificate issued according to Regulation 115 can cover hundreds of vehicles types meeting the criteria of the family of vehicles. Thus the scope of the certificate application in accordance with the Regulation 115 is considerably wider than the type approval certificates of the dual fuel vehicle.

Comparing the emission while running on petrol to the emission on LPG shows that when supplying the EURO 4 and EURO 5 low emission vehicle, the emission of the limited exhausts components has a growing tendency. However in the laboratory conditions majority of vehicles can be prepared in such a way so that they meet emission requirements defined in the Regulation 115. This however does not guarantee the conforming to the emission requirements in every vehicle adapted to run on gas fuel, within the type approval granted.

The Regulation 115 requires to be supplemented further due to not being adjusted to the progress in the gas supply systems. This especially concerns the systems used for the direct petrol injection engines.

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