

Submitted by the expert from Italy

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Agenda item 8)

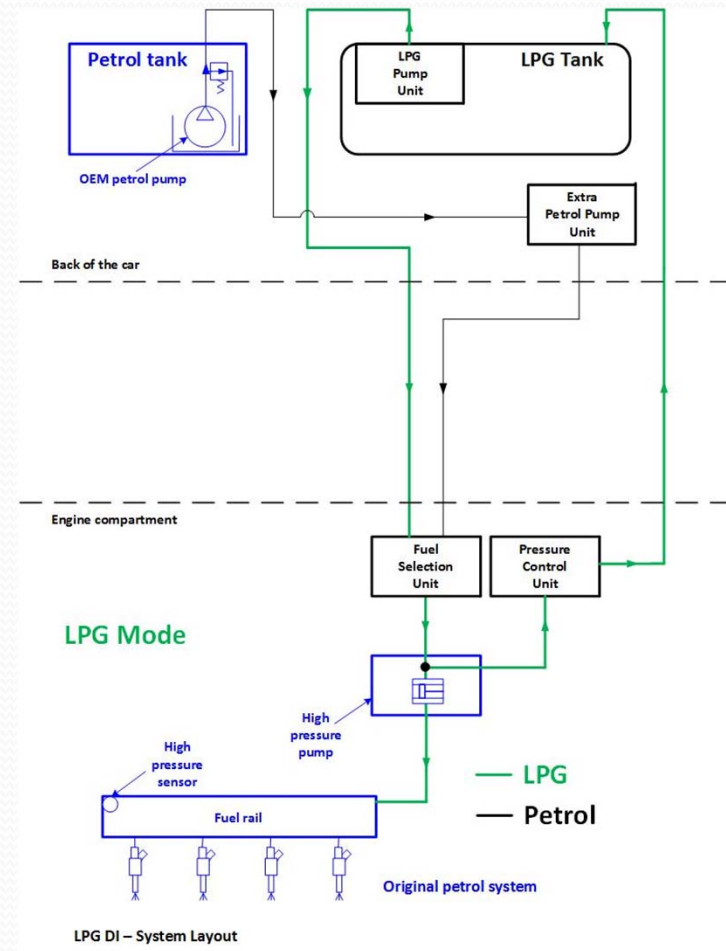
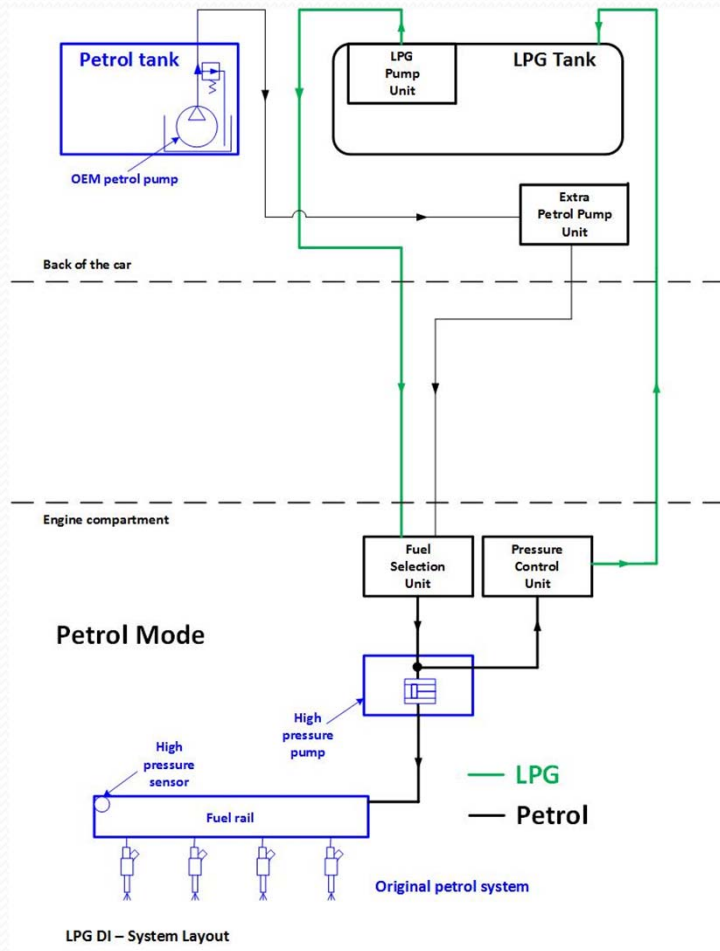
LPG Direct Injection

R67-01 Amendment

Agenda

- Presentation of the LPG Direct Injection technology
- Why petrol in the tank is not an issue
- Amendment proposal
- Clarified doubts

LPG DI Technology



LPG DI Technology

Here a brief introduction of the LPG Direct Injection Technology.

The system is based on the possibility to inject the LPG fuel directly in the combustion chamber, using HP pump and Injectors located in the cylinder head.

The LPG is injected in liquid phase and shall be maintained liquid from the tank to the HP pump, in order to allow the HP pump to work correctly and increase the LPG pressure in the fuel rail.

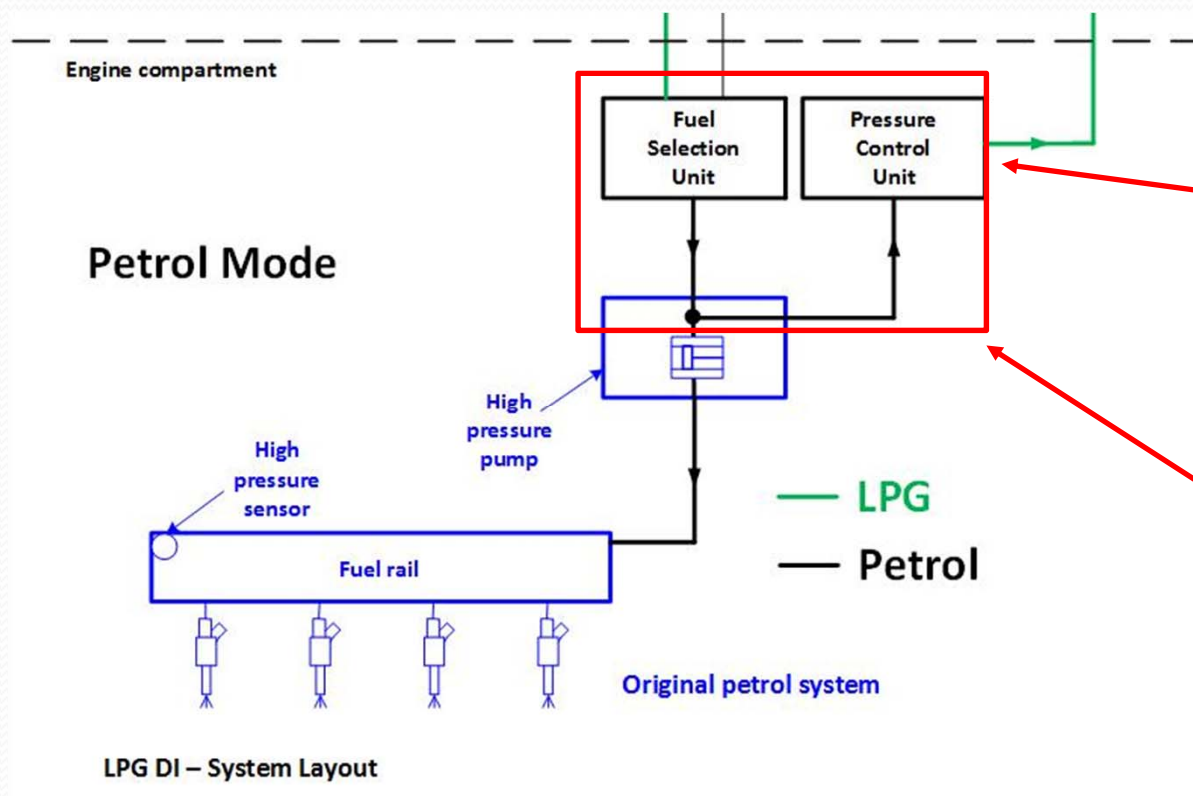
The presence of vapor phase at the inlet of the HP pump would determine that the pump itself will not work correctly.

In order to keep the LPG in liquid phase, considering that the engine bay is hot, circulation of LPG from the tank to the components in the engine bay and then back to the LPG tank is necessary.

This is managed with a tank LPG pump which pumps to the front of the vehicle a flow higher than that required by the engine, and the excess flow goes back to the tank, cooling the components and avoiding the vapor lock occurrence.

The fuel switch

From the tank To the tank



PCU include valves that enable the flow back to the LPG tank

Volume of petrol when the engine runs in petrol mode



The fuel switch

Considering that the system can be bifuel, a fuel switch from LPG to petrol and vice versa is needed.

In this kind of equipment the LPG system and the petrol one use the same HP pump and injectors. That means that the fuel switch shall be done through valves which allow one fuel or the other to reach the inlet of the HP pump.

During the switching phase the two fuels are blended in the volume contained from the Fuel Selector Unit to the Pressure Control Unit.

As already explained, the system needs a recirculation cooling flow which determines that a certain quantity of petrol will flow in the LPG tank.

The flow of petrol in the LPG tank occurs only during the switch phase.

LPG DI Advantages

| | | LPG Vapor PI | LPG DI |
|----------------------------|-----|--------------|--------|
| Engine starts (201k km) | [#] | 55.500 | 55.500 |
| Time gasoline/engine start | [s] | 60 | 0 |
| Time gasoline | [h] | 925 | 0 |

The injection of the LPG in liquid phase directly in the combustion chamber give a lot of advantages both vs. standard LPG port injected system, then vs. petrol DI.

The LPG DI system starts directly with LPG fuel, also in cold conditions.

This feature generates:

- An important reduction of the use of petrol if compared with a standard LPG vapor port injection system (see table)
- The possibility to reduce the emissions also during the engine crank and the cold phase

LPG DI Advantages

| Test | Fuel | CO ₂ | PM | PN |
|-------------------------------|----------|-----------------|---------------|---------------|
| [-] | [-] | [g/km] | [mg/km] | [#/km] |
| [-] | [-] | [-] | [% limit] | [% limit] |
| Average Petrol (2 best tests) | Petrol | 176,4 | 0,41 | 7,88E+11 |
| | | - | 8,2% | 131,3% |
| Average LPG (2 best tests) | LPG B85 | 157,6 | 0,11 | 1,08E+10 |
| | | - | 2,1% | 1,8% |
| LPG vs Petrol | - | -10,7% | -74,0% | -98,6% |

Thanks to the fast vaporization of the LPG, this technology solves the problem of particulate matter emission, which is a not negligible challenge for the petrol DI engines.

Petrol

LPG



Petrol in the LPG tank

Why Petrol in the LPG tank is not dangerous?

Since petrol blended in LPG determines a reduction of the vapor pressure, it does not affect tightness, design and burst pressure requirements and tests defined in R 67/01.

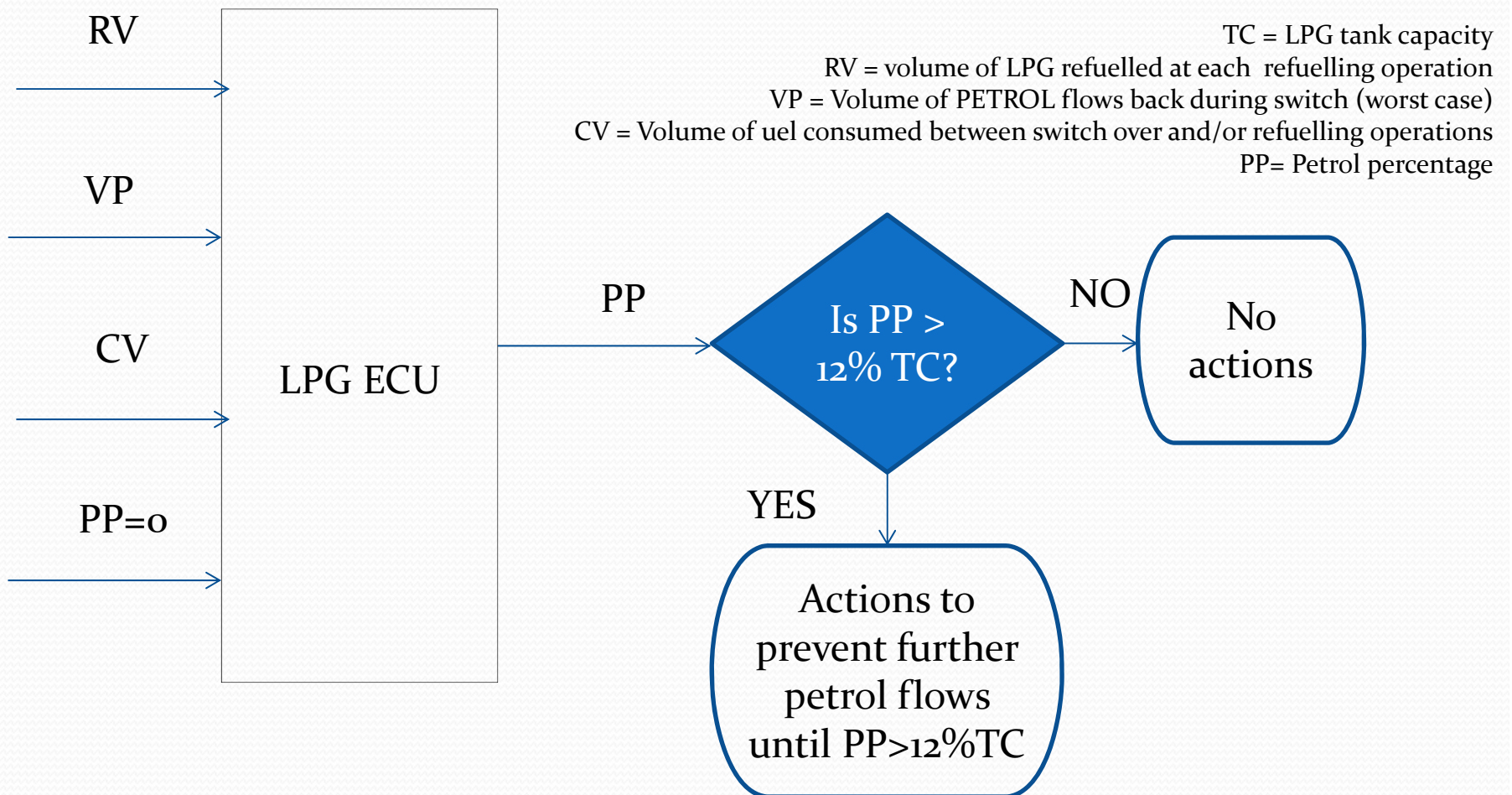
| | Petrol [%] | Propane [%] | T [K] | Vapor Pressure [MPa] |
|----------------|-------------------|--------------------|--------------|-----------------------------|
| Blend A | 100 | 0 | 300 | 7,80E-03 |
| Blend B | 0 | 100 | 300 | 0,996 |
| Blend C | 50 | 50 | 300 | 0,478 |

R67-01 Amendment

1. LPG in the petrol tank has a safety impact
→ Redundant devices shall be introduced to prevent it
2. Petrol in the LPG tank can have a safety impact if the fuel level overcome the 80%
→ The system shall be capable to avoid that the fuel level overcomes the 80%
3. Petrol in the LPG tank does not have impact if the fuel level is below 80%. Nevertheless, petrol blend must be kept under the percentage permitted by emission regulations
→ The system shall be capable to limit the quantity of petrol blended in LPG at a maximum value of 20% in energy unit (13% in volume of tank total capacity)

Doubts clarification

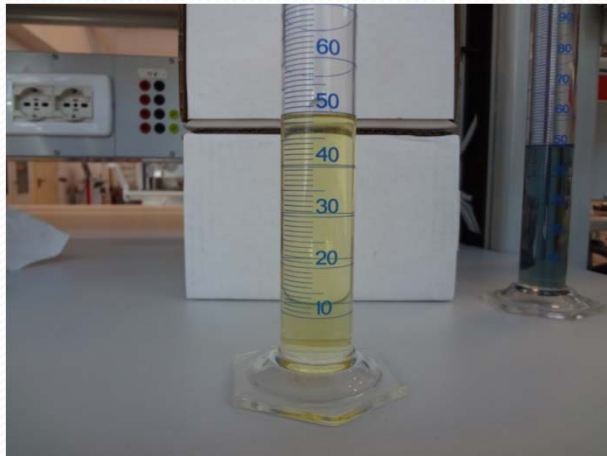
Petrol in LPG % management



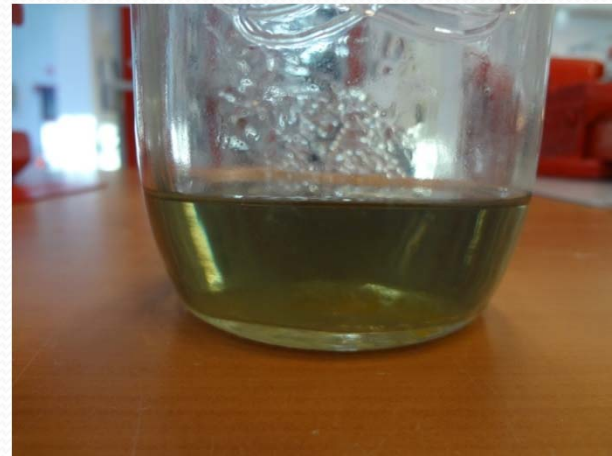
Doubts clarification

Petrol in LPG Miscibility

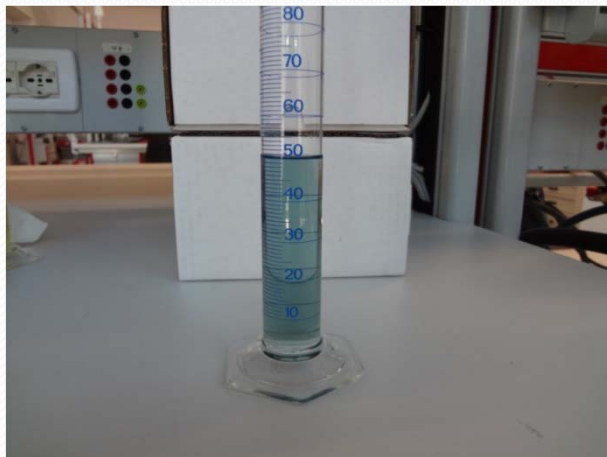
Pentane



Blend



Petrol



Theory:

- Miscibility (in all proportions) and solubility of two or more chemical substances (in this case in the same liquid phase) are based on their "chemical affinity" (intermolecular forces).
- LPG and petrol HC's miscibility/solubility is proven by the fact that petrol commonly contains dissolved LPG's (butane, isobutane, ...).

Experimental test:

- Pentane (close to LPG characteristics) is well miscible with Petrol.
- In the real application the continuous fuel recirculation helps the mixing.