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**TANKS**

**Reduction of the risk of a BLEVE**

**TNO Report**

**TNO-report**

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# BLEVE prevention of a LPG tank vehicle or a LPG tank wagon

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## 1. Introduction

During transport of dangerous goods, loading and unloading of tank vehicles and tank wagons, accidents can occur.These accidents can cause fatalities among people present in vulnerable buildings like houses, offices, schools, hospitals, nursery homes etc. To manage the risks of transport, loading and unloading of dangerous goods the Dutch Government has formulated a probabilistic external safety policy in 4th Environmental Policy Plan of 2002. The targets of the external safety policy are that:

- Vulnerable buildings objects are not allowed within the $10^{-6}$ per year location-based risk zone (formerly known as the individual risk*)*.

- The societal risk (the risk that a group of at least 10 persons will simultaneously be killed) should preferably be below the guide value. The guide value becomes more strict as the number of expected fatalities rises. For transport risk, the frequency for 10 simultaneous fatalities shall be less than once per 10,000 year per kilometre route length; for 100 fatalities the frequency shall be less than once in 1,000,000 year per kilometre route length, etc.. In a formula: for N victims the frequency should be lower than $0.01/N^2$.

- To avoid large accidents that could cause a societal disruption by the large number of victims or a severe damage to buildings and infrastructure.

An assessment of the risks of unloading of LPG at car fuelling stations [1] showed that for 25 % of the 2200 LPG fuel stations the guide values for the societal risk are exceeded. For road and rail transport of LPG the societal risk guide values are exceeded in several Dutch cities (a.o. Amsterdam, Rotterdam, Dordrecht,Breda, Tilburg, Eindhoven). A detailed analysis of the results of the risk assessment showed that the exceedance of these guide values was dominated by one type of accident: a Boiling Liquid Expanding Vapour Explosion (BLEVE) due to overheating of the tank in an external fire (hot BLEVE).

Several technical measures to improve the safety of the road and rail transport were analysed for their risk reducing potential. A Cost Benefit Analysis [1] of the measures showed that a thermal insulation of the road and rail tank to avoid the hot BLEVE would be a cost effective way to reduce the societal risks. The number of LPG fuel stations exceeding the societal risk guide values could be reduced by 90% and the number of road or rail routes exceeding these values could be reduced by 70%.

In June 2005 the Dutch Government and the LPG automotive fuel association agreed that at the latest by 2010 all tank vehicles for the transport of automotive LPG should have additional measures to avoid a thermal BLEVE of the tank. All societal risks problems resulting from transport of dangerous goods in the Netherlands will be solved if not only the tanks for the national transport of automotive LPG but also all other road and rail tankers for the national and international transport of liquefied flammable gasses would be protected against a thermal BLEVE.

Also other countries are attempting to avoid a thermal BLEVE of road or rail tankers. After a severe accident with two tank wagons in 2000, the Norwegian government proposed to change the requirements regarding use of safety valves and thermal insulation for such tanks [2]. To avoid a BLEVE of a tank wagon with flammable liquefied gases Canada and the USA allow the transport of such gases only in tank wagons with a thermal insulation and a pressure relief valve (PRV). Hong Kong only allows the transport of LPG in road tankers provided with thermal insulation and a PRV.

An objective of the Dutch external safety policy is to reduce the societal risk and societal disruption resulting from a hot BLEVE caused by road and rail transport of liquefied flammable gasses to below the guide values. This can be achieved if a hot BLEVE of an LPG tank vehicle or a tank wagon can be avoided. Therefore the objective of this paper is:

***To assess which additional measures can be taken to either:***

***(i)*** ***Avoid the occurrence of a BLEVE of a road or rail tanker when exposed to heat radiation of a fire following an accident, or***

***(ii)*** ***Delay the time that a BLEVE will occur, after the start of the exposure to the heat radiation, for a period long enough for safe and successful abatement of the fire and/or for cooling of the tank by the fire brigade.***

## 2. The BLEVE phenomenon and consequences

The BLEVE acronym stands for *Boiling Liquid Expanding Vapour Explosion.* A BLEVE can occur after an instantaneous rupture of a tank containing pressurised liquefied gas. The sequence of events in a BLEVE is:

- Rupture of the tank resulting in an almost instantaneous release (duration less than 0.1 second) of the contents of the tank.

- Instantaneous evaporation of the released liquid / liquefied gas causing a strong pressure wave (physical explosion) and scattering of tank fragments into the environment (up to 500 m from the accident spot).

- Formation of a large fireball after ignition of the released vapour cloud

Two types of BLEVE are distinguished:

**‘Cold’ BLEVE**

Due to the impact of a collision or derailment the tank will rupture and cause the BLEVE. Also material defects can cause an instantaneous rupture of the tank and result in a BLEVE.

**‘Hot’ BLEVE**

A ‘thermally induced’ BLEVE can occur if an LPG tank is exposed to an external fire.

At the *liquid side* (bottom) of the tank the heat of the fire will be transferred via the steel wall to the liquid and cause a temperature increase of this liquid and consequently an increase of the vapour pressure. The tank wall near the liquid LPG will only have a slightly higher temperature than the liquid LPG inside. The steel will retain its original strength as long it is in contact with the liquid inside. However the temperature of the wall on the *gas side* (top) of the tank will strongly rise due to the poor heat transfer to the gas inside the tank. The steel on the vapour space will lose its strength above 450-550 °C. The vapour pressure will increase due to the temperature increase of the liquid. For propane, for example, the vapour pressure will be 19 bar at 55 °C. The tank can resist this vapour pressure. However if the temperature of the steel on the gas side of the tank exceeds 450-550 °C the steel will lose its integrity and the tank will rupture. The set point of the pressure relief valve (PRV) of the Dutch tank vehicles is generally set at 23 bar to 27 bar depending on the test pressure on the tank required for other gases or mixtures than propane.

The consequences of a cold and a hot BLEVE are indicated in table 1. It can be seen in the table that the consequences for a hot BLEVE are more serious than for a cold BLEVE. Because of the larger consequence distances the hot BLEVE dominates the high societal risks along transport routes in the Netherlands and near refuelling stations. For that reason this paper focuses on measures to prevent a hot BLEVE.

*Table 1 Consequences of the heat radiation and the blast of a BLEVE of propane road or rail tank.*

| **Consequences of a BLEVE** | **Maximum distance for the consequence in meters** | | | |
|---|---|---|---|---|
| | **60 m$^3$ tank vehicle** | | **110 m$^3$ tank wagon** | |
| | **Cold BLEVE** | **Hot BLEVE** | **Cold BLEVE** | **Hot BLEVE** |
| Collapse of buildings | 35 | 50 | 40 | 55 |
| Severe damage to buildings | 50 | 70 | 60 | 85 |
| 100 % lethality | 90 | 150 | 110 | 190 |
| Ignition of buildings | 200 | 270 | 250 | 350 |
| 1% lethality | 220 | 310 | 310 | 410 |
| 1st degree burnings, crack of windows | 400 | 500 | 500 | 700 |

## 3. Accident casuistry and tests

### 3.1 Casuistry of LPG road and rail transport

TNO has performed searches for accidents with LPG road and rail tankers in databases for accidents with hazardous materials (FACTS, MIDAS and BARPI ) [3]. The accident data in these databases are collected from accident investigations, scientific journals, magazines and newspapers. It is estimated that 90% of the major LPG accidents in North America and Western Europe (A, CH, D, DK, E, F, GB, N, NL, S) are collected in the databases. For other parts of the world the coverage is not as extensive. Only a small part of incidents with LPG vehicles and wagons without or with a minor release of LPG are included in the databases.
Table 2 gives an overview of the collected accidents that have occurred between 1950 and 2004. The data given in Table 2 is not fit to derive a BLEVE frequency because of the incomplete coverage and unknown transported ton-kilometres.

*Table 2 Overview of BLEVEs and other LPG incidents (without or with a minor release of LPG) during transport, loading and unloading between 1950 and 2004. The table shows for rail wagons the number of accidents with a BLEVE, most of these accidents were followed by multiple BLEVEs of nearby rail wagons.*

| | **Europe** | | **Rest of the world (mainly USA / CND)** | |
|---|---|---|---|---|
| | **# accidents** | **# Fatalities/ # injuries** | **# accidents** | **# Fatalities / #injuries** |
| Rail | 1 BLEVE<br>29 other incidents | 13/185 | 20 BLEVEs<br>22 other incidents | 105/2155 |
| Road | 8 BLEVEs<br>38 other incidents | 286/283 | 5 BLEVEs<br>23 other incidents | 156/621 |

The number of BLEVEs during rail transport in Canada and the USA seems to be high compared to Europe. Unlike in Europe, in Canada and USA the LPG tank wagon does not have a supporting frame. The majority of the LPG BLEVEs during rail transport in the USA and Canada occurred between 1965 and 1980. Since 1980 the wagon construction has been improved and tanks are equipped with a heat resistant insulation.

### 3.2 Analysis of BLEVE accidents

Analysis of the reported BLEVEs [3] show that:

- In road transport, 50% of the cases are ‘cold’ BLEVEs and 50% of the cases are ‘hot’ BLEVEs.

- An analysis of the other incidents (those without or with only a minor release of LPG) indicates that also 50 % of the other incidents could have resulted in a ‘cold’ BLEVE and 50 % could have resulted in a ‘hot’ BLEVE if the conditions during the incident had been less favourable.

- Concerning rail transport, roughly 70-80 % of the (mainly North American) BLEVEs were ‘hot’ BLEVEs. A considerable number of the BLEVEs occurred with tankers equipped with a PRV (required in North America).

- In some cases fire fighters succeeded to avoid the BLEVE by cooling of the tank with water and extinguishing the fire.

### 3.3 Small and large scale fire tests with LPG tanks

BAM [4,5], Queens University [5,6,7] and TNO [8,9] have performed bonfire tests with tanks filled with LPG (filling levels from 20 to 90%) to understand the BLEVE phenomenon and to determine if the tanks can be protected against a hot BLEVE. These test have been performed both on a small scale (cylinder volumes 0,06 – 1 $m^3$) and on full scale (tank volumes 4 – 120 $m^3$). The conclusions from these tests are:

- The limited heat transfer at the vapour space tank wall increases the wall temperature to high levels. Above 500°C the steel strength will decline rapidly. Large temperature gradients over the tank structure will create additional stress. All tests indicate wall temperatures of about 550 °C when the BLEVE occurs [3-6]. The tank pressure at the moment of rupture is 15 - 30 bars.
- A Pressure Relief Valve does not always prevent a BLEVE. Due to the heating of the steel on the vapour side of the tank up to 550 °C the steel will lose its integrity and it cannot resist the set point pressure of the pressure relief valve (15-25 bar) any longer.
- BLEVEs occur with tanks with different filling degrees (22% - 100%).
- The ‘time to BLEVE’ (time from the start of the fire till the BLEVE occurs) shows a large variation. The BLEVE occurs after a time varying from 5 minutes (60 l cylinder) to 25 minutes (45 $m^3$ tank) exposure to the fire.

### 3.4 Conclusions from casuistry and bonfire tests

Hot BLEVEs did occur during the road and rail transport of LPG. Casuistry and tests show that a Pressure Relief Valve does not always avoid a BLEVE. Casuistry and bonfire tests show that the time to BLEVE of a cylinder / tank engulfed in a fire varies between 5 – 25 minutes.

## 4. Bleve delay time for safe fire abatement

The objective of this paper is to assess whether additional measures can avoid or delay a BLEVE of a road or rail tanker when exposed to the heat radiation of a fire following an accident. In this chapter it is analysed what the required time is to delay a BLEVE by safe cooling of the tank with water by the fire brigade. The casuistry and tests show that the hot BLEVE will occur within 25 minutes for an unprotected tank. In most cases the fire brigade will need more time to reach the accident location and start the cooling of tank with water.

To prevent a BLEVE of a road or rail tanker a cooling water quantity of 10 litres per square meter cooling area per minute is required. This results in the following water quantities required for cooling and extinguishing [10]:

*Table 3* *Required water quantities and fire vehicles for fire abatement and cooling and supporting fire vehicles for water supply if water is not available at the accident location.*

| Transport | Cooling area [$m^2$] | Water quantity [$m^3$/minute] | Number of required fire vehicles | |
|---|---|---|---|---|
| | | | Fire abatement + cooling | Supporting water supply units |
| Tank vehicle | 100 | 1 | 1-2 | 4-8 |
| Tank wagon | 600[1] | 6 | 3-4 | 8-24 |

Abatement by the fire brigade is only possible if the fire fighters have sufficient time to reach the accident location and subsequently can work safely, i.e. are not exposed to the risk of a BLEVE during their activities. For that reason the response time (time between the start of the fire and the beginning the abatement of the fire and cool the tank) has been determined.

The following steps in the fire abatement can be distinguished:

1. Alarming of the fire brigade
2. Time to reach the accident location
3. Time to start the fire abatement and tank cooling, including the time to provide the required flow of water (table 3) if not enough water is available within 160 m of the accident location.

The time step 2 depends on the distance from the fire station to the accident location. Therefore different accident locations have been analysed. Time step 3 depends on the availability of enough water within 160 m of the accident location. The response times, including the time to get a supporting fire water supply over 2.5 km, are presented in table 4.

[1] More wagons can be exposed to the fire

*Table 4* *Fire brigade response time for effective prevention of a BLEVE, including the time to get a supporting water supply over 2.5 km [10].*

| Accident location | Fire brigade response time in minutes | |
|---|---|---|
| | Tank vehicle | Tank wagon |
| City centre, urban area, industrial area | 45 | 105 |
| Rural area | 75 | 105 |
| Highway with multiple accident and blocked access for fire brigade | 75 | - |

**Conclusion**

In order to definitely avoid the BLEVE the additional measures on the tank vehicle and on the tank wagon must delay the 'time to BLEVE' by 75 minutes for a tank vehicle and by 105 minutes for a tank wagon.

## 5. Prevention of a hot BLEVE

This chapter describes the results of a literature search and additional interviews to identify and to assess the state-of-the-art of measures to prevent a hot BLEVE.

### 5.1 Pressure relief valves

The heating of liquefied gas by the fire will increase the vapour pressure. Theoretically the vapour pressure can become higher than the MAWP (maximum allowable working pressure) of the tank. A Pressure Relief Valve (PRV) will prevent this from happening by venting the vapour into the atmosphere. Because of the venting of the vapour and evaporation of the liquid the temperature inside the tank will decrease.
The capacity of a PRV should be based on the maximum vapour generation in a pool fire. Thermally protected UN transport tanks are allowed to have a PRV with a capacity of 25% of the capacity required for non protected tanks (see RID/ADR 6.7.3.8.1.1).

Queens University has tested 136 PRVs under various conditions [5]. These tests show:

- PRV characteristics vary considerably. Many PRVs do not even meet their specifications at the test facility.
- Large blow down via the PRV delayed the failure of the tank and resulted in less mass and energy in the tank at the moment of failure.
- Hot venting vapours and high ambient temperatures heat the PRV itself causing 'spring softening'; the opening pressure will decrease and the cycle will shift to lower pressures (15-20 bars versus 20-25 bar)

An activated PRV will blow off LPG vapour with violence. Although ambient fire conditions will cause the vent to catch fire and form a torch immediately the extra heat radiation to the tank wall will be very limited. Videos from the German BAM institute show that the stream of gas blown off through a PRV is ignited at a distance of 3-5 meters from the tank. This can be explained by the fact that the concentrated LPG vapour first has to be diluted in order to have a concentration below the upper explosive limit (UEL).

TNO field tests with automotive LPG pressure drums showed that after activation of the PRV the tank wall (at the vapour space) is significantly cooled down. The cooling effect is strongest close to the PRV. That is the reason why many tanks fail on the side opposite to where the PRV is mounted [9].

**Conclusion PRV**

- The liquid LPG in the tank and the tank wall will be cooled by venting LPG vapour above the set point of the PRV. In some cases a BLEVE will be avoided because all LPG has been vented before the steel wall temperature exceeds the critical value.

- The casuistry and the tests show that in a lot of cases PRVs will not prevent a hot BLEVE because not all LPG has been vented before the temperature of the tank wall becomes critical.

- In the cases that a PRV does not avoid a BLEVE, the ‘time to BLEVE’ is delayed. The delay is far less than the time needed for safe cooling and extinguishing by the fire brigade (table 4).

## 5.2 Thermal protection

The main cause of a hot BLEVE is heating of the steel wall at the vapour side of the tank to temperatures in excess of 550 °C. Thermal insulation around the tank can significantly retard the excessive heating of the tank wall in a fire. This will allow fire fighters enough time to reach the accident location and to cool the LPG tank to avoid the BLEVE, to extinguish the fire or to evacuate the people in the vicinity of the accident.

After a number of serious BLEVE accidents authorities in Canada and the USA decided to insulate the rail tanks for LPG transport. These tank wagons are also required to have a PRV. In Canada and the USA the thermal insulation shall avoid heating of the steel tank wall to temperatures in excess of 427 °C for 100 minutes if exposed to a pool fire and for 30 minutes if exposed to a torch fire. The PRV should avoid that the pressure in the tank exceeds 17 bar. If the vapour pressure becomes higher the PRV will vent LPG vapour. The temperature of the liquid LPG will decrease because of the evaporation. The combination of thermal insulation and a PRV therefore increases the protection against a hot BLEVE. However it is not strictly necessary to have this combination of thermal insulation and PRV. Only a thermal insulation of the tank will be sufficient, if it prevents excessive heating of the tank for a period long enough to enable the fire brigade to start cooling the tank and extinguishing the fire.

In Canada a research program on heat protection systems (mainly 13 mm mineral wool insulation under a 3 mm steel wall) on tank wagons has been carried out.

The conclusions of the research are:

- The current thermal protection systems are more than adequate to protect a tank for 100 minutes in an engulfing pool fire and for 30 minutes in a torch fire [11]

- After a 100 minute pool fire, the maximum tank pressure (17 bar with PRV and 100 % thermally protected) is well below the theoretical burst pressure of 52 bar [11].

- Thermal protection has to cover 100% of the tank and its connections; an isolation gap of only 40 x 40 cm will annihilate for a great part the protective effect of the system as a whole [12].

The USA Department of Transport (DOT) maintains a list with validated thermal protection systems. Validation is done using a prescribed protocol [13]. The test entails simulating a 100 minute pool fire / 30 minute torch fire. At this moment approx. 10 manufacturers with all together 20-30 different applications are on this list. A method has been published to inspect the quality of the thermal insulation [15].

Since the application of thermal insulation in the early 1980's, the number of BLEVEs in North America had gone down to just about zero. Recently, however, a couple of BLEVEs with rail tankers have occurred. There has been one tank wagon BLEVE in 1999 in Britt, Ontario and an accident with a multiple BLEVE (four-tank wagons) in 2003 in Melrose, Ontario. In the Britt accident, a derailment of a thermally protected LPG rail wagon resulted in a fire and a BLEVE after 37 minutes. In following investigations it appeared that the specific thermal protection system is susceptible for deterioration in time [14].

In Hong-Kong LPG tank vehicles are equipped with a 7 mm epoxy coating to resist a 60 minutes pool fire or a 30 minutes torch fire. The costs of the heat resistant epoxy coating are about 30 000 Euro for a 60 $m^3$ tank vehicle.

**Conclusions:**

- In USA, Canada and Hong Kong, thermal protection systems in combination with a PRV are in use on LPG transport tanks for many years. Thermal insulation is a demonstrated technology to avoid high wall temperatures at the vapour side of the tank and hence to delay the time to BLEVE so much that fire fighters can cool the tank or extinguish the fire.

- The combination of thermal insulation with a PRV gives sufficient protection against a hot BLEVE.

- It is not strictly necessary to have the combination of thermal insulation and PRV. Only a thermal insulation of the tank is sufficient. It can give a delay of the time to BLEVE as required in table 4.

- The costs of an epoxy coating for a 60 $m^3$ tank vehicle are estimated to be 30 000 Euro. For a 110 $m^3$ tank wagon the costs are estimated to be 50 % higher.

- A restriction of the application of thermal insulation to existing tanks can be the maximum allowed vehicle dimensions, as the insulation layer will increase the tank diameter. The insulation will also decrease the pay-load (1-5 %).

- A point of attention is the regular inspection to detect defects in the insulation layer. A derailment or collision prior to the fire could cause defects in the thermal insulation layer.

## 5.3 Conductive cooling

Additional conductive cooling of the tank wall at the vapour side of the tank by heat transfer from the tank wall to the liquid LPG can be applied to avoid heating of the tank wall above the critical temperature. This can be done by:

- An alloy tissue net that is applied in the entire volume of a tank, distributing the heat evenly, avoiding overheated walls and temperature differences.

- Filling the tank completely with porous alloy bulbs.

This measure is only effective if the tissue net or the alloy bulbs are in close contact with the wall and the liquid LPG in order to act as a heat conductive medium. A boundary condition is that transport vibrations, collisions, overturning or derailment does not reduce the contact area between the wall and the heat conductive bulbs or tissue nets. Sufficient additional conductive cooling in combination with a PRV will theoretically avoid a hot BLEVE.

Products to give the required conductive heat transfer from the wall to the liquid LPG are commercially available. Because of the weight of the tissues or bulbs the pay-load will be reduced by 2 %. The commercial products have been tested in bonfire tests. Most of the tests are done on tanks for flammable liquids (gasoline, kerosene). Videos of these tests of household propane cylinders show that steel cylinders filled with porous alloy bulbs do not BLEVE. Bonfire tests have been reported[2] with 1000 litre LPG pressure drums equipped with a PRV and filled in different ways with alloy tissue nets. The pressure drums in these bonfire tests did not BLEVE, the LPG was vented before the pressure drum wall reached the critical temperature. The bonfire duration was relatively short (15 minutes) in these tests. To the opinion of TNO these tests are not enough to demonstrate that a 60 $m^3$ or 110 $m^3$ tank will not BLEVE in a fire.

Real scale tests to prove that the conductive cooling will not be reduced because of vibrations during transport have not been performed.

**Conclusion**

Sufficient additional conductive cooling in combination with a PRV will theoretically avoid a hot BLEVE. However it is not a demonstrated technology to prevent a hot BLEVE of a LPG tank vehicle or tank wagon because real scale bonfire tests have not been performed. Also it has not been demonstrated that vibrations during transport will not reduce the conductive cooling.

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[2] The name of the author(s), test institute and date of the tests are not indicated in the report.

## 5.4 Liquid cooling

A LPG tank wall cooling system has been patented [16]. The idea is to use the energy from a venting PRV to drive a turbo pump spraying liquid to the inside tank top. The whole system is fitted at the inside of the LPG tank. Only the venting line will, of course, have an outside connection [16]. In order to create a flow to drive the turbo pump and subsequent cooling of the upper tank wall in an early phase of a fire engulfment, the set point of the PRV should be a very low pressure.

TNO considers this technology to be technically feasible but not yet demonstrated in field tests. Disadvantage is that the system only works when the tank is in upright position. Furthermore it can not be considered a proven or state-of-the-art technology. Moreover, it will be a costly solution. Also deficiencies in the spraying system will deteriorate the functionality of the system.

## 5.5 Ranking of hot bleve prevention measures

The BLEVE prevention measures have been ranked for different criteria. The table below shows the results.

*Table 5 : Ranking of measures to prevent a hot BLEVE.*

| | Proven Technology | Effectiveness to avoid/ delay BLEVE | Reliability | Pay-load | Testability | Costs |
|---|---|---|---|---|---|---|
| PRV | yes | Low | low | 0 | difficult | low |
| Thermal insulation | yes | High | high | - 2% | good | considerable |
| Thermal insulation and PRV | yes | very high | high | - 2% | good | considerable |
| Conductive cooling and PRV | no | ? | ? | - 2% | difficult | considerable |
| Liquid cooling | no | ? | ? | ? | ? | ? |

From table 5 it can be concluded that only thermal insulation and thermal insulation in combination with a PRV are demonstrated measures that can reliably avoid a hot BLEVE or significantly delay the ‘time to BLEVE’. The fire brigade should cool the tank and extinguish the fire to definitely avoid the hot BLEVE. PRV and thermal insulation can be retrofitted on existing tank vehicles and tank wagons and do not reduce the pay load by more than 2 %.

Only a PRV on an LPG tank vehicle or tank wagon is not a reliable measure to prevent a hot BLEVE.

# 6. Regulations

## 6.1 Europe

**Rail transport**

In the early 80's the RID/ADR working group on PRVs discussed the necessity to equip a LPG tank wagon with a PRV [17]. Also research was done in the Netherlands [18]. Because of lack of research results at that time it was decided that the use of a PRV on a tank wagon remained optional. At the moment the situation with respect to PRVs in Europe is:

- In GB tank wagons carrying LPG shall have a PRV since 1985.
- Within the RID/ADR framework Norway proposed in September 2005 to provide tank wagons carrying liquefied flammable gases with 'safety valves'
- PRVs are neither allowed in the EU nor in USA/CND on tanks carrying liquefied toxic gases
- PRVs are required on UN-transport tanks carrying LPG (see RID/ADR 6.7.3.7.1)
- During LPG transport over sea, PRVs are required.

**Road transport**

In the Netherlands it is agreed that tank vehicles carrying LPG for automotive purposes and delivering at LPG filling stations should be equipped with a PRV. In June 2005, it was agreed that, as from 1 January 2010, these tank vehicles should have additional protection to avoid a hot BLEVE.

## 6.2 Canada and USA

**Rail transport**

Since the mid-1970s tank wagons transporting liquefied flammable gases in Canada and the USA are equipped with a PRV. A thermal protection system is required as well. The requirements and criteria for the installation of thermal protection on tank wagons for the transport of liquefied flammable gases were established by law in Canada (Canadian General Standards Board CAN/CGSB-43.147-2005) and in the USA (CFR 49 Part 179 'Specifications for Tank Wagons').

The same standard states (Part II, Subpart B, Section 73.31) that thermal protection systems shall have sufficient thermal resistance to resist a pool fire for 100 min or a torch fire for 30 min. Protection systems with an overall thermal conductance of not more than 0.613 kJ/h.m$^2$.ºC will be accepted without a validations test.

**Road transport**

The 49 CFR 178.337 refers to specification MC 331 for cargo tank motor vehicle (CTMV's) primarily for transportation of compressed gases. A PRV is required, thermal protection is not.

## 6.3 Hong Kong

**Road transport**

In Hong Kong a thermal protection system and a PRV is required on LPG tank vehicles. The requirements are that the tank vehicle should resist a pool fire for 60 minutes and a torch fire for 30 minutes.

## 7. Conclusions

A 'hot' BLEVE is caused by a weakened tank wall due to local overheating of the vapour phase tank wall (over 500 °C) by the heat radiation of a fire. The heat radiation and blast of a BLEVE can have very serious consequences for people present in a circle with a radius of 500 m (tank vehicle) or 700 m (tank wagon) around the accident location. A BLEVE can occur within 25 minutes of exposure of the tank to the fire. Hot BLEVEs during transport or unloading of a tank vehicle cause that societal risk guide values are exceeded at 25 % of all Dutch automotive LPF refuelling stations and in many cities in the Netherlands. Cooling of the tank or extinguishment of the fire to prevent the hot BLEVE is impossible because fire fighters have to approach the accident up to approximately 40 m. This is within the zone where the BLEVE will cause 100 % lethality. For that reason the Netherlands' policy aims at reducing the risks of a hot BLEVE. Canada and the USA already require a full thermal insulation and PRVs for tank wagons carrying liquefied flammable gases. Hong Kong requires a thermal insulation and PRV on a LPG tank vehicle. Norway also proposes to require additional protection for tank vehicles and tank wagons.

The following can be concluded from the performed research:

- The time needed for the fire brigade to cool the tank to avoid a hot BLEVE and fight the fire shows that up to 75 minutes may be needed for a tank vehicle and 105 minutes for a tank wagon.

- A PRV cannot delay a BLEVE by 75 minutes.

- Thermal insulation can delay a BLEVE by at least 100 minutes for a pool fire and 30 minutes for a torch fire. The thermal insulation is very reliable to delay the BLEVE. Only defects in the insulation of 0.4 m x 0.4 m or larger will make the insulation ineffective.

- The combination of a PRV and thermal insulation increases the reliability of the BLEVE delay.

- For both the PRV and the heat resistant insulation additional abatement of the fire and cooling of the tank is required to definitely avoid the BLEVE.

- New measures like increase of internal conductive cooling of the tank wall by alloy nets or balls or improved internal circulation of the liquid LPG are not demonstrated technologies yet.

On the basis of these findings it is recommended to equip LPG tank vehicles and tank wagons with additional measures to delay the BLEVE of a tank vehicle by 75 minutes and for a tank wagon by 105 minutes. This will make a safe abatement of the fire and cooling of the tank possible.

The current experiences show that a thermal insulation of the tank may give the required protection. However, the combination of thermal insulation and PRV gives a higher degree of reliability.

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## 9. Authentication

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