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Proposal for safety guidelines for DME fuelling systems and their installation in vehicles

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Summary

Based on the European legislation for LPG equipment for automotive use and the installation of this equipment in vehicles (European regulation R67) a translation has been made for DME. Most of the LPG regulations can be used for DME also, although some changes have been made:

- maximum tank filling has been increased from 80% for LPG to 85% for DME because of the lower expansion of liquid DME when compared to Propane over the same temperature range;
- test pressures for DME parts are lowered because of the lower vapour pressure of DME when compared to Propane at the same temperature;
- the use of suitable materials for components and parts of components that are in contact with DME is emphasised since DME is a solvent and attacks most elastomers.

Furthermore it is recommended that:

- components that are designed and/or tested for DME are marked accordingly, in order to prevent "LPG components" to be used in DME applications;
- a special DME filling connection is designed and (preferable wordwide) adopted as a standard.

Contents

1 Introduction

DME is a possible alternative fuel for diesel engines. In its characteristics DME looks like LPG, although there are also differences. In order to have a good "starting point" for DME conversions of vehicles or other DME demonstration vehicle initiatives a safety investigation has been carried out. Based on the European legislation for LPG equipment for automotive use and the installation of this equipment (European regulation R67) a translation has been made for DME. This document intends to provide an overview of (European) regulations for LPG equipment and in-vehicle installation, the parallels to the use of DME in vehicles as well as the relevant differences.

Most important parallels are:
- Both fuels are gaseous at room temperature and have to be contained under pressure in order to remain in liquid phase.
- Both fuels are considered "alternative fuels", LPG as an alternative for Petrol, DME for Diesel.
- Both fuels have the potential to reduce tailpipe emissions.

Important differences are:
- LPG is commonly used in Spark Ignition (SI or Otto) engines where DME is used in Compression Ignition (CI or Diesel) engines.
- Because of its use in Diesel engines DME has to be pressurised to much higher pressures than LPG.
- DME is a solvent and attacks most elastomers, therefore the design of equipment for DME is somewhat more difficult than for LPG since there is fewer suitable material to chose from.

This leads to the conclusion that a lot of the regulations that are now applicable to LPG equipment and its installation in a vehicle can also be used for DME. This is especially true for the fuel container and refilling equipment. For the equipment "under the hood", i.e. the injection system, the LPG regulations are inadequate for DME. For the high pressure parts of the equipment it may be better to draw a parallel to regulations on compressed natural gas equipment since the pressures are in the same order of magnitude.

2 Definitions and classification

DME components for use in vehicles shall be classified with regard to the maximum operating pressure and function.

Class 1 High pressure parts including tubes and fittings containing liquid DME at vapour pressure or increased vapour pressure up to 2,300 kPa (LPG: 3,000 kPa).

Class 2 Low pressure parts including tubes and fittings containing vaporised DME with a maximum operating pressure below 450 kPa and over 20 kPa above atmospheric pressure.

Class 3 Shut-off valves and pressure relief valves, when operating in the liquid phase.

A component can consist of several parts, each part classified in his own class with regard to maximum operating pressure and function.

"Pressure" means relative pressure or overpressure, unless otherwise stated.

"Operating pressure" means the pressure under normal operating conditions.

"Maximum operating pressure" means the maximum pressure in a component which might arise during operation.

"Classification pressure" means the maximum allowable operating pressure in a component according to its classification.

“Specific equipment” means all parts of a vehicle that are specific for the fact that this vehicle is running on DME.

"Container" means any vessel used for the storage of DME.

“Accessories fitted to the container" means the following equipment which may be either separate or combined:

"85 per cent stop valve" means a device that limits the filling at maximum 85 per cent of the capacity of the container (LPG: 80%),
"Level indicator" means a device to verify the level of liquid in the container,
"Pressure relief valve (discharge valve)" means a device to limit the pressure build-up in the container,
remotely controlled service valve with excess flow valve,
fuel pump,
multivalve,

"Gas-tight housing" means a device to protect the accessories and to vent any leakage's to the open air,
power supply bushing (fuel pump/actuators),
non-return valve.

"Remotely controlled service valve with excess flow valve" means a device which allows the establishment and interruption of DME supply to the high pressure pump/ fuel injection equipment; remotely controlled means that the service valve is controlled by the electronic control unit; when the engine of the vehicle is not running the valve is closed; an excess flow valve means a device to limit the flow of DME;

"Fuel pump" means a device to establish the supply of liquid DME to the engine by increasing the pressure of the container with the fuel pump supply pressure;

"Multivalve" means a device consisting of all or part of the accessories mentioned under "Accessories fitted to the container";

"Filling unit" means a device to allow filling of the container; the filling unit can be realised by integration in the 85% stop valve of the container or by a remote filling unit at the outside of the vehicle;

"Service coupling" means a coupling in the fuel line between the fuel container and the engine. If a monofuel vehicle is out of fuel the engine can be operated by means of a service fuel container which can be coupled to the service coupling.

3 Specifications regarding the various components of the DME equipment

3.1 General provisions

The specific equipment of vehicles using DME in their propulsion system shall function in a correct and safe way.

The materials of the equipment which are in contact with DME shall be compatible with it.

The installation of DME-equipment shall comply with relevant electromagnetic compatibility (E.M.C) requirements. European regulations for EMC-compatibility are laid down in directive 95/54/EEC.

3.2 Provisions regarding containers

The DME containers shall comply to the same regulations as LPG containers, except for the maximum tank filling percentage (85% versus 80% for LPG) and the test/ burst pressure (5,175 kPa versus 6,750 kPa for LPG). Next to that, all parts of the container that are in contact with DME shall be compatible with it.

The container shall be equipped with the following accessories, which may be either separate or combined (multivalve's):
- 85 per cent stop valve (LPG: 80%);
- Level indicator;
- Pressure relief valve (discharge valve);
- Remotely controlled service valve with excess flow valve;
- Non-return valve for the DME return flow.

The container must be equipped with a gas-tight housing for these accessories in case the container is mounted in a closed compartment. This gas tight housing shall be vented.

The container may be equipped with a power supply bushing for the sake of actuators/fuel pump.

The container may be equipped with a fuel pump inside the container.

The container as well as all components mounted onto the container shall be designed for proper operation in the temperature range of -20 to 65°C. All other specific equipment shall be designed for proper operation in the temperature range of -20 to 120°C.

All components shall comply to the provisions laid down in Annex A.

4 General design rules regarding components

4.1 Provisions regarding the 85% stop valve

- The connection between the float and the closing unit of the 85 per cent stop valve shall not be deformed under normal conditions of use.
- If the 85 per cent stop valve of the container comprises a float, the latter shall withstand an outside pressure of 5,175 kPa.
- The closing unit of the device that limits the filling, at maximum 85 per cent of the capacity of the container, shall withstand a pressure of 5,175 kPa. At the cut-off position, the filling rate at a differential pressure of 700 kPa shall not exceed 500 cm3/minute.
- When the 85 stop valve does not comprise any float, it shall not be possible to continue filling, after closing-off, at a rate exceeding 500 cm3/minute.
- The device shall bear a permanent marking, indicating the container-type for which it has been designed, diameter and angle, and if applicable mounting indication.

Electrical operated devices containing DME shall have, to prevent in case of fracture of the component, electric sparks on the surface of fracture
(i) insulated in a manner that no current is lead through DME containing parts
(ii) the electrical system of the device shall be isolated:
- from the body
- from the container for the fuel pump.

Isolation resistance shall be > 10 MΩ.

The electrical connections inside the boot and passengers compartment shall comply with insulation class IP 40 according to DIN 40050.

All other electrical connections shall comply with insulation class IP 54 according to DIN 40050.

The power supply bushing to establish an isolated and tight electrical connection shall be of a hermetic sealed type.

Specific provisions on valves activated by an electric/external (hydraulic, pneumatic) power:
In the case of activated by an electric/external power (e.g. 85 per cent stop valve, service valve, shut-off valves, non return valves, gas tube pressure relief valve, service coupling), those valves shall be in "closed" position when their power is switched off.

The power of the fuel pump shall be switched off when the electronic control unit becomes defective or loses power.

A component consisting of both high pressure and low pressure parts shall be so designed to prevent a pressure build up in the low pressure part above 2.25 times the maximum working pressure for which it has been tested. Components connected directly to the tank pressure shall be designed for the classification pressure of 2,300 kPa. Venting to the motor compartment or outside of the vehicle is not allowed.

The low pressure fuel-pump shall be so designed that the outlet pressure never exceeds 2,300 kPa, when there is e.g. blocking of the tubing or not opening of a shut-off valve. This can be realised by switching off the pump or by recirculating to the container.

4.2 Provisions regarding the gas tube relief valve

- The gas-tube pressure relief valve shall be so designed as to open at a pressure of 2,500 ± 200 kPa.
- The gas-tube pressure relief valve shall not have internal leakage up to 2,300 kPa.

4.3 Provisions regarding the pressure relief valve (discharge valve)

- The pressure relief valve shall be mounted inside the container in the gaseous zone.
- The pressure relief valve shall be so designed as to open at a pressure of 1,800 ± 200 kPa.
- The flow capacity of the pressure relief valve, determined with compressed air at a pressure which is 20 per cent higher than the normal operating-pressure must be at least:

  Q = 10.66 A 0.82, in which
  Q = m3/min. (air pressure 100 kPa absolute and 15°C).
  A = exterior surface of the container in m2.

- The pressure relief valve shall not have internal leakage up to 1,600 kPa.

At minimum fuel level whereby the engine is still operating the heat build-up by the fuel pump(s) should never cause the pressure relief valve to open.

The filling unit shall be equipped with at least one gas-tight non-return valve as well as a cap to prevent contamination.

The device to verify the level of liquid of the container shall be of an indirect type (for example magnetic) between the inside and outside of the container. If a direct type is used the electrical power connections should meet Class 1 specifications.

If the level indicator of the container comprises a float, the latter shall withstand an outside pressure of 2,300 kPa.

4.4 The gas-tight housing shall

- at least have one outlet with a total free cross-section of 450 mm2;
- be leak-proof at a pressure of 10 kPa with the aperture(s) closed off, maximum allowed leak rate of 100 cm3/h vapour and show no permanent deformation;
- be designed to withstand a pressure of 50 kPa.

4.5 Provisions regarding the service valve

- In case the service valve is combined with a fuel supply pump, identification of the pump must be realised by the marking "PUMP INSIDE" and the identification of the pump either on the marking plate of the container or on the multivalve if present. Electrical connections inside the container shall comply with insulation class IP 40 according to DIN 40050.
- The service valve shall withstand a pressure of 5,175 kPa in the open and closed position.
- The service valve shall not, at the shut-off position, allow an internal leak rate in the flow direction. There may be leak in the back flow direction.

4.6 Provisions regarding the excess flow valve

- The excess flow valve shall be mounted inside the container.
- The excess flow valve shall be designed with a bypass to allow for equalisation of pressures.
- The excess flow valve shall cut off at a pressure difference over the valve of 90 kPa. At this pressure difference the flow shall not exceed 8,000 cm3/min.
- When the excess flow valve is at cut-off position, the flow through the by-pass shall not exceed 500 cm3/min. at a differential pressure of 700 kPa.

5 Requirements for the installation of specific equipment for the use of DME in the propulsion system of a vehicle

5.1 General

The DME equipment as installed in the vehicle shall function in such a manner that the maximum operating pressure for which it has been designed and approved cannot be exceeded.

All parts of the system shall comply to the components specifications laid down in this document.

The materials used in the system shall be suitable for use with DME.

All parts of the system shall be fastened in a proper way.

The DME-system shall show no leaks.

The DME-system shall be installed such that is has the best possible protection against damage, such as damage due to moving vehicle components, collision, grit or due to the loading or unloading of the vehicle or the shifting of those loads.

All DME-system components shall be installed such that it is possible to inspect them and such that the identification markings may be read, with the exception of inspection of the fuel pump if it is installed in the fuel container. In that event the identification marking of the fuel pump shall be stamped on the identification plate of the container or on the multivalve if present. The fuel container shall have a marking that is clearly legible and indelible.

No appliances shall be connected to the DME-system other than those strictly required for the proper operation of the engine of the motor vehicle.

5.2 Further requirements

No component of the DME-system, including any protective materials which form part of such components, shall project beyond the outline of the vehicle, with the exception of the filling unit if this does not project more than 10 mm beyond its point of attachment.

With the exception of the DME fuel container, in no cross section of the vehicle any component of the DME-system, including any protective material which forms part of such components, may extend beyond the lower edge of the vehicle unless another part of the vehicle, within a radius of 150 mm is situated lower.

No component of the DME-system shall be located within 100 mm of the exhaust or similar heat source, unless such components are adequately shielded against heat.

5.3 Installation of the fuel container

The fuel container shall be permanently installed in the vehicle and shall not be installed in the engine compartment.

The fuel container shall be installed in the correct position, according to the instructions from the container manufacturer.

The fuel container shall be installed such that there is no metal to metal contact, other than at the permanent fixing points of the container.

The fuel container shall have permanent fixing points to secure it to the motor vehicle or the container shall be secured to the motor vehicle by a container frame and container straps.

When the vehicle is ready for use the fuel container shall not be less than 200 mm above the road surface unless the container is adequately protected, at the front and the sides and no part of the container is located lower than this protective structure.

The fuel container shall be secured to the motor vehicle in such a way that it can withstand for a minimum time of 30 ms a forward acceleration of [20 g] in case of vehicles with technically permissible maximum mass lower or equal to 3500 kg and of [10 g] in case of vehicles with technically permissible maximum mass higher than 3500 kg.
For the purpose of this test, the container shall be filled up to its maximum mass in running order and the measuring channel frequency class (CFC) shall be equal to 60, according to specifications of ISO 6487:1987. After the test the container shall not be separated from its support.
A reference to a static test can be accepted, as a resistance to a force directed forwards and equal to at least [20 times] the product of the gravitational force (g) and the mass of the filled-up container in case of vehicles with technically permissible maximum mass lower or equal to 3500 kg and at least [10 times] the product of the gravitational force (g) and the mass of the filled-up container in case of vehicles with technically permissible maximum mass higher than 3500 kg. The force shall be applied as rapidly as possible through the centre of gravity of the DME container and maintained for a period of at least 0.2 s.

If more than one DME container is connected to a single delivery tube each container shall be fitted with a non-return valve installed downstream of the remotely controlled service valve and a tube pressure relief valve shall be installed in the delivery tube, downstream of the non-return valve. An adequate filter system has to be placed upstream of the non-return valve(s) to prevent fouling of the non-return valve(s).

A non-return valve and tube pressure relief valve shall not be required if the backflow pressure of the remotely controlled service valve in the closed position exceeds 500 kPa. In that case the control of the remotely controlled service valves shall be constructed such that it is impossible for more than one remotely controlled valve to be open at any time. The overlap time to allow switching is limited to two minutes.

5.4 Container frame

The fuel container shall not be secured by cables (wire ropes).

The fuel container shall be secured to the container frame by at least two container straps.

If the container straps also carry the weight of the fuel container at least three container straps shall be provided.

The container straps shall ensure that the fuel container will not slide, rotate or be dislodged.

A protective material such as felt, leather or plastic shall be interposed between the fuel container and the container straps.

The container straps shall enclose the full or almost full circumference of the container, in so far as this is not enclosed by the container frame.

A fuel container secured to a motor vehicle by a container frame and container straps shall not move significantly if the container is subjected for a minimum time of 30 ms to a forward acceleration of [20 g] in case of vehicles with technically permissible maximum mass lower or equal to 3500 kg and of [10 g] in case of vehicles with technically permissible maximum mass higher than 3500 g.
For the purpose of this test the container shall be filled up to its maximum mass in running order and the measuring channel frequency class (CFC) shall be equal to 60, according to specifications of ISO 6487:1987. After the test the container shall not be separated from the container frame.
A reference to a static test can be accepted, as a resistance to a force directed forwards and equal to at least [20 times] the product of the gravitational force (g) and the mass of the filled-up container in case of vehicles with technically permissible maximum mass lower or equal to 3500 kg and at least [10 times] the product of the gravitational force (g) and the mass of the filled-up container in case of vehicles with technically permissible maximum mass higher than 3500 kg. The force shall be applied as rapidly as possible through the centre of gravity of the container and maintained for a period of at least 0.2 s.

The remotely controlled service valve with excess flow valve shall be installed directly on the fuel container, without any intervening fittings.

The remotely controlled service valve with excess flow valve shall be controlled such that it is automatically closed when the engine is not running, irrespective of the position of the ignition switch, and shall remain closed as long as the engine is not running.

The spring-loaded pressure relief valve shall be installed in the fuel container in such a manner that it is connected to the vapour space and can discharge to the surrounding atmosphere. The spring-loaded pressure relief valve may discharge into the gastight housing.

The automatic filling level limiter shall be suitable for the fuel container it is fitted to and shall be installed in the appropriate position to ensure that the container cannot be filled to more than 85% (LPG: 80%).

The level indicator shall be suitable for the fuel container it is fitted to and shall be installed in the appropriate position.

A gastight housing over the container fittings, which fulfils the requirements of the following paragraphs shall be fitted to the fuel container, unless the container is installed outside the vehicle and the container fittings are protected against dirt and water.

The gastight housing shall be in open connection with the atmosphere, where necessary through a connecting hose and a lead-through which shall be resistant against DME.

The ventilation opening of the gastight housing shall point downwards at the point of exit from the motor vehicle. However, it shall not discharge into a wheel arch, nor shall it be aimed at a heat source such as the exhaust.

Any connecting hose and lead-through in the bottom of the bodywork of the motor vehicle for ventilation of the gastight housing shall have a minimum clear opening of 450 mm2.

The housing over the container fittings and connecting hoses shall be gastight at a pressure of 10 kPa. When subjected to the test pressure, they shall not show any permanent deformations and never result in a leak.

The connecting hose shall be secured in a proper way to the gastight housing and the lead-through to ensure that a gastight joint is formed.

5.5 Tubes and hoses

Metallic gas tubes shall be secured such that they shall not be subjected to vibration of stresses.

Hoses and non-metallic tubes shall be secured such that they shall not be subjected to stresses.

At the fixing point the tube or hose shall be fitted with a protective material.

Tubes or hoses shall not be located at jacking points.

5.6 Connections between the components of the DME-system

Soldered or welded joints and bite-type compression joints are not permitted.

Stainless steel tubes shall only be joined by stainless steel fittings.

Copper tubes shall only be joined by fittings of corrosion-resistant material.

Tubes shall be connected by appropriate joints, for example, two-part compression joints in steel tubes and joints with olives tapered on both sides or two flanges in copper tubes. Gas tubes shall be connected with appropriate connections. Under no circumstances couplings may be used whereby the tube will be damaged. The burst pressure of the mounted couplings shall be the same or higher as specified for the tube.

The number of joints shall be limited to a minimum.

Any joints shall be made in locations where access is possible for inspection.

In a passenger compartment or enclosed luggage compartment the tube or hose shall be no longer than reasonably required. For this purposes a gas tube or hose which is no longer than reasonably required shall be a tube or hose which does not extend further than from the fuel container to the side of the vehicle.

There shall be no gas-conveying connections in the passenger compartment or enclosed luggage compartment with the exception of:

(i) the connections on the gastight housing; and

(ii) the connection between the gas tube or hose and the filling unit if this connection is fitted with a sleeve which is resistant against DME and any leaking gas will be discharged directly into the atmosphere.

The provisions of the previous two paragraphs shall not apply if the vehicle is a bus and the gas tubes or hoses and connections are fitted with a sleeve which is resistant against DME and which has an open connection to the atmosphere. The open end of the sleeve or ducting shall be situated at the lowest point.

5.7 Remotely controlled shut-off valve

A remotely controlled shut-off valve shall be installed in the tube from the fuel container to the fuel injection system, as close as possible to the fuel injection system.

The remotely controlled shut-off valve may be incorporated into the fuel injection system.

The remotely controlled shut-off valve, as well as the remotely controlled valve on the tank, shall be installed such that the fuel supply is cut off when the engine is switched off or stalls.

5.8 Filling unit

The filling unit shall be secured against rotation and shall be protected against dirt and water.

When the fuel container is installed in the passenger compartment or an enclosed (luggage) compartment, the filling unit shall be located at the outside of the vehicle.

5.9 Electrical installation

The electrical components of the DME-system shall be protected against overloads and at least one separate fuse shall be provided in the supply cable.

The fuse shall be installed in a known location where it can be reached without the use of tools.

The electrical power to DME-system components which also carry gas may not be conducted by a gas tube.

All electrical components installed in a part of the DME-system where the pressure exceeds 20 kPa shall be connected and insulated in a manner that no current is led through DME containing parts.

Electrical cables shall be adequately protected against damage. The electrical connections inside the boot and passengers compartment shall comply with insulation class IP 40 according to DIN 40050. All other electrical connections shall comply with insulation class IP 54 according to DIN 40050.

The electrical connections and components in the gastight housing shall be constructed such that no sparks are generated.

6 Explanation of the changes for DME when compared to LPG

In this document the 80% fill stop that is used in LPG vehicles is increased to 85% for DME. In chemical installations normally the same limits are applied for LPG and DME. When looking at the expansion of liquid LPG vs. DME this seems a safe option. Figure 1 shows the relative expansion of Propane, Butane and DME when heating it up from -20°C.

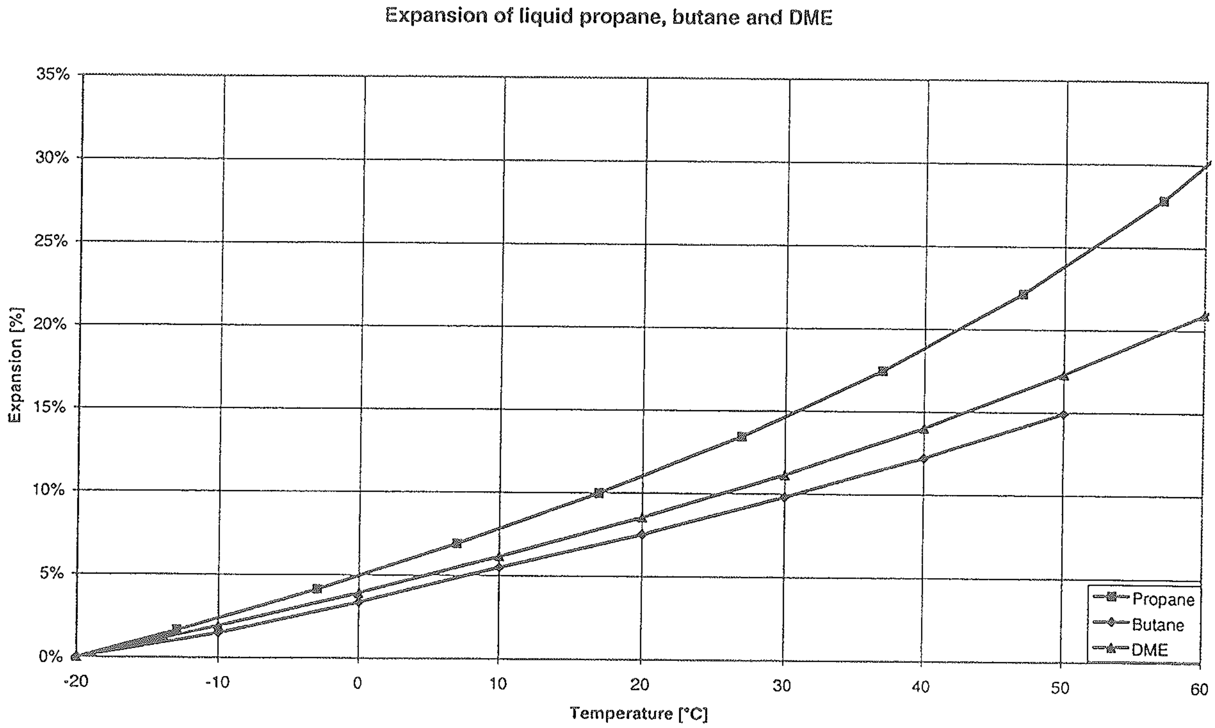

Figure 1: Expansion of liquid propane, butane and DME

As can be seen in the figure the expansion of liquid DME is less than Propane, but more than Butane. For the determination of the safety margin, necessary for LPG, Propane is used (being the worst case). The temperature range for this calculation is -20 up to 52°C. Propane expands 25% over this range, thus going from 80% to 100% filling. Over the same temperature range DME expands only 18%. Using this criterion it is safe to say that for DME an 85% fill stop can be used. In order not to propose stricter safety regulations for DME than necessary this 85% is used in this document.

Next important differences between the proposed legislation for DME in this document and the current European legislation for LPG are the test/burst

pressures. For LPG class 1 and 3 components are rated at 3,000 kPa, corresponding to ± 78 °C (propane). At this same temperature DME has a vapour pressure of approximately 2,300 kPa. Since there is a significant difference, applying the LPG pressures would make the DME equipment unnecessary big and heavy. For this reason the test and burst pressures of class 1 and 3 components have been reduced for DME in this document.
It is very important to realise that these lower pressures are safe for the current situation where DME storage systems are very similar to LPG systems. If this would change in the future, the test pressures for DME have to be re-evaluated.

Another point of attention is the filling unit to be used for DME. In order to prevent wrongly filling a DME vehicle with LPG or vice versa a special DME filling unit should be designed. Preferably this will become one world standard. If this world standard is the objective, now is the time to design and adopt it.

7 Conclusions / Recommendations:

- Use DME compatible materials.
- Mark all components for use with DME. Prevent "LPG components" to be used in DME applications.
- Design and adopt a special DME filling connection, preferably a world standard.

Appendix A Test procedures for the various components of a DME system

This annex describes the test procedures for the various components of a DME system. Because of the similarity of DME and LPG components these test procedures are copied from the European LPG Regulation without any modifications. Ofcourse in this Annex LPG must be read as DME, for the rest the procedures are believed to be applicable for DME components as well, except for:

- Class 2A. This class is considered not applicable for DME and should therefore be discarded.

- Test pressures. These pressures are different for DME (see chapter 6). The table below provides an overview.

pressures in [kPa]	LPG	DME
Classification pressure Class 1 & 3	3,000	2,300
Test pressure for over-pressure test Class1 & 3	6,750	5,175
Test pressure for leakage test Class 1 Class 3	 4,500 6,750	 3,450 5,175

Annex 15 1/

TEST PROCEDURES

1. **Classification**

1.1. LPG components for use in vehicles shall be classified with regard to the maximum operating pressure and function, according to Chapter 2 of this Regulation.

1.2 The classification of the components determines the tests which have to be performed for type approval of the components or parts of the components.

2. **Applicable test procedures**

In table 1 the applicable test procedures dependent on the classification are shown.

Table 1

Test	Class 1	Class 2(A)	Class 3	Paragraph
Overpressure	x	x	x	4.
External leakage	x	x	x	5.
High temperature	x	x	x	6.
Low temperature	x	x	x	7.
Seat leakage	x		x	8.
Endurance / Functional tests 1/	x		x	9.
Operational test 3/			x	10.
LPG compatibility 2/	x	x	x	11.
Corrosion resistance	x	x	x	12.
Resistance to dry heat	x			13.
Ozone ageing	x			14.
Creep 2/	x		x	15.
Temperature cycle 2/	x		x	16.

1/ For parts subjected to a functional test see paragraph 8 of this annex.
2/ Only applicable for non-metallic parts.
3/ Only applicable for parts mentioned in paragraph 8.

Class 1 and 3 components should withstand a pressure of 6,750 kPa and Class 2 a pressure of 1,015 kPa.

The materials used for the components shall have written specifications that fulfil at least or exceed the (test) requirements laid down in this document with respect to:
(i) temperature
(ii) pressure
(iii) LPG compatibility
(iv) durability

3. **General requirements**

3.1. Leakage tests shall have to be conducted with pressurized gas like air or nitrogen.

3.2. Water or another fluid may be used to obtain the required pressure for the hydrostatic strength test.

3.3. All test values shall indicate the type of test medium used, if applicable.

3.4. The test period for leakage- and hydrostatic strength-tests shall be not less than 1 minute.

3.5. All tests shall be performed at a room temperature of 20°C ± 5°C, unless otherwise stated.

4. **Overpressure test under hydraulic conditions**

A LPG containing component shall withstand without any visible evidence of rupture or permanent distortion a hydraulic test pressure which is determined by Table 1 (of 2.25 times the maximum classification pressure) during minimal 1 minute with the outlet of the high pressure part plugged.

The samples, previously subjected to the durability test of paragraph 7 are to be connected to a source of hydrostatic pressure. A positive shut-off valve and a pressure gauge, having a pressure of not less than 1.5 times nor more than 2 times the test pressure, are to be installed in the hydrostatic pressure supply piping.

Table 1 shows the classification pressure and the pressures to be used in the over-pressure test according to the classification:

Classification of component	Classification pressure [kPa]	Hydraulic test pressure for over-pressure test [kPa]
Class 1, 3	3,000	6,750
Class 2A	120	270
Class 2	450	1,015

5. **External leakage test**

5.1. A component shall be free from leakage through stem or body seals or other joints, and shall not show evidence of porosity in casting when tested as described in paragraph 5.2. at any aerostatic pressure between 0 and the pressure shown in table 2.

5.2. The test shall be performed at the following conditions:
(i) at room temperature
(ii) at the minimum operating temperature
(iii) at the maximum operating temperature

The maximum and minimum operating temperatures are given in the annexes.

5.3. During this test the equipment under test (EUT) will be connected to a source of aerostatic pressure (of 1.5 times the maximum classification pressure). A positive shut-off valve and a pressure gauge having a pressure range of not less than 1.5 times nor more than 2 times the test pressure are to be installed in the pressure supply piping. The pressure gauge is to be installed between the positive shut-off valve and the sample under test. While under the applied test pressure, the sample should be submerged in water to detect leakage or any other equivalent test method (flow measurement or pressure drop).

Table 2: the classification and leakage test pressures according to the classification:

Classification of component	Classification pressure [kPa]	Test pressure for leakage test [kPa]
Class 1	3,000	4,500
Class 2A	120	180
Class 2	450	675

Class 3	3,000	6,750

5.4. The external leakage must be lower than the requirements stated in the annexes or, if no requirements are mentioned, the external leakage shall be lower than 15 cm^3/hour with the outlet plugged, when submitted to a gas pressure equal to the leakage test pressure.

6. **High temperature test**

A LPG containing component shall not leak more than 15 cm^3/hour with the outlet plugged when submitted to a gas pressure at maximum operating temperature, as indicated in the annexes, equal to the leakage test pressure (Table 2, paragraph 5.3.). The component shall be conditioned for at least 8 hours at this temperature.

7. **Low temperature test**

A LPG containing component shall not leak more than 15 cm^3/hour with the outlet plugged when submitted to a gas pressure, at the minimum operating temperature (-20°C), equal to the leakage test pressure (Table 2, paragraph 5.3.). The component shall be conditioned for at least 8 hours at this temperature.

8. **Seat leakage test**

8.1. The following tests for seat leakage are to be conducted on samples of service valve or filling unit which have previously been subjected to the external leak test of paragraph 3 above.

8.1.1. Seat leakage tests are conducted with the inlet of the sample valve connected to a source of aerostatic pressure, the valve in the closed position, and with the outlet open. A positive shut-off valve and a pressure gauge having a pressure range of not less than 1.5 times nor more than 2 times the test pressure are to be installed in the pressure supply piping. The pressure gauge is to be installed between the positive shut-off valve and the sample under test. While under the applied test pressure, observations for leakage are to be made with the open outlet submerged in water unless otherwise indicated.

8.1.2. Conformance with paragraphs 8.2. and 8.3. of the Regulation is to be determined by connecting a length of tubing to the valve outlet. The open end of this outlet tube is to be located within an inverted graduated cylinder which is calibrated in cubic centimetres. The inverted cylinder is to be closed by a water seal. The apparatus is to be adjusted so that:

(1) the end of the outlet tube is located approximately 13 mm above the water level within the inverted graduated cylinder, and

(2) the water within and exterior to the graduated cylinder is at the same level. With these adjustments made, the water level within the graduated cylinder is to be recorded. With the valve in the closed position assumed as the result of normal operation, air or nitrogen at the specified test pressure is to be applied to the valve inlet for a test period of not less than 2 minutes. During this time, the vertical position of the graduated cylinder is to be adjusted, if necessary, to maintain the same water level within and exterior to it.

At the end of the test period and with the water within and exterior to the graduated cylinder at the same level, the level of water within the graduated cylinder is again recorded. From the change of volume within the graduated cylinder, the leakage rate is to be calculated according to the following formula:

$$V_l = V_t \cdot \frac{60}{t} \cdot \left(\frac{273}{T} \cdot \frac{P}{101.6}\right)$$

Where:

V_l = leakage rate, cubic centimetres of air or nitrogen per hour.

V_t = increase in volume within graduated cylinder during test.

t = time of test, minutes.

P = barometric pressure during test, in kPa.

T = ambient temperature during test, in K.

8.1.3. Instead of the method described above, leakage may be measured by a flowmeter installed on the inlet side of the valve under test. The flowmeter shall be capable of indicating accurately, for the test fluid employed, the maximum leakage flow rates permitted.

8.2. The seat of a shut-off valve, when in the closed position, shall be free from leakage at any aerostatic pressure between 0 to 3,000 kPa.

8.3. A non-return valve provided with a resilient seat, when in the closed position, shall not leak when subjected to any aerostatic pressure between 50 and 3,000 kPa.

8.4. A non-return valve provided with a metal-to-metal seat, when in the closed position, shall not leak at a rate exceeding 0.50 dm^3/hour of air when subjected to an inlet pressure up to the test pressure according to Table 2 in paragraph 5.3.

8.5. The seat of the upper non-return valve used in the assembly of a filling unit, when in the closed position, shall be free from leakage at any aerostatic pressure between 50 and 3,000 kPa.

8.6. The seat of a service coupling, when in the closed position, shall be free from leakage at any aerostatic pressure between 0 to 3,000 kPa.

8.7. The gas-tube pressure relief valve shall not have internal leakage up to 3,000 kPa.

8.8. The pressure relief valve (discharge valve) shall not have internal leakage up to 2,300 kPa.

9. **Endurance test**

9.1. A filling unit or service valve shall be capable of conforming to the applicable leakage test requirements of paragraphs 3.1. and 6.2., or 3.1. and 6.4., after being subjected to a number of cycles of opening and closing as mentioned in the annexes.

9.2. A shut-off valve is to be tested with the valve outlet plugged. The valve body filled with n-hexane, and the valve inlet subjected to a pressure of 3,000 kPa.

9.3. An endurance test is to be conducted at a rate not faster than 10 times per minute. For a shut-off valve, the closing torque is to be consistent with the size of handwheel, wrench, or other means employed to operate the valve.

9.4. The appropriate tests for external and seat leakage, as described under external leakage test under paragraph 3 and seat leakage test under paragraph 6 are to be conducted immediately following the endurance test.

10. **Operational tests**

10.1. **Operation test of the (gas-tube) pressure relief valve**

10.1.1. In the case of pressure relief valves, three samples of each size, design, and setting are to be used for start-to-discharge and resealing pressure tests. This same set of three valves is to be used for flow capacity tests for other observations indicated in the following paragraphs.

Not less than two successive start-to-discharge and resealing pressure observations are to be made on each of the three test valves under test No. 1 and 3 of paragraphs 10.1.2. and 10.1.4. below.

10.1.2. **Start-to-discharge and resealing pressures of pressure relief valves - test No. 1**

10.1.2.1. Before being subjected to a flow capacity test, the start-to-discharge pressure of each of three samples of a pressure relief valve of a specific size, design, and setting shall be within + 3 per cent of the average of the pressures, but the start-to-discharge pressure of any one of the three valves shall be not less than 95 per cent, not more than 105 per cent, of the set pressure marked on the valve.

10.1.2.2. The resealing pressure of a pressure relief valve before being subjected to a flow capacity test shall be not less than 90 per cent of the initially observed start-to-discharge pressure.

10.1.2.3. A pressure relief is to be connected to an air or other aerostatic supply source capable of being maintained at a pressure of at least 500 kPa effective pressure above the marked set pressure of the valve being tested. A positive shut-off valve and a pressure gauge having a pressure range such that the test pressure will be between 1 1/2 and 2 times the maximum scale reading of the gauge, are to be installed in the pressure supply piping. The pressure gauge is to be installed in the piping between the valve being tested and the positive shut-off valve. Start-to-discharge and resealing pressure are to be observed through a water seal not over 100 mm in depth.

10.1.2.4. After recording the start-to-discharge pressure of the valve, the pressure is to be increased sufficiently above the start-to-discharge pressure to ensure unseating of the valve. The shut-off valve is then to be closed tightly and the water seal, as well as the pressure gauge, are to be observed closely. The pressure at which bubbles through the water seal cease is to be recorded as the resealing pressure of the valve.

10.1.3. **Flow capacity of pressure relief valves - test No. 2**

10.1.3.1. The flow capacity of each of three samples of a pressure relief valve of a specific size, design, and setting shall fall within a range of 10 per cent of the highest observed capacity.

10.1.3.2. During flow capacity tests on each valve, there shall be no evidence of chattering or other abnormal operating condition.

10.1.3.3. The blow-down pressure of each valve shall be not less than 65 per cent of the initially recorded start-to-discharge pressure.

10.1.3.4. A flow capacity test on a pressure relief valve is to be conducted at a flow rating pressure of 120 per cent of the maximum set pressure.

10.1.3.5. A flow capacity test on a pressure relief valve is to be conducted by utilizing a properly designed and calibrated orifice flowmeter of the flange type connected to a source of air supply of adequate capacity and pressure. Modifications of the flowmeter from that described herein, and an aerostatic flow medium other than air, may be used provided the end results are the same.

10.1.3.6. The flowmeter is to be arranged with sufficiently long lengths of pipe both preceding and following the orifice, or other arrangements including straightening vanes, to assure no disturbance at the orifice place for the ratios of orifice to pipe diameters to be employed.

Flanges between which the orifice plate is located and clamped are to be provided with pressure take-off lines connected to a manometer. This instrument indicates the pressure differential across the orifice plate and the reading is used in the flow calculation. A calibrated pressure gauge is to be installed in that portion of the meter pipe downstream of the orifice plate. This gauge indicates the flow pressure and the reading is also used in the flow calculation.

10.1.3.7. A temperature-indicating instrument is to be connected to the meter pipe downstream of the orifice plate to indicate the temperature of the air flowing to the safety valve. The reading of this instrument is to be integrated in the calculation to correct the temperature of the air flow to a 15°C base temperature. A barometer is to be available for indicating the prevailing atmospheric pressure.

The reading of the barometer is to be added to the indicated air-flow gauge pressure. This absolute pressure is similarly to be integrated in the flow calculation. The air pressure to the flowmeter is to be controlled by a suitable valve installed in the air-supply piping ahead of the flowmeter. The pressure relief valve under test is to be connected to the discharge end of the flowmeter.

10.1.3.8. After all preparations for flow capacity tests have been made, the valve in the air-supply line is to be opened slowly and the pressure to the valve under test is to be increased to the appropriate flow rating pressure. During this interval, the pressure at which the valve "pops" open is to be recorded as the popping pressure.

10.1.3.9. The predetermined flow rating pressure is to be maintained constant for a brief interval until the readings of the instruments become stabilized. Readings of the flow pressure gauge, pressure differential manometer, and the flowing air temperature indicator are to be recorded simultaneously. The pressure is then to be decreased until there is no further discharge from the valve.

The pressure at which this occurs is to be recorded as the blow-down pressure of the valve.

10.1.3.10. From the recorded data and the known orifice coefficient of the flowmeter, the air-flow capacity of the pressure relief valve tested is to be calculated using the following formula:

$$Q = \frac{F_b \,.\, F_t \,.\, \sqrt{0.1 \,.\, h \,.\, p}}{60}$$

where:

Q = Flow capacity of pressure relief valve - in m^3/min. of air at 100 kPa absolute and 15°C.

F_b = Basic orifice factor of flowmeter at 100 kPa absolute and 15°C.

F_t = Flowing air temperature factor to convert recorded temperature to base of 15°C.

h = Differential pressure across orifice of meter in kPa.

p = Flowing air pressure to pressure relief valve - in kPa absolute (recorded gauge pressure plus recorded barometric pressure).

60 = Denominator to convert equation from m^3/hour to m^3/min.

10.1.3.11. The average flow capacity of the three pressure relief valves rounded off to the nearest five units is to be taken as the flow capacity of the valve of that specific size, design, and setting.

10.1.4. **Recheck start-to-discharge and resealing pressures of pressure-relief-valves test No. 3**

10.1.4.1. Subsequent to flow capacity tests, the start-to-discharge pressure of a pressure relief valve shall be not less than 85 per cent, and the resealing pressure shall be not less than 80 per cent of the initial start-to-discharge and resealing pressures recorded under test No. 1 of paragraph 10.1.2.

10.1.4.2. These tests are to be conducted approximately 1 hour after the flow capacity test, and the test procedure is to be the same as described under test No. 1 of paragraph 10.1.2.

10.2. **Operation test excess flow valve**

10.2.1. An excess flow valve shall operate at not more than 10 per cent above, nor less than 20 per cent below the rated closing flow capacity specified by the manufacturer, and shall close automatically at a pressure differential across the valve of not more than 100 kPa during the operation tests described below.

10.2.2. Three samples of each size and style of valve are to be subjected to these tests. A valve intended for use only with liquid is to be tested with water, otherwise the tests are to be made both with air and with water. Except as indicated in paragraph 10.2.3., separate tests are to be run with each sample installed in vertical, horizontal and inverted positions. The tests with air to be made without piping or other restriction connected to the outlet of the tests sample.

10.2.3. A valve intended for installation in one position only may be tested only in that position.

10.2.4. The test with air is to be conducted by utilizing a properly designed and calibrated orifice flowmeter of the flange type, connected to a source of air supply of adequate capacity and pressure.

10.2.5. The test sample is to be connected to the outlet of the flowmeter. A manometer or calibrated pressure-gauge reading in increments of not more than 3 kPa is to be installed on the upstream side of the test sample to indicate the closing pressure.

10.2.6. The test is conducted by slowly increasing the flow of air through the flowmeter until the check valve closes. At the instant of closing, the pressure differential across the flowmeter orifice and the closing pressure indicated by the gauge are to be recorded. The rate of flow at closing is then to be calculated.

10.2.7. Other types of flowmeters and a gas, other than air, may be used.

10.2.8. The test with water is to be conducted using a liquid flowmeter (or equivalent) installed in a piping system having sufficient pressure to provide the required flow. The system is to include an inlet piezometer or pipe at least one pipe size larger than the valve to be tested, with a flow control valve connected between the flowmeter and piezometer. A hose or hydrostatic relief valve, or both, may be used to reduce the effect of the pressure shock when the excess flow valve closes.

10.2.9. The test sample is to be connected to the outlet end of the piezometer. A manometer or calibrated pressure gauge of the retard type, which will permit readings in the range of 0 to 1,440 kPa is to be connected to a pressure take-off on the upstream side of the test sample to indicate the closing pressure. The connection is to be made using a length of rubber hose between the pressure gauge and the pressure take-off, with a valve installed at the gauge inlet to permit bleeding air from the system.

10.2.10. Prior to the test, the flow control valve is to be opened slightly, with the bleed valve at the pressure gauge open, to eliminate air from the system. The bleed valve is then to be closed and the test is conducted by slowly increasing the flow until the check valve closes. During the test the pressure gauge is to be positioned at the same level as the test sample. At the instant of closing, the rate of flow and closing pressure are to be recorded. When the excess flow valve is at cut-off position, the leakage or by-pass rate of flow is to be recorded.

10.2.11. An excess flow valve used in the assembly of a filling unit shall close automatically at a pressure differential of not more than 138 kPa when tested as described below.

10.2.12. Three samples of each size of valve are to be subjected to these tests. The tests are to be made with air, and separate tests are to be run with each sample mounted vertically and horizontally. The tests are to be conducted as described in paragraphs 8.2.4. to 8.2.7., with a filling unit hose coupling connected to the test sample and with the upper non-return valve held in the open position.

10.3. **Charging-speed-test**

10.3.1. The good function of the device limiting the filling degree of the container has to be performed by filling speeds of 20, 50 and 80 l/min.

10.4. **Endurance-test for the filling limiter**

The device limiting the filling degree of the container shall be capable of withstanding 6,000 complete filling cycles to the maximum filling degree.

10.5. **Vibration test procedure**

10.5.1. **Scope**

Any device limiting the filling degree of the container and operating by a float, after having been subjected to the tests verifying that:

It limits the degree of filling of the container to 80 per cent or less of its capacity;

It does not allow - at the cut-off position - any filling of the container at a rate exceeding 1 litre/minute,

shall be subjected to one of the test procedures laid down in paragraph 10.5.5. or 10.5.6. below to ensure that the device is constructed to withstand expected dynamic vibrational stresses and to ensure that performance degradations or malfunctions will not be produced by the service vibration environment.

10.5.2. **Equipment and mounting techniques**

The test item shall be attached to the vibration equipment by its normal mounting means, either directly to the vibration exciter or transition table, or by means of a rigid fixture capable of transmitting the specified vibration conditions. Equipment used to measure and/or record the acceleration level or amplitude level and the frequency shall have an accuracy of at least 10 per cent of the measured value.

10.5.3. **Choice of procedure**

At the choice of the authority granting type-approval the tests shall be performed according to either procedure A described in paragraph 10.5.5. or procedure B described in paragraph 10.5.6.

10.5.4. **General**

The following tests shall be carried out along each of the three orthogonal axes of the test item.

10.5.5. **Procedure A**

10.5.5.1. **Resonance search**

Resonant frequencies of the filling limiter shall be determined by varying the frequency of applied vibration slowly through the specified range at reduced test levels but with sufficient amplitude to excite the item. Sinusoidal resonance search may be performed using the test level and cycling time specified for the cycling test, provided the resonance search time is included in the required cycling test time of paragraph 10.5.5.3.

10.5.5.2. **Resonance dwell test**

The test item shall be vibrated for 30 minutes along each axis at the most severe resonant frequencies determined in paragraph 10.5.5.1. The test level shall be 1.5 g (14.7 m/sec^2). If more than four significant resonant frequencies are found for any one axis, the four most severe resonant frequencies shall be chosen for this test. If a change in the resonant frequency occurs during the test, its time of occurrence shall be recorded and immediately the frequency shall be adjusted to maintain the peak resonance condition. The final resonant frequency shall be recorded. The total dwell test time shall be included in the required cycling test time of paragraph 10.5.5.3.

10.5.5.3. **Sinusoidal cycling test**

The test item shall be sinusoidally vibrated for three hours along each of its orthogonal axes in accordance with:

an acceleration level of 1.5 g. (14.7 m/sec^2),

a frequency range of 5 to 200 Hz,

a sweep time of 12 minutes.

The frequency of applied vibration shall be swept over the specified range logarithmically.

The specified sweep time is that of an ascending plus a descending sweep.

10.5.6. **Procedure B**

10.5.6.1. The test shall be performed on a sinusoidal vibrating bench, at a constant acceleration of 1.5 g and at frequencies ranging between 5 and 200 Hz. The test shall last for 5 hours for each of the axes specified in paragraph 8.5.4. The frequency band 5-200 Hz shall be covered in each of the two senses in 15 minutes.

10.5.6.2. Alternatively, in case the test is not conducted by utilizing a constant acceleration bench, the frequency band from 5 to 200 Hz has to be subdivided in 11 semi-octave bands, each of them covered by a constant amplitude, so that the theoretical acceleration is included between 1 and 2 g (g = 9.8 m/sec^2).

Vibration amplitudes for each band are as follows:

Amplitude in mm (crest value)	Frequency in Hz (for acceleration = 1g)	Frequency in Hz (for acceleration = 2g)
10	5	7
5	7	10
2.50	10	14
1.25	14	20
0.60	20	29
0.30	29	41
0.15	41	57
0.08	57	79
0.04	79	111
0.02	111	157
0.01	157	222

Each band shall be covered in both directions in 2 minutes, 30 minutes totally for each band.

10.5.7. **Specification**

After having been subjected to one of the vibration test procedures described above the device shall show no mechanical failures and is deemed to conform to the vibration test requirements only in the case the values of its characteristic parameters:

filling degree at the cut-off position,

filling rate allowed at the cut-off position,

do not exceed the prescribed limits and are not exceeding by more than 10 per cent the values preceding the vibration test procedure.

11. **LPG compatibility tests for synthetic materials**

11.1. A synthetic part in contact with LPG-liquid shall not show excessive volume change or loss of weight.

Resistance to n-pentane according to ISO 1817 with the following conditions:

(i) medium: n-pentane

(ii) temperature: 23 °C (tolerance acc.to ISO 1817)

(iii) immersion period: 72 hours

11.2. Requirements:

maximum change in volume 20 %

After storage in air with a temperature of 40°C for a period of 48 hours the mass compared to the original value may not decrease more than 5 %.

12. **Corrosion resistance**

12.1. A metal LPG containing component shall comply with the leakage tests mentioned in 4, 5, 6 and 7 and after having been submitted to 144 hours salt spray test according to DIN 50021 or ISO 9227, with all connections closed.

or an optional test

12.1.1. A metal LPG containing component shall comply with the leakage tests mentioned in 4, 5, 6 and 7 and after having been submitted to a salt spray test according to IEC 68-2-52 Kb: Salt Spray Fog Test.

Test procedure:

Before the test the component shall be cleaned according to the instructions of the manufacturer. All the connections shall be closed off. The component shall not be operated during the test.

Subsequently the component shall be submitted during 2 hours to spraying with a solution of salt, containing 5% NaCl (mass %) with less than 0.3 % contamination and 95% distilled or demineralised water, at a temperature of 20°C. After the spraying the component is stored at temperature of 40°C and 90-95% relative humidity for 168 hours. This sequence shall be repeated 4 times.

After the test the component shall be cleaned and dried during 1 hour at 55°C. The component shall now be conditioned to reference conditions during 4 hours, before submitting it to further testing.

12.2. A copper or brass LPG containing component shall comply with the leakage tests mentioned in 4, 5, 6 and 7 and after having been submitted to 24 hours immersion in Ammonia according to DIN 50916 or ISO 6957 with all connections closed.

13. **Resistance to dry-heat**

The test has to be done in compliance with ISO 188. The test piece has to be exposed to air at a temperature equal to the maximum operating temperature for 168 hours.

The allowable change in tensile strength should not exceed + 25 %. The allowable change in ultimate elongation shall not exceed the following values:

Maximum increase 10 %
Maximum decrease 30 %

14. **Ozone ageing**

14.1. The test has to be in compliance with ISO 1431/1.

The test piece, which has to be stressed to 20 % elongation shall be exposed to air at 40°C with an ozone concentration of 50 parts per hundred million during 120 hours.

14.2. No cracking of the test piece is allowed.

15. **Creep**

A non metallic part containing liquid LPG shall comply with the leakage tests mentioned in paragraphs 3, 4 and 5 after having been submitted to a hydraulic pressure of 2.25 times the maximum operating pressure at a temperature of 120°C during minimal 96 hours. Water or any other suitable hydraulic fluid may be used as a test medium.

16. **Temperature cycle test**

A non metallic part containing liquid LPG shall comply with the leakage tests mentioned in 3, 4 and 5 after having been submitted to a 96 hours temperature cycle from the minimum operating temperature up to the maximum operating temperature with a cycle time of 120 minutes, under maximum working pressure.