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Background paper to TRANS/WP.29/GRPE/2004/7

Transmitted by the expert for the Netherlands

Improvement of Bonfire test Regulation (ECE Regulation No. 67-01)
Evaluation of the current test requirements

Summary

In Revision 1 of ECE Regulation No. 67 the Bonfire test for LPG containers was introduced. The general objective of the bonfire test is to demonstrate that a container complete with the fire protection system, specified in the design, will prevent the burst of the container when tested under the specified conditions.

In the regulation an acceptable result is defined as:
"The container shall vent through the pressure relief device and no burst of the container takes place"

Experience by the technical service from The Netherlands learnt that in some cases an approval must be given although the container showed such an unsafe behaviour during the bonfire test that the result should be considered as 'unacceptable'. Although the containers did not burst, high pressures were measured and plastic deformation was observed at the end of the test indicating that the containers were close to failure.

To avoid these undesirable situations it is necessary to amend the bonfire test requirements in such a way that relevant observations are taken into account in the judgement of the test result.

In first instance an evaluation of the current regulation was carried out based on the experience gained during the performance of 120 bonfire tests. This evaluation resulted in an overview of draft amendments and is given in this report. Based upon this evaluation the resulting proposal for improvement of the regulation is written, this proposal is presented in a separate document [6].

For each element as mentioned in the regulation , i.e. 'container set-up', 'fire source', 'temperature and pressure measurements', 'general test requirements' and 'acceptable result' an overview is given of the draft amendments. In addition an amendment is proposed with respect to the resealing pressure of the pressure relief valve.

Container set-up
The following amendments are proposed with respect to the container set up:
- The container shall be placed in the designed position by the manufacturer of the container.
  This is a further specification of the position in which the container shall be tested.
- Put § 2.6 (position of the LPG container) and § 2.2 (container set up) together.
  Both paragraphs describe the container set-up during the test.
- For containers with a length of less than 1.65 m the centre of the container shall be positioned over the centre of the fire source.
  This is a further specification of the current requirement and in line with ECE Regulation No. 110 [2].
- For containers with a length equal to or more than 1.65 m the position depends on the location of the pressure relief device:
  - If the container is fitted with a pressure relief device at one side, the fire source shall commence at the opposite side of the container.
  - If the container is fitted with pressure relief devices at both sides, or at more than one location along the length of the container, the centre of the fire source shall be centred midway between the pressure relief devices that are separated by the greatest horizontal distance.

  This is a further specification of the requirement with respect to the container set-up and in line with ECE Regulation No. 110 [2].
- Shielding shall be used to prevent direct flame impingement on the fusible plug (PRD) if present. The shielding shall not be in direct contact with the fusible plug.
  This requirement provides the possibility to test a container without a gastight housing.

- The manufacturer shall describe the behaviour of the complete fire protection system including the designed drop to atmospheric pressure.
  Based on this requirement the manufacturer has to specify the fire protection system and the behaviour during the test. In case the gaseous LPG at the end of the test has to be released via a leakage of the gasket (liquid level indicator) the manufacturer has to specify the type of gasket that is used.

Fire source
No amendments are proposed with respect to the fire source.

Temperature/pressure measurements
The following amendments are proposed with respect to the temperature/pressure measurements:
- Irrespective the length of the container, the wall temperature on the top of the container, in the centre of the fire shall be measured.
  This is a further specification of the temperature measurement on top of the container.
- During the test the thermocouple temperatures and the container pressure shall be recorded at intervals of 2 seconds or less.
  This is a further specification of the time interval between measurements.

General test requirements
The following amendments are proposed with respect to the general test requirements:
- Ambient conditions may not influence the result of the test.
  This requirement does not allow the performance of a test during rain or other mitigating conditions.

Acceptable result
The following amendments are proposed with respect to the definition of an acceptable result:
- A pressure of more than 37 bar, i.e. 136 per cent of the set pressure of the PRV (rounded off upwards) shall be considered as an unacceptable test result.
  This requirement is in line with the draft new regulation for liquid hydrogen [4].
- A pressure between 30 and 37 bar shall be considered as an unacceptable test result in case visible plastic deformation is observed.
  This new requirement does not allow an increase of the container diameter of (more than) 2%.
- In case the behaviour of the protection system does not comply with the specification of the manufacturer (see § 6.1) and it leads to a mitigating test condition the result shall be considered as unacceptable.
  This requirement does not allow any unexpected behaviour of the protection system during the test that influences the test result in a positive way. An example is the presence of a gastight housing that was blown away after activation of the PRV. If it is defined that the gastight housing shall not be removed due to the activation of the PRV this leads to a mitigating condition thus influencing the test result.
- For an all-composite container a release of LPG via the surface is accepted in case the release takes place in a controlled way. A release of gaseous LPG within 2 minutes after the start of the test or a release capacity of more than 30 litres per minute shall lead to an unacceptable test result.
  This requirement allows the venting of LPG via the wall of the all-composite container which is not the case for LPG containers in general.
- The result shall be presented in a test summary and shall include the following data for each container as a minimum:
  - Description of the container configuration
  - Photo of the container set-up and PRD;

- Applied method including the time interval between measurements;
- The elapsed time from ignition of the fire to the start of venting of LPG and actual pressure in the container;
- Time to reach atmospheric pressure;
- Pressure and temperature diagrams.

This requirement makes it possible to evaluate the Bonfire test result based on the test report.

Resealing pressure

With respect to the resealing pressure of the pressure relief valve it is recommended to lower the minimum required pressure at which the pressure relief valve closes to a value of 50 per cent of the initially observed start-to-discharge pressure.

This requirement has a positive effect on the release of LPG via the pressure relief valve.

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1. Introduction

In Revision 1 of ECE Regulation No. 67 [1] the bonfire test is introduced as one of the tests that is required for homologation of the container configuration. In § 1.6.4 of [1] it is written that one container, representative of the type of container, all accessories fitted on it and any added insulation or protective material, shall be subjected to a bonfire test as specified in paragraph 2.6 of annex 10.

The general objective of the bonfire test is to demonstrate that a container complete with the fire protection system, specified in the design, will prevent the burst of the container when tested under the specified conditions.

Experience by the technical service from the Netherlands learnt that in some cases the result of the test should be considered as 'acceptable' while in the opinion of the Dutch technical service the container configuration showed such an unsafe behaviour during the test that the result should be considered as 'unacceptable'. Although the containers did not burst, high pressures (up to 45 bar) were measured and plastic deformation was observed at the end of the test indicating that the containers were close to failure.

To avoid these undesirable situations it is necessary to amend the Bonfire test requirements in such a way that relevant observations are taken into account in the judgement of the test result.

For the set-up of a proposal for improvement of the regulation first of all an evaluation of the current regulation will be performed (phase 1) which is based on the experience gained during the performance of 120 tests. This evaluation will result in an overview of requirements that can be improved. Based upon this evaluation the resulting amendment will be written (phase 2).

This report gives an overview of phase 1. In chapter 2 an overview is given of the current regulation. Chapter 3 gives a description of the behaviour of a LPG automotive container in a fire. This information is very helpful by the evaluation of the current regulation that is presented in chapter 4. In chapter 5 an overview is given of other parameters that can be used for the evaluation of the test result while in chapter 6 an overview is given of the draft amendments to Regulation No. 67.

The proposal for improvement of the regulation is presented in a separate document.

2. Bonfire test regulation

In § 2.6 of ECE Regulation No. 67 [1] the Bonfire test for LPG automotive containers is described. In this chapter an overview of the complete text of this regulation is presented.

2.1 General

The Bonfire test is designed to demonstrate that a container complete with the fire protection system, specified in the design, will prevent the burst of the container when tested under the specified fire conditions.

2.2 Container set-up

Container shall be placed horizontally with the container bottom approximately 100 mm above the fire source;
Metallic shielding shall be used to prevent direct flame impingement on container valves, fittings, and/or pressure relief device. The metallic shielding shall not be in direct contact with the specified fire protection system (pressure relief valve or container valve). Any failure during the test of a valve, fitting or tubing that is not part of the intended protection system for the design shall invalidate the result.

2.3 Fire source

A uniform fire source of 1.65 m length shall provide direct flame impingement on the container surface across its entire diameter.
Any fuel may be used for the fire source provided that it supplies uniform heat sufficient to maintain the specified test temperatures until the container is vented. The arrangement of the fire shall be recorded in sufficient detail to ensure that the rate of the heat input of the container is reproducible. Any failure or inconsistency of the fire source during a test shall invalidate the result.

2.4 Temperature and pressure measurements

During the Bonfire test the following temperatures shall be measured:

(a) The fire temperature just below the container, along the bottom of the container at minimum two locations, not more than 0.75 meter apart.
(b) The wall temperature in the bottom of the container;
(c) The wall temperature within 25 mm from the pressure relief device;
(d) In case of a container longer than 1.65 m, the wall temperature on the top of the container, in the center of the fire.
(e) The pressure inside the container.

Metallic shielding shall be used to prevent direct flame impingement on the thermocouples. Alternatively, thermocouples may be inserted into blocks of metal, measuring less than 25 mm^2.

During the test the thermocouple temperatures and the container pressure shall be recorded at intervals of 30 seconds or less.

2.5 General test requirements

(a) Container shall be filled with 80 per cent in volume of LPG (commercial fuel) and tested in the horizontal position at working pressure.
(b) Immediately following the ignition, the fire shall produce flame impingement on the surface of the container, along 1.65 m length of the fire source across the container.
(c) Within 5 minutes of ignition at least one thermocouple shall indicate the temperature of the fire just below the container of at least 590 °C. This temperature shall be maintained for the remaining duration of the test, namely until when no overpressure is present in the container.

2.6 Position of the LPG container

The centre of the container shall be positioned over the centre of the fire source.

2.7 Acceptable results

The LPG in metal container shall vent through a pressure relief device, and no burst shall occur.
The LPG in all-composite containers may vent through a pressure relief device and/or may vent though the container wall or other surface, and no burst shall occur.

3. Behaviour of an LPG automotive container in a fire

In this chapter a description is given of the behaviour of a LPG automotive container in a fire. This description gives the basic information that is used in the evaluation of the current test regulation (see chapter 4).

Figure 3.1 gives an example of the pressure measurements (deep blue line) during a Bonfire test for a *steel* LPG container equipped with a PRV (set point 27 bar). In this figure also the most relevant temperature measurements are presented, namely the temperature on the bottom side of the container (light blue line) and the temperature in the vicinity of the PRV (reddish brown line).

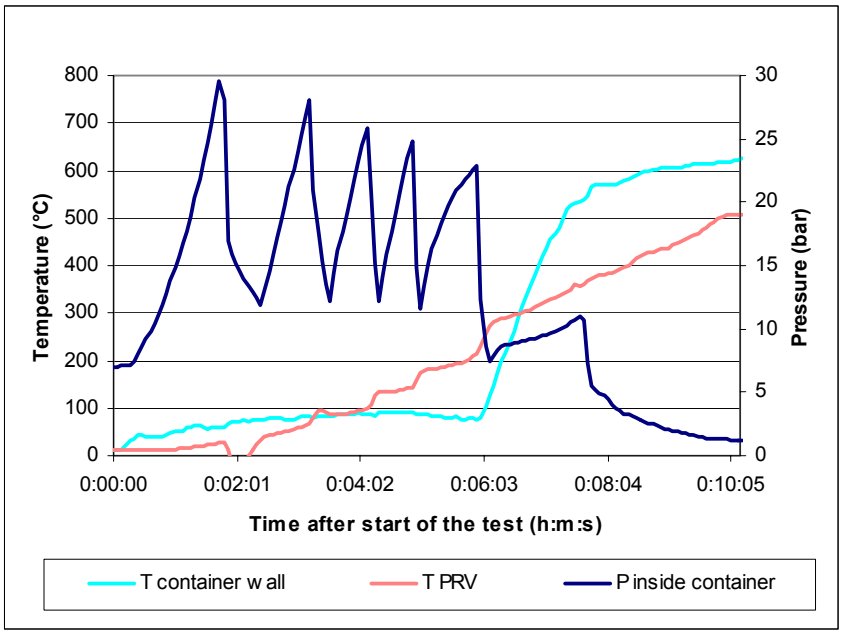

Figure 0.1 Pressure- and temperature measurements during a bonfire test

By studying the pressure curve and the temperature curve 'T container wall' it is noticed that approximately 6 minutes after the start of the test the gradient of both curves changes. In fact two stages can be distinguished, indicated with stage I (00:00 – 06:00) and stage II (06:00 – 10:00). Each of these stages is discussed in more detail below.

3.1 Stage I: presence of liquid LPG

Stage I is characterized by the presence of liquid LPG in the container. With respect to the temperature- and pressure measurements during this stage the following can be observed:

1. After the ignition of the fire (00:00) the pressure inside the container increases rapidly. This can be explained by the fact that the generated heat of combustion is completely used for heating up the liquid LPG in the container. The increase in pressure continues until the set point of the PRV is reached (01:48) through which the PRV opens and gaseous LPG is vented. The LPG that is blown off via the PRV will be ignited by the fire underneath the container resulting in a so-called jet fire with a length of approximately 5 to 10 meters. In figure 3.2 the venting of LPG via the PRV is presented.

Figure 0.2 Venting of LPG via the PRV resulting in a jet fire with a length of approximately 5 to 10 meters

As a result of the venting of LPG the pressure inside the container drops until the pressure comes below a certain value (in this example approximately 12 bar) after which the PRV closes (02:24). Also the temperature of the container wall in the vicinity of the PRV decreases as a result of the removal of heat caused by the venting/evaporation of LPG. Due to the continuation of the fire after the PRV closes the pressure inside the container increases until the PRV is activated for another time. This phenomenon repeats until all the liquid LPG in the container is evaporated. The number of times that the PRV is activated, in this example 5 times, is determined by the amount of liquid LPG in the container and the properties of the PRV.
In case the PRV is not able to vent the LPG in a controlled way the possibility exists that in a certain moment the container can not longer withstand the internal pressure resulting in a burst of the container. Due to the presence of liquid LPG in the container such a situation is called a Boiling Liquid Expanding Vapour Explosion (BLEVE).

2. The temperature on the bottom side of the container increases somewhat after the start of the test but is relatively low compared to the temperature of the fire due to the presence of liquid LPG in the container.
   Although this suggests that the temperature of the container wall is low during this stage of the test, there might be locally a stronger heating up of the container wall, e.g. on the top side of the container as a result of the venting of LPG via the PRV.
3. During stage I the blow off capacity of the PRV is critical with respect to the occurrence of a BLEVE. The minimum required blow off capacity is determined by the external surface of the LPG container. In case the external surface increases, also the minimum required blow off capacity increases.
   The *Bonfire test is therefore very suitable for determining if the PRV has enough blow-off capacity.*

3.2 Stage II: presence of gaseous LPG

Stage II is characterized by the presence of gaseous LPG in the container, the so-called 'remaining gas'. With respect to the temperature- and pressure measurements during this stage the following can be observed:

1. At the moment the PRV closes for the 5th time (06:16) the pressure in the container slightly increases compared to the previous time period. This is caused by the fact that at this moment the container is only filled with gaseous LPG. Due to the very bad heat transfer of gas, the generated heat of combustion is only partially used for heating up the gaseous LPG in the container.
   After 07:44 the pressure inside the container drops as a result of a leakage via the gasket of the liquid level indicator through which the pressure in the container reduces to atmospheric (10:00).
2. The temperature of the container wall increases rapidly after the PRV closes for the 5th time caused by the fact that the most important part of the generated heat of combustion is absorbed by the container wall.
   In case the container wall reaches a temperature of approximately 550 °C, the steel starts to weaken significantly. If the heating of the container wall continues and the gaseous LPG can not be released in time, in the end the container is not longer able to withstand the internal pressure through which a burst of the container is inevitable.
3. The venting of gaseous LPG is therefore critical with respect to the occurrence of a container burst. A burst of a container that is only filled with gaseous LPG is called a physical explosion. Due to the slightly increase of the pressure the PRV is not able to release the remaining gaseous LPG in a controlled way since the actual pressure in the container is too far below the set point of the PRV. During the performed bonfire tests a leakage via the gasket of the liquid level indicator is responsible for the controlled release of gaseous LPG. This leakage is caused by degradation of the material of the gasket as a result of the increased temperature of the container wall.
   This property*, the leakage of the gasket, is not laid down in the regulation. This means that in case the leakage via the gasket does not take place (e.g. by using another material for the gasket) or takes place at a later point in time (e.g. due to the specific circumstances in the fire), a physical explosion of the container will occur.*

From the information presented above it can be concluded that in case the container is filled with liquid LPG and flames impinge on the top (gas) side of the container (e.g. due to the activation of the PRV) the situation is 'worst case' with respect to the occurrence of a burst of the container.

Different container configurations

In this chapter the behaviour is described of a steel LPG container equipped with a PRV. This container configuration is the common configuration in The Netherlands. Nevertheless, there are also containers equipped with both a PRV and a fusible plug. This fusible plug is activated in case a temperature of 120 °C is reached in the immediate vicinity of the plug. The advantage of this fusible plug is that the leakage for venting the gaseous LPG in a controlled way (stage II) is guaranteed. A disadvantage of the fusible plug (compared to the PRV) is that in case the valve is activated the total amount of LPG in the container will release.

For containers that are *equipped with both a PRV and a fusible plug* the behaviour is different from the situation as described above (see figure 3.3). At the moment the fusible plus is activated, the LPG is released via this valve through which the pressure in the container reduces to atmospheric.

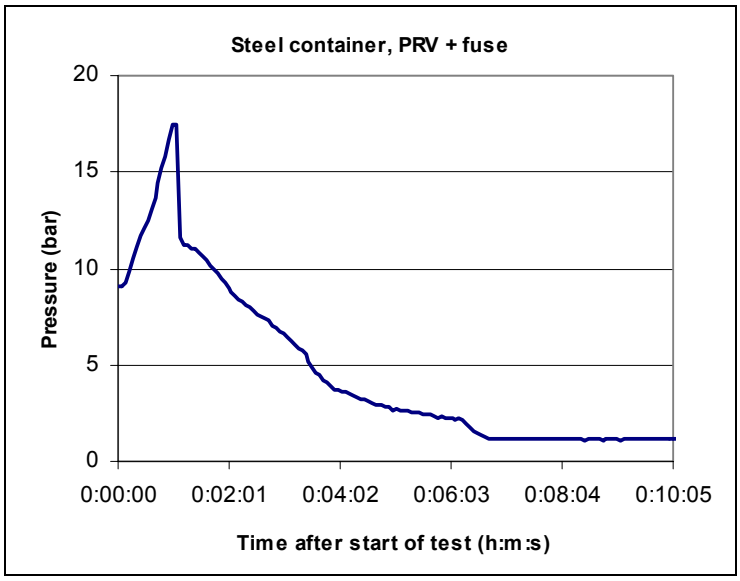

Figure 0.3 Pressure measurements steel container, functioning of the fusible plug

4. Evaluation of the current Bonfire test regulation

Since 1999 the technical service from The Netherlands for testing the LPG automotive containers in a fire has performed a number of 120 Bonfire tests. During the use of the regulation, this technical service learnt that 1) not all the information that is available from the Bonfire test is used in the evaluation of the test result, 2) not all the situations that can occur during the Bonfire test are foreseen in the regulation and 3) the descriptions of the test requirements are sometimes not specific enough.

In order to improve the test regulation the current regulation is evaluated. For each element that is mentioned in the test regulation, i.e. 'container set-up', 'fire source', 'temperature and pressure measurements', 'general test requirements' and 'acceptable result' an overview is given of the applied method and experience gained during the performance of the Bonfire tests. These experiences are compared with the test regulation and, if applicable, a suggestion is made for an improvement of the regulation.

4.1 Container set-up

In § 2.6.2 of the Regulation the following is mentioned with respect to the container set-up:

1. *Position of the container;* container shall be placed horizontally with the container bottom approximately 100 mm above the fire source.
2. *Metallic shielding (gastight housing);* metallic shielding shall be used to prevent direct flame impingement on the container valves, fittings and/or pressure relief device. The metallic shielding shall not be in direct flame contact with the specified fire protection system (pressure relief device or container valve.
3. *Venting of LPG;* any failure during the test of a valve, fitting or tubing that is not part of the intended protection system for the design shall invalidate the result.

In addition in § 2.6.6 of [1] another requirement is given with respect to the container set-up, namely:

4. *Position vs. fire source*; the centre of the container shall be positioned over the centre of the fire source.

Each of these items is discussed in more detail below.

4.1.1 Position of the container

- **Applied method / expertise of the Dutch technical service**

Based on the requests of the principals tests have been performed on LPG containers in different positions, namely:

- normal position, i.e. the position in which the container is mounted in the car),
- upside down position, i.e. with the gastight housing on the bottom (liquid) side of the container;
- Special position, i.e. container placed under an angle of 45°.

The latter two positions where chosen to simulate a car accident with (partly) turnover of the car. It should however be noted that during Bonfire tests for homologation of the container configuration, LPG containers are only tested in the normal position.

The containers are placed upon a frame. The height of this frame is chosen in such a way that in case the liquid reservoir is filled with fuel the bottom of the container is approximately 100 mm above the liquid level in the reservoir.

Although all the (cylindrical) containers are fixed on the under frame, one container rolled forward as a result of the test. Due to this movement the temperature measurements on the container wall became useless while the outflow of the PRV was not longer positioned in the gas phase. It is therefore of relevance that the container is fixed properly to ensure the same position during the complete test.

- **ECE Regulation 67-01**

In the regulation no position other than 'horizontally' is mentioned.

- **Suggestion for improvement of regulation**

To avoid misinterpretation of the position in which the container should be tested it is recommended to specify this position in more detail, i.e. the designed position by the manufacturer of the container for installation inside or underneath the car.

Based on the experience it can be learnt that it is important to fix the container in its position to avoid the influence of a rolling/moving container during the test. The fixation of the container is already covered in two test requirements, i.e. the position of the container as designed by the container manufacturer and the position of the thermocouple on the container wall, therefore it is not necessary to add another requirement.

4.1.2 Metallic shielding/ gastight housing

- **Applied method / expertise of the Dutch technical service**

Bonfire tests have been performed on container configurations that were equipped with metallic shielding, synthetic shielding and configurations without gastight housings.

Synthetic shielding was used on LPG container configurations equipped with an Italian multivalve. *No gastight housing* was used on a container configuration for installation underneath the car, with the accessories mounted in the end plate.

In general, the presence of a gastight housing influences:
1. The direction of the vented LPG;
2. The activation of the fusible plug.

Ad 1: Direction of the vented LPG

The gastight housing is provided with openings for the connection of pipes/hoses to the 80% stop valve (filling of the container), service valve (fuel consumption), and/or bypass of the fuel pump (if present). Another hose is connected to the gastight housing to lead a possible leakage of LPG via an accessory to outside the car. Due to the location of the gastight housing, the resulting jet fire is directed via the gas side of the container away from the container. For containers with a small length, the jet fire does not impinge on the container wall itself, for containers with a larger length (≥ 1.65 meter) the jet fire is partly directed over the gas side of the container. This means that due to the direction of the jet fire, impingement on the gas side of the container takes place, thus being the worst case situation.

In case the gastight housing is not present during the test, the resulting jet fire is directed away from the container (see figure 3.2). This means that for a container with a length of more than 1.65 metre, in contradistinction to the situation in which the gastight housing is present, there is no impingement of the jet fire on the gas side of the container through which the tested situation is not the worst case situation.

During one test on a container configuration with a length of more than 1.65 meter and equipped with a gastight housing, the housing was blown away after the activation of the PRV. Due to this phenomenon the resulting jet was directed away from the container not resulting in an additional heat input on the gas side of the container.

Ad 2: The activation of the fusible plug
Since the fusible plug is protected against direct flame contact by the presence of a gastight housing it will take more time before the fusible plug is activated (i.e. the temperature of the container wall in the immediate vicinity of the fusible plug reaches a value of 120 °C). From the results of the tested containers it can be observed that before this temperature is reached, in a number of cases the pressure inside the container already reached a pressure of 27 bar, resulting in the activation of the PRV.
In case a fusible plug is installed in the same gastight housing as the PRV, the activation of the PRV results in a decrease of temperature thus delaying the activation of the fusible plug.

- **ECE Regulation 67-01**

The test requirements suggest that metallic shielding should be used during the test. However, the use of metallic shielding is not required in the regulation itself.

- **Suggestion for improvement of regulation**

In the opinion of Dutch technical service the commercial LPG container configuration should be tested as far as possible. This means that, in case the accessories are not protected against direct flame contact (no shielding) or protected with synthetic shielding, the test shall be performed on this configuration. It is therefore recommended to redefine the use of shielding in a bonfire test taking into account that there are containers equipped with no- or synthetic shielding.
For containers that are provided with a fusible plug shielding shall be used to prevent against direct flame contact.

With respect to the behaviour of the shielding during the test it is recommended that the manufacturer of the container specifies the intended behaviour. In case the behaviour during the test differs from this intended behaviour through which the tested situation is less severe (in the opinion of the Dutch technical service) the result of the test shall be considered as unacceptable.

4.1.3 Venting of LPG

- **Applied method / expertise of the Dutch technical service**

Bonfire tests have been performed on both steel and all-composite LPG containers.

Steel containers
For steel containers the venting of LPG depends on the container configuration. In chapter 3 the difference between a container equipped with a PRV (figure 3.1) and a container equipped with both a PRV and a fusible plug (figure 3.3) is shown.

All-composite containers
The Dutch technical service has also performed Bonfire tests on all-composite containers equipped with a PRV (see figure 4.1).

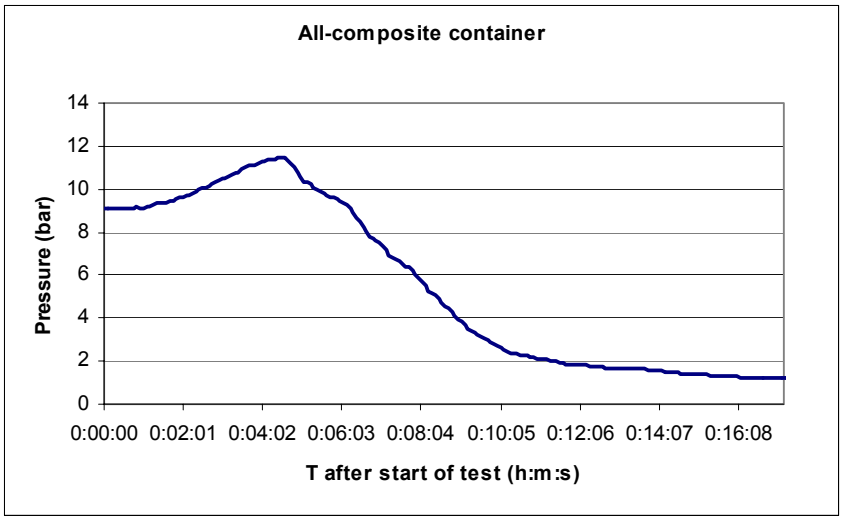

Figure 0.1 Pressure measurements all-composite container

From figure 4.1 it can be concluded that the behaviour of an all-composite container in a fire is different from a steel container equipped with a PRV (see figure 3.1). Due to the good heat transfer of steel the pressure inside the container increased rapidly (from 7 up to 28 bar in approximately 2 minutes, i.e. $\Delta P = 10$ bar per minute). Composite has a bad heat transfer through which the increase in pressure is less (increase from 9 to 12 bar in approximately 4 minutes, i.e. $\Delta P = 1$ bar per minute). Another difference is that LPG is not released via the PRV but via the complete surface of the container (sweating) as a result of the degradation of the material. It should however be noticed that the LPG is released in a controlled way. Based on the experimental data for steel containers a typical outflow of 20 - 25 litres (liquid) LPG per minute was determined.
Another aspect that should be taken into account which respect to the controlled release of LPG is the minimum time between the start of the test and the venting of LPG via the surface. From the experimental data it was derived that most of the PRDs are activated approximately 2 minutes after the start of the test.

- **ECE Regulation 67-01**

In the regulation it is laid down that for metal containers no leakage other than via the protection system might occur. For all-composite containers LPG may be vented through a pressure relief device and/or may vent through the container wall or other surfaces.

- **Suggestion for improvement of regulation**

In chapter 3 it is written that the remaining gaseous LPG in a steel container equipped with a PRV is vented via a gasket, not being a screwed connector. In fact this observation conflicts with the regulation. However, in case this leakage does not take place, a physical explosion will occur. It is therefore recommended to change the regulation on this particular item. A possibility is to specify that a leakage via a valve, fitting or tubing that is not part of the intended protection system will be considered as an unacceptable result only in case the leakage takes place during stage I of the test in which the container is filled with liquid LPG. However, this change of the regulation will not guarantee the occurrence of a leakage via the gasket in the future. It is therefore recommended to indicate the gasket as part of the protection system. In that case the properties (material) of the gasket have to be laid down, and in case another gasket is used, a new Bonfire test has to be performed to show the behaviour of this (new) gasket in the fire.
Another option is that the manufacturer of the container specifies in which way the gaseous LPG is released in a controlled way. In case the behaviour during the test differs from this intended behaviour through which the tested situation is less severe (in the opinion of the Dutch technical service) the result of the test shall be invalided.

For all-composite containers the observed release via the container wall (sweating) is accepted. However, the regulation does not specify the conditions for which such a release is acceptable. In other words, the regulation should give a definition for an acceptable (controlled) release of LPG via the container wall. Based on experimental data a release can be indicated as acceptable in case 1) within 2 minutes after the start of the test no leakage via the surface takes place and 2) the release capacity via the surface is not more than 30 litres (liquid) LPG per minute.

4.1.4 Position versus fire source

- **Applied method / expertise of the Dutch technical service**

Bonfire tests have been performed on containers with different length and different protection systems. For containers with a length of less than 1.65 meter the container is positioned over the centre of the fire source. For containers with a length of more than 1.65 meter there are two possibilities, namely:
1) Container equipped with pressure relief devices located on more than one position, see figure 4.2 and 4.3.

Figure 0.2 Container equipped with a PRV and fusible plug on two locations

The container as presented in figure 4.2 is provided with both a PRV and a fusible plug. Each device is positioned in separate gastight housing.

Figure 0.3 Container equipped with a PRV and two fusible plug on three locations

The container in figure 4.3 has, in contradistinction to the container in figure 4.2, an additional fusible plug that is installed in the middle of the container. Since the outflow of this valve was (partly) directed downwards, a reflection plate was installed to avoid venting of LPG in the liquid reservoir. This reflection plate also prevents the fusible plug against direct flame contact.

2) Container equipped with pressure relief devices located on one position (gastight housing), see figure 4.4.

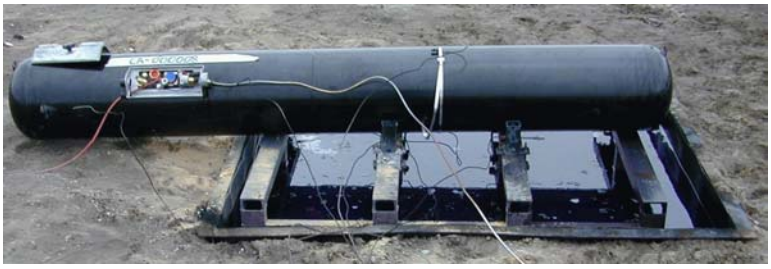

Figure 0.4 LPG container equipped with a PRV and fusible plug on one location

The container with a length of more than 1.65 meter equipped with one gastight housing was positioned in such a way that the end of the container without gastight housing was located above the liquid reservoir. Subsequently the end of the container with gastight housing is located outside the liquid reservoir.

- **ECE Regulation 67-01**

In the regulation no position other than 'symmetry with regard to the fire source' is mentioned.

- **Suggestion for improvement of regulation**

To avoid discussion with respect to the position of a container with a length of more than 1.65 meter equipped with parts of the protection system that are located on one or more than one position, it is recommended to distinguish different situations in the regulation (see also Regulation No. 110 [2]):
If the container is fitted with a pressure relief device at one side, the fire source shall commence at the opposite side of the container. If the container is fitted with pressure relief devices at both sides, or at more than one location along the length of the container, the centre of the fire source shall be centred midway between the pressure relief devices that are separated by the greatest horizontal distance.

4.2 Fire source

In § 2.6.3 of the regulation the following is mentioned with respect to the fire source:
– *Dimensions of fire source;* a uniform fire source of 1.65 m length shall provide direct flame impingement on the container surface across its entire diameter.

- *Fuel;* any fuel may be used for the fire source provided that it supplies uniform heat sufficient to maintain the temperatures until the container is vented.
- *Heat input;* the arrangement of the fire shall be recorded in sufficient detail to ensure that the rate of the heat input of the container is reproducible.
- *(External) causes affecting bonfire;* any failure or inconsistency of the fire source during a test shall invalidate the result.

Each of these items is discussed in more detail below.

4.2.1 Dimensions of the fire source

- **Applied method / expertise of the Dutch technical service**

To meet the requirement of complete engulfment of the container by flames a liquid reservoir with a length of 1.65 meter and a width of 1.35 meter is used. Since the Bonfire tests are performed outside screens are used (see also § 4.2.3) to avoid the influence of the wind as far as possible.

- **ECE Regulation 67-01**

In the regulation the length of the fire source is specified, the width of the fire source is not mentioned. However, the requirement with respect to flame impingement across the entire diameter of the container implicates a certain width of the fire source.

- **Suggestion for improvement of regulation**

There is no need for an improvement of the regulation with respect to the 'dimensions of the fire'.

4.2.2 Fuel

- **Applied method / expertise of the Dutch technical service**

For heating up the LPG containers a mixture of diesel oil and petrol in a ratio 5:1 is used. This mixture was chosen after some tests with pure petrol. Based on these experiments is was concluded that the burning of petrol resulted in relative short flames through which it is not possible to completely engulf the container by flames. In addition, petrol has a high burning rate compared to diesel oil. To minimize the amount of liquid in the reservoir and guarantee full engulfment of the container by flames diesel oil was chosen. Due to the flash point of diesel oil (> 50 °C) petrol was added to ignite the fuel and to reach the minimum required temperature of 590 °C within 5 minutes.

Although natural gas is a cleaner fuel than the chosen mixture of diesel oil and petrol, there are two good reasons for not choosing a gas burner system:
- Since an explosion of a LPG container during a test can not be excluded, there is always a potential risk of damaging the test facility. In case of a gas burner system an explosion of the LPG container might result in a domino effect by damaging the gas system as well. *For the same reason it is preferable to minimize the amount of fuel in the reservoir.*
- A mixture of diesel oil / petrol is more representative regarding a car accident / fire in a car than natural gas.

- **ECE Regulation 67-01**

In the regulation no specific requirements are written down with respect to the fuel of the fire source.

- **Suggestion for improvement of regulation**

Although there are no specific requirements with respect to the fuel of fire source there is no need for an improvement of the regulation with respect to this item. In the opinion of the Dutch technical service the heat input is more important than the fuel that is used for the Bonfire (see § 4.2.3).

4.2.3 Heat input

- **Applied method / expertise of the Dutch technical service**

Since the tests are performed outside, the influence of wind can not be excluded. In order to minimize the influence of wind[1] as much as possible and to guarantee a reproducible heat input to the container, screens are placed on the two sides and the back of the liquid reservoir. These screens have to guarantee a regular fire and to avoid that flames are blown away from the container.

Besides, tests are canceled in case of rain (see § 4.2.4).

- **ECE Regulation 67-01**

In the regulation a reproducible heat input is guaranteed by means of the following requirements:
- Full engulfment of the container by flames;
- A minimum temperature of the Bonfire of 590 °C until the pressure inside the container reduced to atmospheric.

- **Suggestion for improvement of regulation**

Based on the fact that a reproducible heat input is already guaranteed by the abovementioned requirements there is no need for an improvement of the regulation with respect to the item 'heat input'.

4.2.4 (External) causes affecting Bonfire

- **Applied method / expertise of the Dutch technical service**

Since the Bonfire tests are performed outside there are weather conditions that affect the test conditions, namely wind and rain.

Wind might influence the Bonfire test by blowing the flames away from the LPG container. To meet the test requirement of compete engulfment screens are used to avoid this undesirable effect as far as possible (see § 4.2.3).

Rain will influence the Bonfire temperature but the minimum required temperature of 590 °C (see § 4.2.3) will guarantee a minimum heat load on the container. More important than the effect on the fire temperature is the cooling effect of rain on the gas (critical) side of the container.

Another (external) cause that influences the behaviour of the Bonfire is the activation of the PRV/fusible plug. Sometimes the outflow via the PRV/fusible plug is directed downwards thus effecting the temperature measurement below the container (see figure 4.5).

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[1] The presence of wind results in a more or less irregular fire. Besides, the wind might blow away the flames around the container through which the container is not completely engulfed by flames.

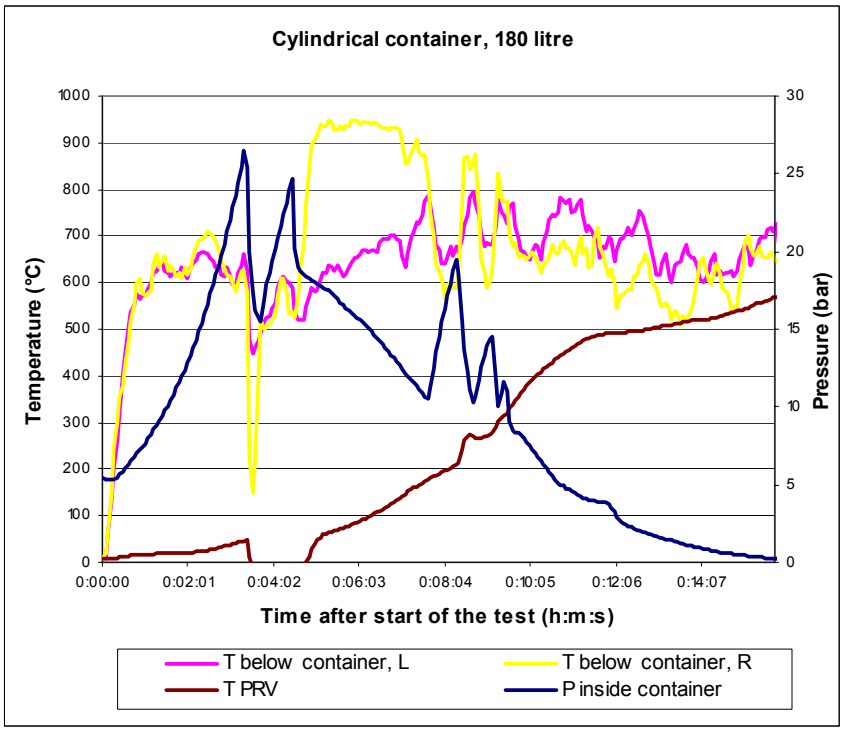

Figure 0.5 Temperature measurements affected by the activation of the PRV

A disadvantage of a downward directed outflow is that fuel is blown away from the liquid reservoir resulting in a shorter duration of the fire. In the worst case situation there is no liquid left in the reservoir at the moment that the container is still pressurised. The required temperature of 590 °C during the remaining test period (i.e. until the pressure inside the container reduced to atmospheric) does require a minimum heat load on the container during the complete test.

- **ECE Regulation 67-01**

In the regulation it is guaranteed that external causes will not affect the result of the test by the following requirements:

– Full engulfment of the container by flames;
– A minimum temperature of the Bonfire of 590 °C until the pressure inside the container reduced to atmospheric.

- **Suggestion for improvement of regulation**

In order to avoid the cooling effect of rain on the top (gas) side of the container it is recommended to include that a bonfire test can not be performed in case of rain.

For situations in which the temperature of the fire comes below the minimum required value of 590 °C the technical service has to explain in the test report by which external cause (e.g. wind, activation of PRV) the temperature was affected. In addition, the technical service has to decide whether this situation shall be
considered as unacceptable or not. Due to the fact that this explanation/decision is depending on the specific conditions during the test, it is not possible to set up a general requirement for this item.

4.3 Temperature/pressure measurements

In § 2.6.4 of the Regulation the following is mentioned with respect to the temperature and pressure measurements:

- *Temperature measurements*; during the Bonfire test the following temperatures shall be measured:
  - The fire temperature just below the container, along the bottom of the container at minimum two locations, not more than 0.75 meter apart.
  - The wall temperature in the bottom of the container;
  - The wall temperature within 25 mm from the pressure relief device;
  - In case the container is longer than 1.65 m, the wall temperature on the top of the container, in the center of the fire.
- *Pressure measurement;* during the bonfire test the pressure inside the container shall be measured.
- *Interval between measurements*; during the test the thermocouple temperatures and the container pressure shall be recorded at intervals of 30 seconds or less.
- *Metallic shielding*; metallic shielding shall be used to prevent direct flame impingement on the thermocouples. Alternatively, thermocouples may be inserted into blocks of metal, measuring less than 25 mm^2.

Each of these items is discussed in more detail below.

4.3.1 Temperature measurements

- **Applied method / expertise of the Dutch technical service**

According to the regulation temperatures are measured on 4 locations, namely below the container (2x), on the container wall (bottom side) and in the vicinity of the PRD. A fifth thermocouple is installed on top of the container, in the middle of the container in case the container has a length of more than 1.65 meter.
If the container is equipped with more than one PRD and these devices are located on different positions (see for example figure 4.2 and 4.3) additional thermocouples are installed in the vicinity of these devices.

The thermocouples below the container indicate the minimum required temperature of 590 °C during the test. This measurement can be influenced by the activation of the PRV (see § 4.2.4).

According to the regulation the thermocouple ‘container wall, bottom’ was placed in a metal block to avoid direct flame contact. However, the temperature that was measured by this thermocouple was relatively high in comparison with the expected temperature of the liquid LPG. It was therefore concluded that the metal block was more influenced by the fire temperature than by the temperature of the container wall (liquid LPG). Based on this conclusion it was decided to fasten the thermocouple directly on the container wall by using steel band and to protect this thermocouple against direct flame contact by using a small piece of rock wool.

For the thermocouple that should be installed near the PRV it is not always possible to use a metal block. In such a situation the thermocouple is fastened by using only steel band.

- **ECE Regulation 67-01**

The regulation prescribes the number and position of the thermocouples on the container and below the container (fire).

- **Suggestion for improvement of regulation**

As mentioned above, the top (gas) side is the most critical side of the container with respect to a container burst. From that point of view it is rather strange that the temperature measurement on top of the container is only required for containers with a length of more than 1.65 meter. Also for containers with a length of less than 1.65 meter it is interesting to measure the temperature on top side of the container. On the other hand, temperatures on top of the container can fluctuate a lot due to (partly) impingement of the resulting jet fire and ice formation due to the evaporation of LPG. Nevertheless, it is recommended to install an additional thermocouple on top of each container, in the centre of the fire.
In the regulation it is written that the temperature shall be measured within 25 mm from the PRD. This implies that in case the container is equipped with more than one PRD, within 25 mm of each PRD a thermocouple shall be installed. It is therefore not necessary to change the regulation on this item.

4.3.2 Pressure measurement

- **Applied method / expertise of the Dutch technical service**

In order to test the commercial configuration (as far as possible) the technical service tried to measure the pressure via an existing accessory (service valve). However, this introduced a number of teething troubles. The most important problem was a blockage of the pressure line due to carbonisation of (liquid) LPG in an oxygen less atmosphere at high temperature. Based on this phenomenon it was decided to make a pressure connection via an additional plug. This plug is installed on the top (gas) side of the container and as far away from the PRV as possible. In addition the pressure line is covered with rock wool.

- **ECE Regulation 67-01**

In the regulation no specific requirements other than the time interval between pressure measurements are written down.

- **Suggestion for improvement of regulation**

There is no need for an improvement of the Bonfire test regulation with respect to the item ‘pressure measurements’.

4.3.3 Interval of the measurements

- **Applied method / expertise of the Dutch technical service**

The pressure- and temperature measurements are registered at 4 seconds interval. This interval is chosen based upon the accuracy of the data gathered and the size of the data files that are generated.

- **ECE Regulation 67-01**

The regulation requires the registration of pressure- and temperature measurements at 30 seconds interval or less.

- **Suggestion for improvement of regulation**

In figure 4.6 the pressure inside the container is presented based upon an interval of 4 seconds, 16 seconds and 28 seconds (requirement of regulation).

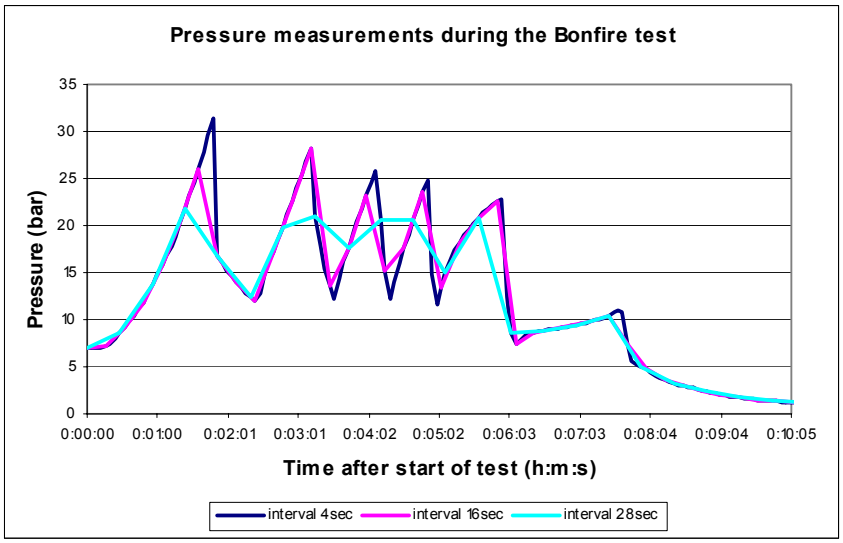

Figure 0.6 Pressure diagrams based on different time intervals

From this figure it can be observed that the chosen interval has a large influence on the actual (measured) pressure in the container. For evaluation of the functioning of the PRV in more detail (see § 5.1) it is recommended to use a very short time interval between measurements.

4.3.4 Metallic shielding

- **Applied method / expertise of the Dutch technical service**

From § 4.2.2 it can be concluded that not always metallic shielding is used to protect the accessories that are mounted on the container.

For the thermocouple that is installed on the top (gas) side of the container a metal block was used to avoid direct flame contact. As discussed in § 4.3.1 the metal block on the bottom side of the container influenced the measurement based upon which it was decided to fasten the thermocouple directly on the container wall with steel band and protect it against direct flame contact by using a small piece of rock wool.

- **ECE Regulation 67-01**

The regulation prescribes the use of metallic shielding or alternatively metal blocks to prevent direct flame contact on the thermocouples.

- **Suggestion for improvement of regulation**

In the opinion The Netherlands the regulation does not exclude the use of steel band together with rock wool for measuring the right temperature on the container wall. Based on this opinion there is no need for changing the regulation to allow the use of band in combination of rock wool for avoiding direct flame impingement on the concerning thermocouple.

4.3.5 Additional information of measurements

The pressure and temperature measurements are only used to make sure that;
1. The pressure in the container reduced to atmospheric at the end of the test.
2. The Bonfire reaches the required temperature of 590 °C within 5 minutes.
3. This minimum temperate is maintained during the remaining test period.

The measurements give also information of:
- The functioning of the PRD (see § 5.1 and 5.2).
- The presence of liquid/gaseous LPG in the container during the test.
- Actual temperature on top of the container in relation to the temperature above which weakening of the steel takes place.

4.4 General test requirements;

In § 2.6.5 of the regulation the general test requirements are presented. These requirements are:
- *Filling degree*; container shall be filled with 80 per cent in volume of LPG (commercial fuel) and tested in the horizontal position at working pressure.
- *Behaviour of fire following ignition*; immediately following the ignition, the fire shall produce flame impingement on the surface of the container along 1.65 m length of the fire source across the container.
- *Time to reach 590 °C*; Within 5 minutes of ignition at least one thermocouple shall indicate the temperature of the fire just below the container of at least 590 °C.
- *Temperature development during test*; this temperature shall be maintained for the remaining duration of the test, namely until when no overpressure is present in the container.

Each of these items is discussed in more detail below.

4.4.1 Filling degree

- **Applied method / expertise of the Dutch technical service**

Bonfire test have been performed on LPG containers with different filling degrees. Besides the required filling degree of 80% also tests have been performed on containers that were filled for 22 respectively 30%.

In the opinion of the Dutch technical service a filling degree of 80% is the worst case for testing the capacity of the pressure relief valve/fusible plug (see also chapter 2). In theory, a low filling degree is the worst case situation with respect to the integrity of the container itself (heating the gas side of the container might result in a burst of the container). However, the tests that were performed on containers with a filling degree of maximum 30% did not result in a burst of the container based upon which this statement was not demonstrated.

- **ECE Regulation 67-01**

The regulation prescribes that the container should be filled for 80% with LPG.

- **Suggestion for improvement of regulation**

Based on the results of tests that have been performed on containers with a different filling degree it can be concluded that there is no need for an improvement of the regulation with respect to the filling degree.

4.4.2 Behaviour fire immediately following the ignition

- **Applied method / expertise of the Dutch technical service**

Due to the chosen mixture of petrol and diesel oil the ignition of the fuel will almost immediately result in a fire that covers the complete surface of the reservoir.
In addition screens are used to guarantee a uniform fire source (see § 4.2.3).

- **ECE Regulation 67-01**

The regulation prescribes a uniform fire source of 1.65 m length.

- **Suggestion for improvement of regulation**

There is no need for an improvement of the Bonfire test with respect to the item ‘Behaviour fire immediately following the ignition’.

Time to reach minimum temperature of 590 °C;

- **Applied method / expertise of the technical service from The Netherlands**

Due to the chosen mixture of petrol and diesel oil the minimum required temperature of 590 °C is reached within 20 - 60 seconds after the start of the test.

- **ECE Regulation 67-01**

The regulation requires that within a period of 5 minutes the Bonfire reaches a temperature of 590 °C.

- **Suggestion for improvement of regulation**

Based on experience it is concluded that a period of 5 minutes to reach a temperature of 590 °C is rather large. On the other hand there is no need to reduce the time period that is necessary to reach a temperature of 590 °C in the regulation.

4.4.4 Temperature development during test

- **Applied method / expertise of the Dutch technical service**

Without the influence of rain or wind (see § 4.2.4) the fire generates a temperature of more than 590 °C.

Another factor that might influence the temperature of the fire is the activation of the PRV/fusible plug. In case the LPG is vented in downward direction the possibility exists that the temperature lines 'T below container' measure a temperature below the minimum required temperature.

- **ECE Regulation 67-01**

In the regulation it is stated that the minimum temperature of 590 °C should be maintained during the remaining test period.

- **Suggestion for improvement of regulation**

A suggestion for improvement with respect to this item is already given in § 4.2.4.

4.5 Acceptable result

In § 2.6.7 of the regulation an acceptable result is defined as:
'The LPG in metal containers shall vent through a pressure relief device, and no burst shall occur. The LPG in all-composite containers may vent through a pressure relief device and/or may vent through the container wall or other surfaces, an no burst shall occur.'

- **Applied method / expertise of the Dutch technical service**

As already mentioned in the introduction of this report it was observed that during the performance of a number of Bonfire tests the pressure inside the container increased to a value that was far above the set point of the PRV (pressures up to 45 bar). Due to the fact that no burst of the container took place, the test criteria are met through which the container configuration will receive a homologation. In the opinion of the Dutch technical service these container configurations should be excluded from homologation since the containers had a narrow escape (plastic deformation was visible after the test) and a burst of the container can not be excluded by repetition of the test.

- **ECE Regulation 67-01**

In the regulation the only criteria that can invalidate the test is a burst of the container.

- **Suggestion for improvement of regulation**

The evaluation of the Bonfire test result is not based on all the relevant information that is gained during the test. It is therefore recommended to extend the regulation with other criteria, i.e. the functioning of the PRD and/or a criterion for a critical situation during the test (a narrow escape).
For all-composite containers already a suggestion is given for improvement of the regulation with respect to the venting of LPG via the container wall (see § 4.1.3).

5. Evaluation of test result based on other parameters

In chapter 4 an evaluation is given of the current test regulation. At the end of this chapter (§ 4.5) it was concluded that for the evaluation of the test result more parameters should be taken into account, namely:
- Functioning of the PRD;
- Criterion for a critical situation during the test.

Besides these parameters the influence of another aspect, i.e. the presence of fuel pump is described in more detail below as well as the minimum required information that should be present in the test report.

5.1 Functioning of the PRD

With respect to the functioning of the PRV the following parameters are evaluated in more detail:
- Opening pressure of the PRV;
- Maximum pressure in the container;
- Activation of the PRV;
- Activation of the fusible plug;
- Reproducibility of the test.

5.1.1 Opening pressure of the PRV

The PRV has a set point of 27 ± 1 bar. This means that the PRV should open at a maximum pressure of 28 bar. The functioning of the valve is also tested during the start-to-discharge test as described in annex 15 of [1]. The difference between the start-to-discharge test and the Bonfire test is that during the start-to discharge test the pressure is observed at which the PRV starts leaking while during the Bonfire test the pressure is registered at which the PRV opens completely.

This means that the opening pressure of the PRV during the bonfire test might be higher than during the start-to-discharge test. Another explanation for a relative high opening pressure in the Bonfire test is that the valve sticks in the housing of the PRV. However, also in a bonfire test the opening pressure should be maximised. An analysis of the test that have been performed learnt that during 18 of the 120 tests (15%) the PRV opened at a pressure of more than 30 bar[2]. Below the pressure diagrams of these containers are presented. Due to large number of pressure diagrams it was decided to present the diagrams in two figures, i.e. figure 5.1 and 5.2.

[2] I.e. 110% of the set point of the PRV (27 bar), rounded off upwards.

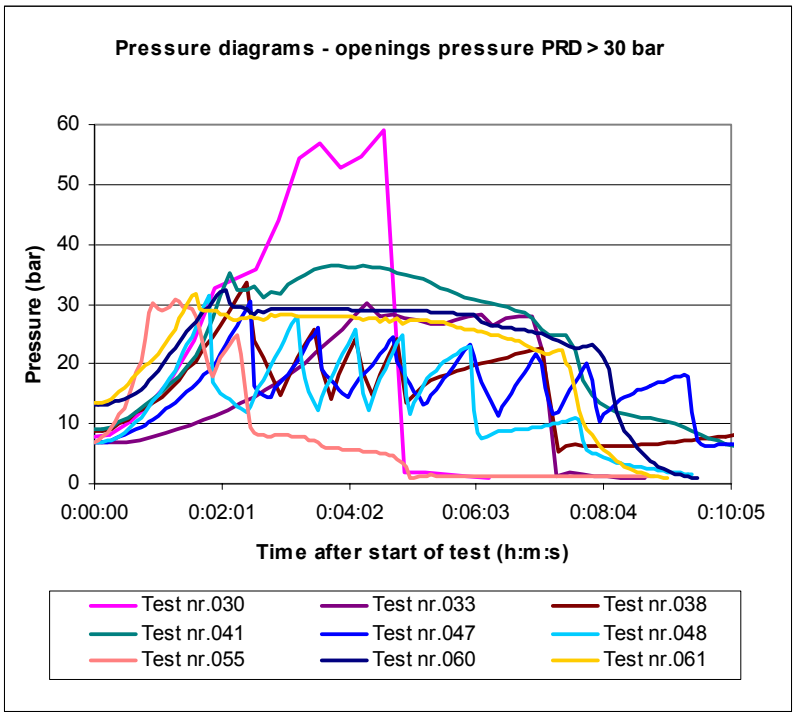

Figure 0.1 Overview of pressure diagrams of tested containers with an opening pressure of more than 30 bar

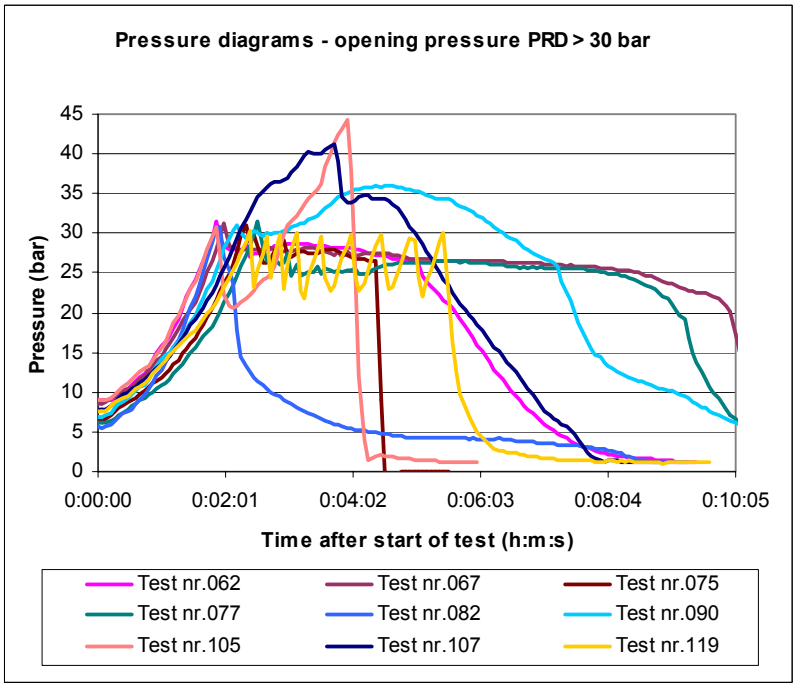

Figure 0.2 Overview of pressure diagrams of tested containers with an opening pressure of more than 30 bar

From these figures the following can be concluded:

– For most of the containers the opening pressure is just above 30 bar. During three tests, i.e. test no. 30, (33,0 bar), no. 38 (33,6 bar) and no. 41 (35,1 bar) the PRV opened at a pressure of at least 33 bar.
– For most of the containers the opening pressure is also the maximum pressure. During six tests, i.e. test no. 30, 41, 55, 90, 105, and 107 the pressure increased despite the activation of the PRV.

Analysis of the test reports learnt that during three tests, i.e. test no. 30, 33 and 75 a burst of the container took place (i.e. 17% of the containers with an opening pressure of more than 30 bar). In addition, during three tests, i.e. test no. 90, 105 and 107, plastic deformation was observed.

By comparing the occurrence of a container burst/plastic deformation with the conclusions related to figure 5.1 and 5.2 the following can be noticed:
1. From the three containers having an opening pressure of more than 33 bar, a container burst took place during one test (test no. 30);
2. From the six containers showing an increase in pressure after activation of the PRV, plastic deformation took place during three tests (test no. 90, 105 and 107) while during one test (test no. 30) a burst of the container took place.

Based on the information as presented above it is concluded that the opening pressure of the PRV might differ from the set point through which this criterion is less appropriate as an instrument for invalidation of the test result. From that point of view a maximum pressure seems to be a better (more effective) criterion.

5.1.2 Maximum pressure inside the container

As mentioned above the PRV has a maximum opening pressure of 28 bar. The maximum pressure in relation to the registered opening pressure gives insight in the blow off capacity of the PRV. In case the pressure in the container increases to a value above the opening pressure of the PRV, or in case the opening pressure is lower than the set point to a pressure above the set point, it is demonstrated that the PRV does not have enough blow off capacity to control the pressure inside the LPG container. In figure 5.3 an example is given of a PRV with too little blow off capacity.

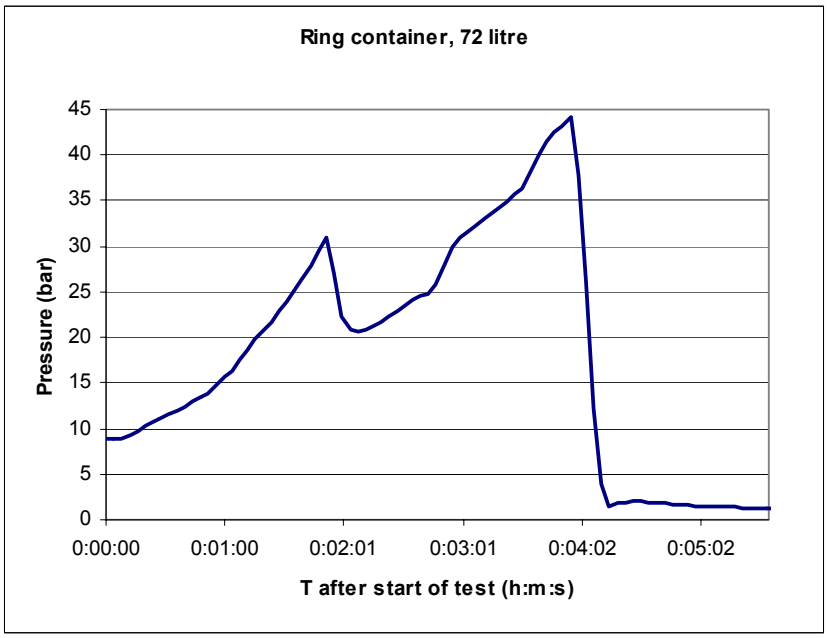

Figure 0.3 Pressure diagram indicating that the PRV does not have enough blow off capacity

Based on the analysis of the tests that have been performed, it was noticed that during 28 Bonfire tests the maximum pressure inside the container reached a value of more than 30 bar. In this number of tests already the containers with an opening pressure of more than 30 bar are included (see § 5.1.1). This means that during 10 tests the container reached a maximum pressure of more than 30 bar while the opening pressure of the PRD was less than 30 bar. In figure 5.4 the pressure diagrams of these containers are presented.

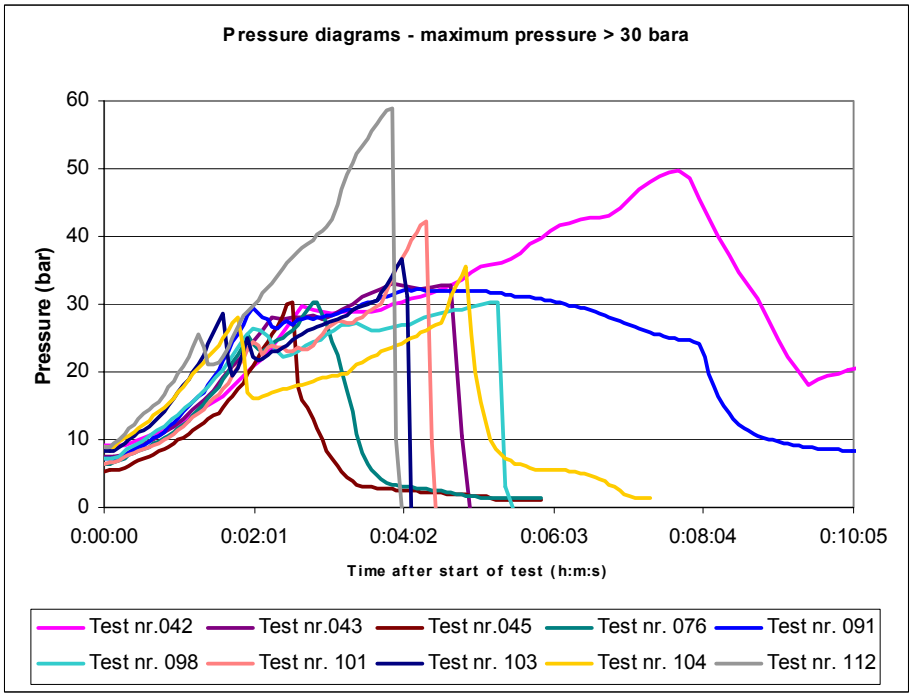

Figure 0.4 Overview of pressure diagrams of tested containers with a maximum pressure of more than 30 bar

From figure 5.4 the following can be concluded:
- For half of the containers the maximum pressure is just above 30 bar. During the other five tests, i.e. test no. 42 (49,8 bar), 101 (42,2 bar), 103 (36,7 bar), 104 (35,5 bar) and 112 (59 bar), a maximum pressure of at least 35 bar was measured.

Analysis of the test reports learnt that during five tests, i.e. test no. 43, 98, 101, 103 and 112, a burst of the container took place. That means that in 50% of the containers with a maximum pressure of more than 30 bar a burst of the container took place. In addition during one test (no. 104) plastic deformation was observed.

By comparing the occurrence of a container burst/plastic deformation with the conclusions related to figure 5.4 the following can be noticed:
1. From the five containers having a maximum pressure of more than 35 bar a container burst took place during 3 tests (i.e. test no. 101, 103 and 112) while at the end of one test (test no. 104) plastic deformation was observed. This means that in 80% [3]of the containers having a maximum pressure of at least 35 bar the strength of the container was significantly influenced.

The abovementioned selection criterion also invalidates tests that do not result in a burst of the container or in plastic deformation[4]. Therefore other Bonfire test regulations were studied, i.e. compressed natural gas [2], compressed gaseous hydrogen [3] and liquid hydrogen [4]. In the first two regulations no criterion is mentioned, in the latter a maximum pressure of 136 per cent of the set pressure of the PRV is defined. For LPG containers this criterion results in a maximum pressure of 37 bar, rounded off upwards. Based on this criterion a number of 6 tests are selected. During 3 tests (test no. 30, 101 and 112) a burst of the container took place while during 2 tests (test no. 105 and 107) plastic deformation was observed.
Due to the fact that the maximum pressure of 37 bar does not exclude all the tests that resulted in plastic deformation[5], it is recommended to use two criteria, namely a maximum pressure (37 bar) in combination with the observation of plastic deformation (see § 5.2).
In order to measure an accurate pressure it is necessary to use a short interval between measurements (see § 4.3.3).

5.1.3 Activation of the PRV

The behaviour after the activation depends on the type of PRV that is used. The following types of PRV have been tested in a Bonfire, i.e. a PRV as a separate unit and a PRV as part of a multivalve. Each of these items is discussed in more detail below.

PRV as separate unit
For tested PRVs with a set point of 25 bar the pressure diagram can be indicated as a so-called saw tooth, see figure 5.5. The peaks in this diagram show the point in time at which the PRV opens, the duration of the activation is the time period in which the pressure drops.

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[3] Inspection of the container at the end of the test was not performed on test no. 42, see also § 5.2.

[4] It should be noted that during test 1 to 89 no visual inspection was performed in order to determine plastic deformation (see also § 5.2).

[5] At the end of test no. 90 and 104 also plastic deformation was observed. During these tests the maximum pressure was however lower than 37 bar.

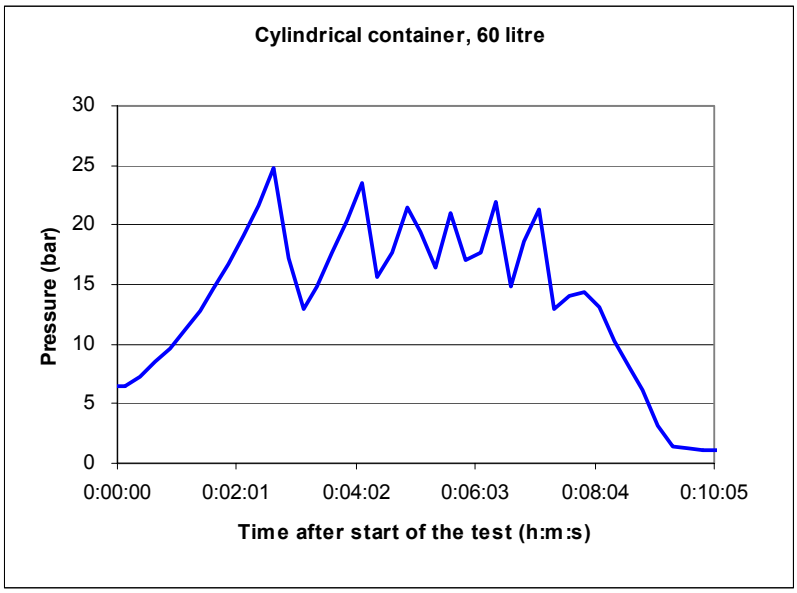

Figure 0.5 Pressure diagram of cylindrical container (set point 25 bar)

From this figure it can be observed that the PRV is activated for periods of approximately 20 seconds. The advantage of this relative long time period is that a lot of LPG can be vented through which the pressure inside the container decreases significantly. Another advantage is that the container wall is cooled down by the evaporation of LPG in the container.

In December 1999 (test no. 49) and February 2000 (test no. 58) Bonfire tests were performed on LPG containers equipped with a PRV of 27 bar. The behaviour of these valves was similar to tests performed on containers equipped with the 25 bar PRV. However, during tests performed in October 2000 (test no. 89) the behaviour of the PRV was completely different, see figure 5.6.

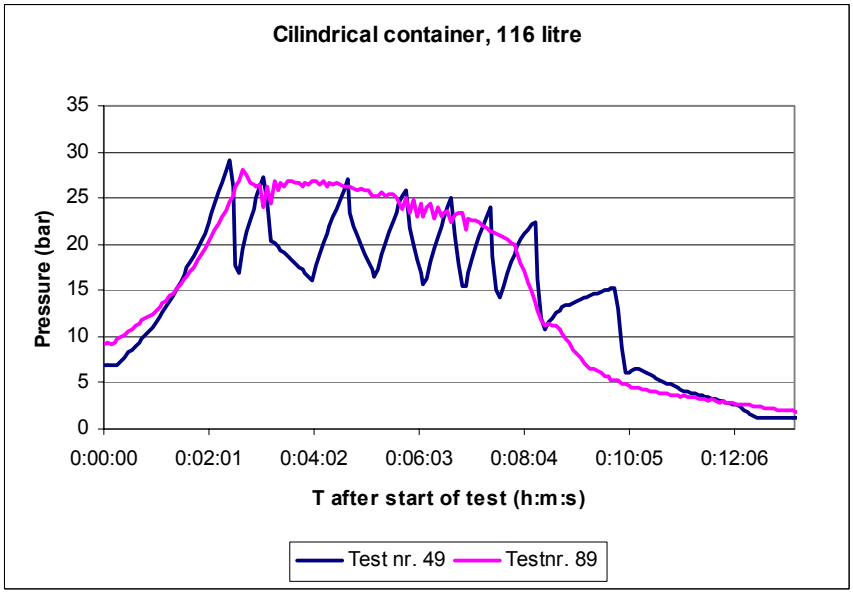

Figure 0.6 Pressure diagrams of cylindrical containers (set point 27 bar)

Instead of an activation of the PRV that lasts for a period of approximately 20 seconds (test no. 49), the activation of the PRV during test no. 89 lasts for a maximum of a few seconds after which the

PRV closes again. Therefore it is hard to see the activations (peaks in graph) from the pressure diagram since the duration of the activation is less than the time interval between pressure measurements (i.e. 4 seconds). This behaviour is less favourable due to the fact that per unit of time less LPG is vented. Due to this phenomenon there is hardly any cooling effect on the container wall. In addition, during the main period of the bonfire test the pressure inside the container stays at an undesirable high value.
This difference in activation of the PRV is caused by a requirement in R67-01 which prescribes that the resealing pressure of the valve might not be less than 90% of the initial start-to-discharge-pressure (annex 15 of [1]). In the opinion of the Dutch technical service it is better to define a maximum resealing pressure in stead of a minimum pressure or a lower minimum resealing pressure.

- **PRV as part of the multivalve**

For PRVs that are part of the multivalve, the behaviour of the pressure during the test is more or less similar to the observed behaviour of the 27 bar PRV during tests in October 2001 (see figure 5.7).

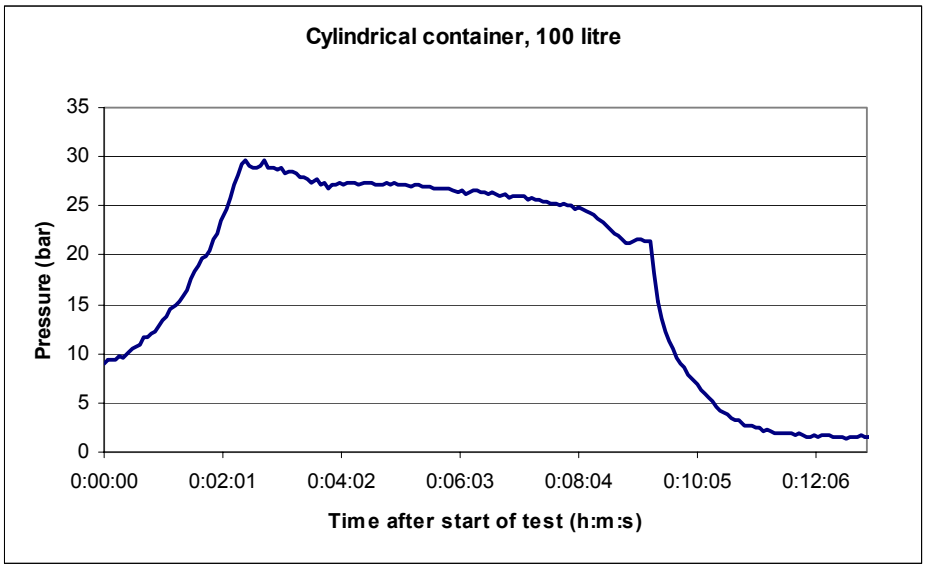

Figure 0.7 Pressure diagram of cylindrical container equipped with a multivalve (set point 27 bar)

5.1.4 Activation of the fusible plug

The activation of the fusible plug depends on the location of the fusible plug on the container (§ 4.1.2). In case the fusible plug is located in a gastight housing, there is no direct flame impingement. This means that the temperature in the vicinity of the fusible plug stays relatively low compared to the temperature of the fire through which it will take more time before the fusible plug is activated. Based on experimental data it is concluded that the fusible plug is activated at a point in time at which the PRV is already activated. Due to the activation of PRV, the container wall is cooled thus influencing the temperature in the vicinity of the fusible plug.
In figure 5.8 the pressure diagram is presented together with the temperature measurements in the gastight housing near the PRV, i.e. temperature line 'T PRV'. From this temperature line it can be observed that due to the activation of the PRV (02:49) a decrease of temperature took place thus influencing the point in time at which the fusible plug is activated. In this example the fusible plug is activated after 3 minutes and 38 seconds.

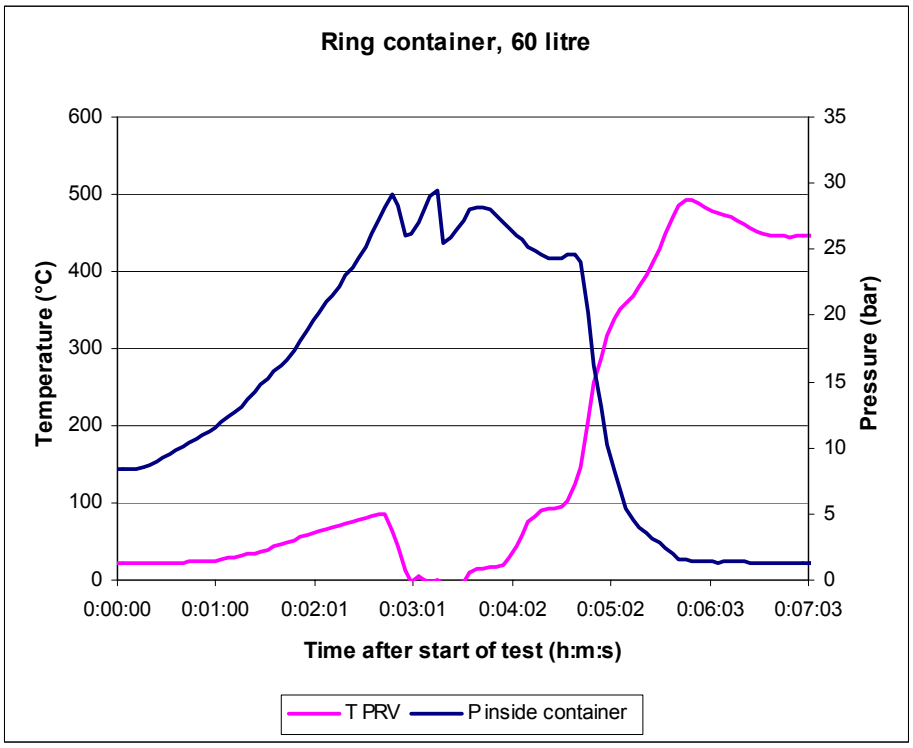

Figure 0.8 Activation of PRV affecting the temperature in the vicinity of the PRV

5.1.5 Reproducibility of the test

For homologation of a LPG container configuration (i.e. the container together with the protection system) only one bonfire test has to be performed. This suggests that the result of the Bonfire test is always reproducible.
In order to evaluate the reproducibility of the Bonfire test results, difference is made between a container equipped with a PRV and a container equipped with both a PRV and a fusible plug.

Container equipped with a PRV
From the tests that have been performed on LPG containers that are only equipped with a PRV there are only a few situations in which the container configuration is tested twice. By comparing the results of these tests it is concluded that the behaviour of these container configuration is more or less reproducible. In figure 5.9 an example is given of a repetition of the Bonfire test on the same container configuration.

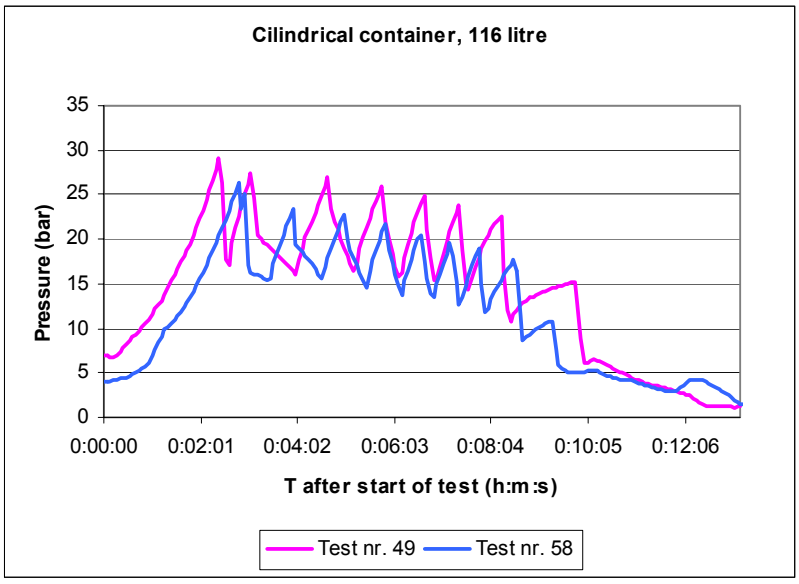

Figure 0.9 Pressure diagrams for two bonfire tests performed on the same container configuration

Container equipped with both PRV and fusible plug

Also for LPG containers equipped with both a PRV and fusible plug there are only a few situations in which the container configuration is tested more than once. The results of these tests are shown in the figures 5.10 and 5.11.

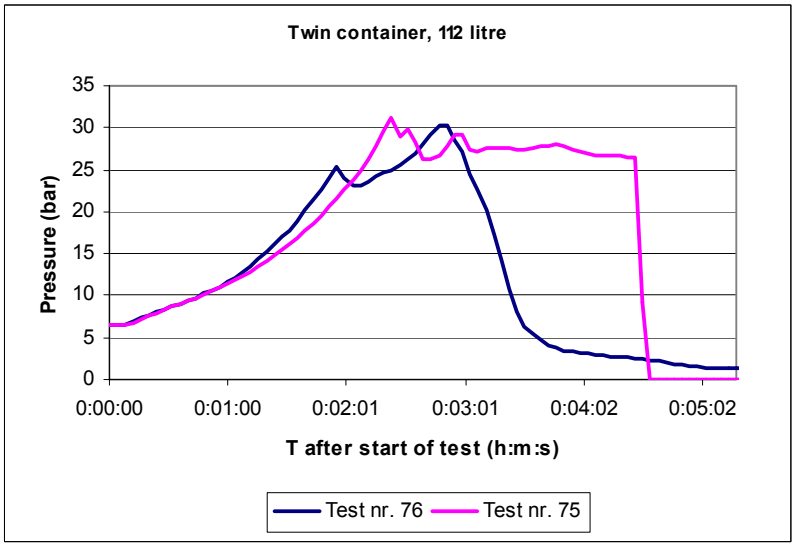

Figure 0.10 Pressure diagrams for two bonfire tests performed on a twin container equipped with the same protection system

(Note with respect to figure 5.10):
During test 76 the twin container passes the test while test 75 results in a BLEVE of the LPG container.

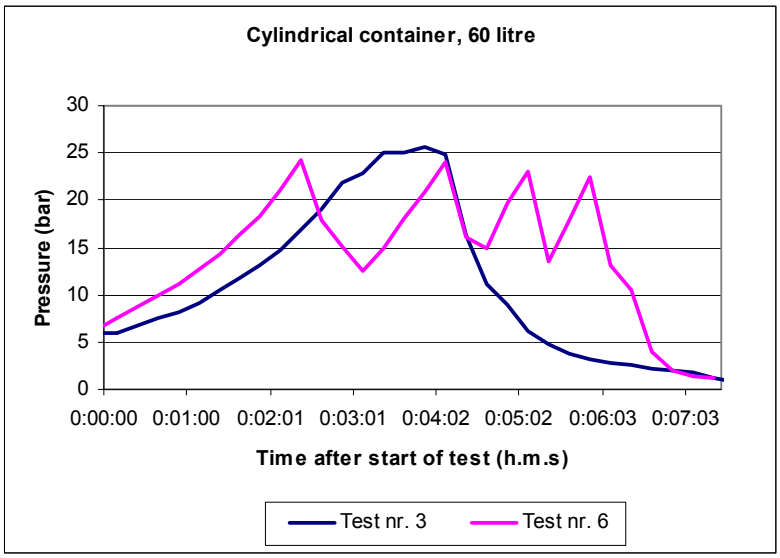

Figure 0.11 Pressure diagrams for two bonfire tests performed on a cylindrical container equipped with the same protection system

(Note with respect to figure 5.11):
Although the pressure diagrams of test 3 and 6 are different, both cylindrical containers passed the test.

While comparing the behaviour of this container configuration in a fire it is concluded that repetition of the test does not automatically result in the same behaviour. From that point of view it is desirable to perform at least two tests for homologation of this container configuration. On the other hand, a different behaviour does not automatically result in a more critical situation (see figure 5.11). In addition, such a requirement can not only concern on a specific container configuration but should refer to all container configurations. This is however not preferable since there are container configurations that do show a more or less reproducible behaviour. Taking into account that there are already two amendments proposed with respect to the evaluation of the test result, it was decided not to propose an additional amendment with respect to the number of bonfire tests for homologation of a LPG container configuration.

5.2 Criterion for a critical situation during the test

In the opinion of The Netherlands the definition of an acceptable result should not only focus on the occurrence of a container burst. Containers that did not burst but for which the conditions during the test were so critical that a burst of the container can not be completely excluded by repetition of the test should also be part of the definition.

In order to define such a ‘critical situation’ the Dutch technical service studied a model in which the theoretical tensile strength to withstand a burst of the container are compared to the calculated decrease of the tensile strength based on the actual temperature and pressure during the test [5]. The advantage of this model is that based on temperature and pressure measurements it is possible to indicate whether the conditions during the test are critical or not. A disadvantage of this model is that it is a theoretical model (how can the result of the model be verified?) and strongly depending on the temperature measurement on the container wall. Since it was concluded that actual temperature on the

container wall can fluctuate a lot (see § 4.3.1), the result of the model might be under- or overestimating.

In order to find a suitable criterion a literature search was carried out. This literature search ended by Professor Doctor A.M. Birk, working at Queens University in Canada on BLEVE research. According to Birk, an indication of a critical situation during a bonfire test is the occurrence of plastic deformation. A high pressure, whether or not in combination with a high temperature, will deform the LPG container based on the properties of the container. As a result of this plastic deformation the volume of the container increases and in the same time the strength of the container is influenced due to a reduction of the container wall thickness.
The parameters that form a criterion for plastic deformation are:

- Volume of the container;
- The external diameter of the container;
- The container wall thickness.

From these parameters the external diameter of the container is the most efficient way of (visually) determining the occurrence of plastic deformation.

During 4 tests (test no. 90, 104, 105 and 107) plastic deformation was observed while studying the container at the end of the test. It should however be noted that during the tests 1 up to 89 no visual inspection of the container was performed due to lack of knowledge. In figure 5.13 the pressure diagrams of these four tests are presented.

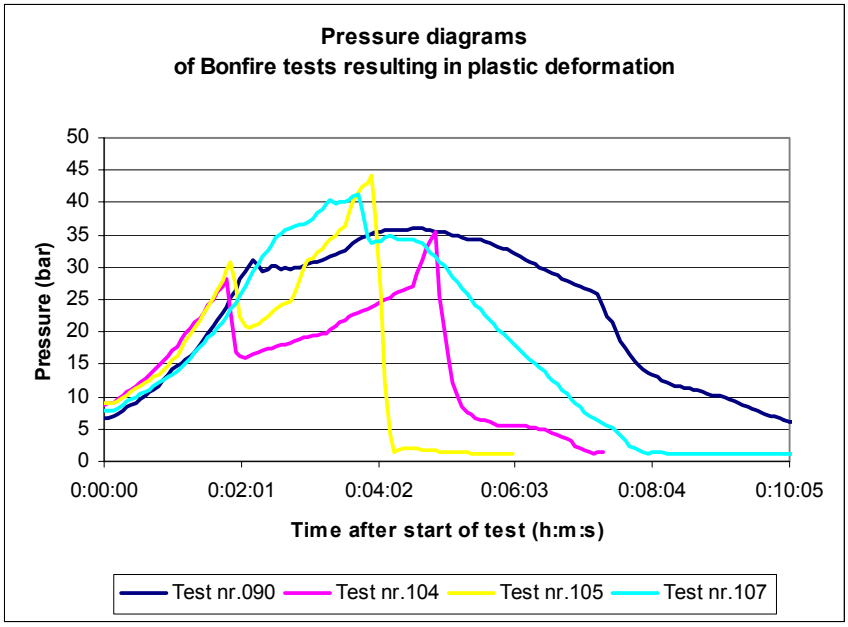

Figure 0.12 Pressure diagrams of bonfire tests resulting in plastic deformation of the container

From this figure it can be observed that the maximum pressure in the container varied from 35,5 (test no. 104) to 44,2 bar (test no.105). This suggests that a maximum pressure of at least 35 bar results in plastic deformation of the test. If this selection criterion is used for the containers that were selected in § 5.1.2 (based on a maximum pressure of more than 30 bar) it is observed that for test no. 42 (maximum pressure of 49,8 bar) no plastic deformation was registered. It should however be noticed that at the end of this test no visual inspection was carried out.

Plastic deformation is defined as an increase of tensile strength of more than 0,2 per cent, i.e. an increase of the diameter of at least 0,2 per cent. Since containers should be able to withstand an increase in volume of 20% an acceptance criteria of 2 per cent is proposed. This value is still a factor 5 below the minimum required increase in volume, is beyond the tolerance of the diameter, and is visible to the naked eye.

In order to determine the specific conditions that results in plastic deformation of the container, it is recommended to inspect all the containers for which a pressure of more than 30 bars was measured during the Bonfire test.

5.3 Presence of fuel pump

- **Applied method / expertise of the Dutch technical service**

Bonfire test have been performed on container configurations with and without an internal fuel pump. For the containers that are equipped with an internal fuel pump in first instance bonfire tests were performed without the presence of this pump. This decision was based on the argumentation that the presence of the fuel pump would not influence the behaviour of the container during the test. However, questions were raised with respect to the synthetic material of the fuel pump. It was stated that this material will be affected during the test (due to the increased temperature) and might influence the functioning of the PRD in case the material deposits in the opening of the PRD. On the other hand, the synthetic material of the fuel pump is cooled by the liquid LPG due to the fact that the fuel pump is installed in the liquid phase. That means that the synthetic material will be affected from the point in time at which the liquid LPG has been evaporated. At that point in time the PRD doesn't need it specified flow capacity to reduce the pressure inside the container to atmospheric due to the fact that the container is only filled with gaseous LPG.

In order to show the correctness of the abovementioned argumentation a number of three tests were performed on LPG containers that are equipped with an internal fuel pump. During test no. 75, 76 and 77 it was demonstrated that the presence of the internal fuel pump did not influence the functioning of the PRD.

- **ECE Regulation 67-01**

In paragraph 1.6.4 of [1] it is written down that a container representative of the type of container, all accessories fitted on it and any added insulation or protective material, shall be subjected to a bonfire test as specified in paragraph 2.6 of annex 10. In the opinion of The Netherlands this requirement means that the internal pump should be present during the bonfire test.

- **Suggestion for improvement of regulation**

In the opinion of technical service the commercial LPG container should be tested as far as possible. From this point of view the internal fuel pump (if applicable) should be present during the test although the results of the tests that were performed on containers equipped with an internal pump do not show that the presence of the pump does influence the functioning of the PRD. Based on this argument there is no need for an improvement of the regulation with respect to this item.

5.4 Documentation of the test

- **Applied method / expertise of the Dutch technical service**

In the test reports information is given about the container configuration, the applied method, the test date and test results.

Besides the performance of Bonfire tests the technical service was once contacted to assess a bonfire test that was performed by another notified body. Due to lack of information in the test report it was however not possible to perform this assessment.

- **ECE Regulation 67-01**

In the regulation no specific requirements are given with respect to the contents of the test report.

- **Suggestion for improvement of regulation**

In order to create the possibility to evaluate the result of a Bonfire test and to aim for uniformity it is required that at least the following information is documented in the test report:

- Description of the container configuration;
- Photo of the container set-up and PRD;
- Applied method including the time interval between measurements;
- The elapsed time from ignition of the fire to the start of venting of LPG and actual pressure;
- Time to reach atmospheric pressure;
- Pressure and temperature diagrams.

5.5 Suggestion for improvement of regulation

Based on the evaluation of the parameters ‘functioning of the PRD’, ‘criterion for a critical situation during the test’, ‘presence of the fuel pump’ and ‘documentation of the test’ the following improvements of the regulation are recommended:

- A pressure of more than 37 bar shall be considered as an unacceptable test result. *In order to determine the pressure inside the container in an accurate way, it is recommended to use an interval between measurements of not more than 2 seconds.*
- The containers for which a pressure of more than 30 bar was measured during the bonfire test shall be inspected to see if plastic deformation has taken place. In case of plastic deformation (2 per cent increase of diameter) the test result shall be considered as unacceptable.
- In order to evaluate the Bonfire test result the test report should as a minimum provide the following information:
  - Description of the container configuration
  - Photo of the container set-up and PRD;
  - Applied method including the time interval between measurements;
  - The elapsed time from ignition of the fire to the start of venting of LPG and actual pressure in the container;
  - Time to reach atmospheric pressure;
  - Pressure and temperature diagrams.

6. Proposal for draft amendments to Regulation No. 67

Experience by the technical service from The Netherlands learnt that in some cases an approval must be given although the container showed such an unsafe behaviour during the bonfire test that the result should be considered as 'unacceptable'. Although the containers did not burst, high pressures were measured and plastic deformation was observed at the end of the test indicating that the containers were close to failure.

To avoid these undesirable situations it is necessary to amend the bonfire test requirements in such a way that relevant observations are taken into account in the judgement of the test result.

In first instance an evaluation of the current regulation was carried out based on the experience gained during the performance of 120 bonfire tests. This evaluation resulted in an overview of draft amendments and is given in this report. Based upon this evaluation the resulting proposal for improvement of the regulation is written, this proposal is presented in a separate document [6].

For each element as mentioned in the regulation , i.e. 'container set-up', 'fire source', 'temperature and pressure measurements', 'general test requirements' and 'acceptable result' an overview is given of the draft amendments. In addition an amendment is proposed with respect to the resealing pressure of the pressure relief valve.

6.1 Container set-up

The following amendments are proposed with respect to the container set up:

- The container shall be placed in the designed position by the manufacturer of the container.
  This is a further specification of the position in which the container shall be tested.
- Put § 2.6 (position of the LPG container) and § 2.2 (container set up) together.
  Both paragraphs describe the container set-up during the test.
- For containers with a length of less than 1.65 m the centre of the container shall be positioned over the centre of the fire source.
  This is a further specification of the current requirement and in line with ECE Regulation No. 110 [2].
- For containers with a length equal to or more than 1.65 m the position depends on the location of the pressure relief device:
  - If the container is fitted with a pressure relief device at one side, the fire source shall commence at the opposite side of the container.
  - If the container is fitted with pressure relief devices at both sides, or at more than one location along the length of the container, the centre of the fire source shall be centred midway between the pressure relief devices that are separated by the greatest horizontal distance.

  This is a further specification of the requirement with respect to the container set-up and in line with ECE Regulation No. 110 [2].
- Shielding shall be used to prevent direct flame impingement on the fusible plug (PRD) if present. The shielding shall not be in direct contact with the fusible plug.
  This requirement provides the possibility to test a container without a gastight housing.
- The manufacturer shall describe the behaviour of the complete fire protection system including the designed drop to atmospheric pressure.
  Based on this requirement the manufacturer has to specify the fire protection system and the behaviour during the test. In case the gaseous LPG at the end of the test has to be released via a

leakage of the gasket (liquid level indicator) the manufacturer has to specify the type of gasket that is used.

6.2 Fire source

No amendments are proposed with respect to the fire source.

6.3 Temperature/pressure measurements

The following amendments are proposed with respect to the temperature/pressure measurements:

- Irrespective the length of the container, the wall temperature on the top of the container, in the centre of the fire shall be measured.
  This is a further specification of the temperature measurement on top of the container.
- During the test the thermocouple temperatures and the container pressure shall be recorded at intervals of 2 seconds or less.
  This is a further specification of the time interval between measurements.

6.4 General test requirements

The following amendments are proposed with respect to the general test requirements:

- Ambient conditions may not influence the result of the test.
  This requirement does not allow the performance of a test during rain or other mitigating conditions.

6.5 Acceptable result

The following amendments are proposed with respect to the definition of an acceptable result:

- A pressure of more than 37 bar, i.e. 136 per cent of the set pressure of the PRV (rounded off upwards) shall be considered as an unacceptable test result.
  This requirement is in line with the draft new regulation for liquid hydrogen [4].
- A pressure between 30 and 37 bar shall be considered as an unacceptable test result in case visible plastic deformation is observed.
  This new requirement does not allow an increase of the container diameter of (more than) 2%.
- In case the behaviour of the protection system does not comply with the specification of the manufacturer (see § 6.1) and it leads to a mitigating test condition the result shall be considered as unacceptable.
  This requirement does not allow any unexpected behaviour of the protection system during the test that influences the test result in a positive way. An example is the presence of a gastight housing that was blown away after activation of the PRV. If it is defined that the gastight housing shall not be removed due to the activation of the PRV this leads to a mitigating condition thus influencing the test result.
- For an all-composite container a release of LPG via the surface is accepted in case the release takes place in a controlled way. A release of gaseous LPG within 2 minutes after the start of the test or a release capacity of more than 30 litres per minute shall lead to an unacceptable test result.

This requirement allows the venting of LPG via the wall of the all-composite container which is not the case for LPG containers in general.

- The result shall be presented in a test summary and shall include the following data for each container as a minimum:
  - Description of the container configuration
  - Photo of the container set-up and PRD;
  - Applied method including the time interval between measurements;
  - The elapsed time from ignition of the fire to the start of venting of LPG and actual pressure in the container;
  - Time to reach atmospheric pressure;
  - Pressure and temperature diagrams.

  This requirement makes it possible to evaluate the Bonfire test result based on the test report.

6.6 Resealing pressure

With respect to the resealing pressure of the pressure relief valve it is recommended to lower the minimum required pressure at which the pressure relief valve closes to a value of 50 per cent of the initially observed start-to-discharge pressure.

This requirement has a positive effect on the release of LPG via the pressure relief valve.

7. References

[1] ECE Regulation No. 67
UN ECE Regulation from the transport division, world forum for harmonisation of vehicle regulations (WP.29)
Regulation 67 is the 66 addendum of the 1958 Agreement.
Last amendments:
R67/Rev. 1/Am. 1, dated 20-03-2001
R67/Rev. 1/Cor. 1, dated 09-11-2000
R67/Rev. 1/Cor. 2, dated 28-06-2001
R67/Rev. 1/Am. 2, dated 16-07-2003
Internet: http://www.unece.org/trans/main/welcwp29.htm

[2] ECE Regulation for compressed natural gas (R110)

[3] New draft ECE Regulation for compressed gaseous hydrogen
TRANS/WP.29/GRPE/2004/3

[4] New draft ECE Regulation for liquid hydrogen
TRANS/WP.29/GRPE/2003/14

[5] Safety of the LPG tanks, overfilling & fire test report
Consorzio G.P.L. Autotrazione report, April 1998

[6] Proposal for draft amendments to Regulation No. 67
TRANS/WP.29/GRPE/2004/7