ECONOMIC COMMISSION FOR EUROPE

INLAND TRANSPORT COMMITTEE

Working Party on the Transport of Dangerous Goods

Joint Meeting of the RID Safety Committee and the Working Party on the Transport of Dangerous Goods
(Bern, 7-11 March 2005)

TANKS

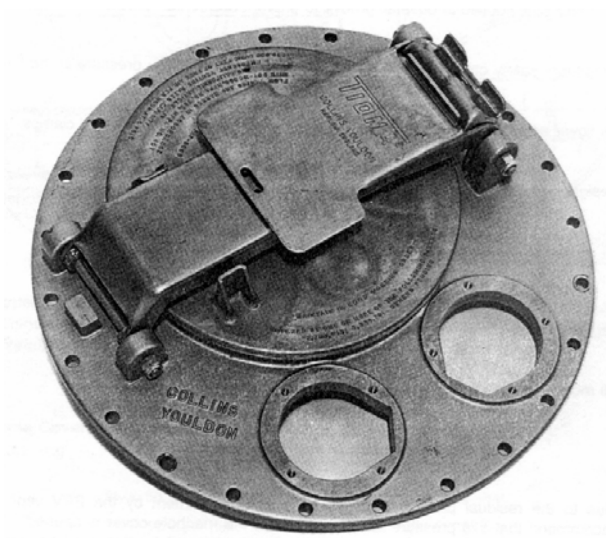
Research Project on Emergency Pressure Relief Valves on Flammable Liquid Tankers

Transmitted by the Government of the United Kingdom

This report from the United Kingdom Health and Safety Laboratory (HSL) reviews the information available relating to EPRVs on tank vehicles carrying Class 3 flammable liquids. The document is presented as an annex to TRANS/WP.15/AC.1/2005/21.

HEALTH & SAFETY LABORATORY

Harpur Hill, Buxton, Derbyshire, SK17 9JN
Telephone: 0114 2892000
Facsimile: 0114 2892160



Review of information relating to emergency pressure relief valves (fire engulfment valves) on flammable liquid tankers

PS/01/09

Project Leader: **C J Butler**
Authors: **C J Butler and M Royle**
Science Group: **Fire & Explosion**

An agency of the Health and Safety Executive

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Mr M Royle	HSL
Archive (3)	HSE archival privacy marking: D
HSE LIS (9)	Availability: Available to the public

HSE Authorising Officer:	Dr J Sawyer
HSL Report Approval:	T A Roberts (Section Head)
Date of Issue:	30 December 2003
Job Number:	JS40.00802
Registry File:	PS/07/2000/20204
Document Filename(s):	ps01ir09.lwp

EXECUTIVE SUMMARY

Position Statement

HSE believes that, due to perceived differences, there are issues across Europe relating to the use, type and installation of emergency pressure relief devices for tankers carrying flammable liquids. HSE considers there to be a need to produce a harmonised approach to the protection of tankers under emergency over-pressurisation conditions, e.g. as a result of engulfment by fire.

This report is offered for further discussion in order to address these issues.

Whilst this report reflects HSE's current knowledge and understanding of the use, type and installation of pressure relief devices, it is accepted that it is not a definitive account of the current situation throughout Europe due to limitations in obtaining information.

Background

The transport of dangerous goods is regulated by international agreements, which, in the case of land transport within Europe, are known by the abbreviations ADR ("Accord européen relatif au transport international des marchandises dangereuses par route") for road transport and RID (Règlement concernant le transport international ferroviaire des marchandises dangereuses) for transport by rail. Within the European Union, in order to avoid duplication of the work already carried out by other international organisations, legislation has been drawn up on the basis of the following principles:

- Uniform application of the international agreements at national level, relying at technical level on European standardisation;
- The adoption of measures at EU level, aimed at supplementing international agreements;
- Bringing down trade barriers created by non-harmonised national standards; and
- Coherence of EU legislation with other EU policies such as environmental protection.

These principles are applied within the field of the transport of dangerous goods, by the adoption of the following directives:

- Council Directive 94/55/EC of November 21 1994 relative to the approximation of the legislations of the member states concerning the transport of dangerous goods by road ("ADR Framework Directive"); and
- Council Directive 96/49/EC of July 23 1996 relative to the approximation of the legislations of the member states concerning the transport of dangerous goods by rail ("RID Framework Directive").

These Directives deal with the transport and marking requirements of dangerous goods and include basic requirements for design, construction, periodic inspection and use, etc., of transportable tanks. However, they do not deal with protection of tanks containing flammable liquids of class 3 due to over-pressures, such as those that may arise from a fire situation.

NOTE: Pressure relief devices generally are of two types:

1. Pressure/vacuum vent valve (p/v valve) which operates under normal filling, discharge and transport activities. These valves cater for minor fluctuations in pressure and/or vacuum.
2. Emergency pressure relief valve (EPRV) - sometimes known as a fire engulfment valve (FEV) - is an emergency venting system which operates under significant over-pressures such as those encountered during fire conditions e.g. fire engulfment.

This report is concerned, in the main, with pressure relief under emergency conditions i.e. type (2) above.

Current UK practice is to carry petrol and petroleum-derivative products in non-cylindrical, low pressure road tanks (known as 'BOX' or 'MAX' section) fitted with pressure/vacuum vent valves and *emergency pressure relief valves [EPRVs] (fire engulfment valves [FEVs]).* This does not prevent other Class 3 flammable liquids from being carried in such tanks. Traditionally, however, these other flammable liquids are usually carried in cylindrical tanks, designed for higher internal pressures and fitted with pressure/vacuum valves only. Petrol (and derivatives) may also be carried in cylindrical tanks. However, it is often a commercial decision to use a non-cylindrical tank for petrol/diesel only, since this geometry allows a larger payload.

The European standardising committee CEN/TC296 is concerned with the standardisation of design, construction, inspection and testing of metallic tanks and equipment, intended for the transport of dangerous goods. This covers tanks on road tankers, rail-tank-wagons and those intended for multimodal transport. Working groups 2-9 of CEN/TC296 are currently developing design, construction, inspection, testing and equipment standards for tankers. However, the existence of national standards and strong national practices, renders reaching a consensus difficult. In particular, currently there are differing opinions across the EU regarding the fitting of *EPRVs [FEVs]* on tankers containing petroleum products. The UK and, it is understood, other EU members, such as Sweden, Spain and France, fit these valves, but other member states, including Germany, Austria and Belgium, do not require them to be fitted. Conversely, there appears to be a common approach to pressure relief for tankers carrying other Class 3 flammable liquids. Table 1 (page 3) summarises our understanding of the current practices adopted across Europe for pressure relief of tankers.

In order to resolve these differences in philosophy for emergency pressure relief, work may be required to study the effect of fire engulfment on flammable liquid tankers fitted with differing pressure relief devices.

Scope

The scope of the report is limited to road tankers and does not, therefore, cover rail tankers (however, see section 3.2) and multimodal tank containers. In the main, the report relates to those road tankers that are non-cylindrical (i.e. of BOX or MAX section geometry) and are used for the carriage of petrol and petroleum derivatives (e.g. diesel, kerosene, aviation fuel).

Objectives

This review aims to provide information on the following areas:

- Tanker design codes/legislation;
- Vent requirements;
- Fire engulfment;
- EPRVs;
- Prevention of spillage in the event of a tanker roll-over;
- Accidents and incidents; and
- Research undertaken in this area.

Main findings

The following conclusions are drawn:

- The venting requirements for low and atmospheric pressure tanks in the various national codes are based on API 2000.
- The emergency venting recommendations in API 2000 are based on fire tests performed on a single tank geometry in 1961.
- No records of controlled fire engulfment of complete, low pressure road tanker tanks have been found. (Some tests have been undertaken on compartments or sections of tankers, but not whole tankers.)
- There is evidence to suggest that thermal radiation from burning fuel vapour from an open emergency pressure relief valve may result in the top of an aluminium tank melting.
- Emergency pressure relief provision is universally recognised as being desirable on static tanks, but the situation for low pressure road tankers used for flammable liquids is less clear.
- EPRVs which pass containment tests on rollover are required in US and Australian codes. (Note: The containment test of the Australian code is largely adopted by the UK, and contained within EN standards.)
- EPRVs which do pass containment tests are readily available from a number of manufacturers.
- The US DOT 406 specification has the most stringent product containment requirements.
- The ability of EPRVs to contain product on tanker rollover may be affected by the strength of the tank.
- Evidence from reported incidents suggests that EPRVs do offer protection for tankers engulfed in fire and limit the consequences of the incident.
- In the available literature, no reports have been found of catastrophic low pressure tanker rupture, where relief valves have not been fitted. However, this may simply reflect that there are a limited number of reports, rather than incidents not occurring.
- Steel tanks (if used) may perform differently from aluminium in the event of fire engulfment.
- No validation trials have been undertaken in order to confirm the efficiency of EPRVs fitted to tankers, or the behaviour of tankers not fitted with EPRVs when engulfed in fire.

Recommendations

The following recommendations are made:

- Carry out trials to investigate the effect of fire engulfment on non-cylindrical (especially BOX / MAX section), low pressure tanks, used for the carriage of petrol, when fitted with either EPRVs, or other pressure relief devices as currently used in Europe.
- Provide relevant information from these studies to TC296 Working Group 9 to assist in producing a harmonised approach across the EU.
- Consideration should be given to a similar study to investigate the behaviour of cylindrical, pressure tanks.

CONTENTS

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1. INTRODUCTION

1.1 Position statement

HSE believes that, due to perceived differences, there are issues across Europe relating to the use, type and installation of emergency pressure relief devices for tankers carrying flammable liquids. HSE considers there is a need to produce a harmonised approach to the protection of tankers under emergency over-pressure, e.g. as a result of engulfment by fire.

This report is offered for further discussion in order to address these issues.

Whilst this report reflects HSE's current knowledge and understanding of the use, type and installation of pressure relief devices, it is accepted that it is not a definitive account of the current situation throughout Europe due to limitations in obtaining information.

1.2 Background

The world-wide transport of dangerous goods is regulated by international agreements. For full international transport, the requirements(1) laid down in the United Nations' *"Recommendations for the Transport of Dangerous Goods"* apply to all modes of transport (road, rail, sea and air). These Recommendations are contained within Model Regulations (sometimes known as the *'Orange Book'*).

In the case of land transport within Europe, the regulations are known by the abbreviations ADR(2) ("Accord européen relatif au transport international des marchandises dangereuses par route") for road transport and RID(3) (Règlement concernant le transport international ferroviaire des marchandises dangereuses) for transport by rail. Within the European Union, in order to avoid duplication of the work already carried out by other international organisations, legislation has been drawn up on the basis of the following principles:

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The European standardising committee CEN/TC296 is concerned with the standardisation of design, construction, inspection and testing of metallic tanks and equipment, intended for the transport of dangerous goods[(4)]. This covers tanks on road tankers, rail-tank-wagons and those intended for multimodal transport. Working groups 2-9 of CEN/TC296 are currently developing design, construction, inspection, testing and equipment standards for tankers. However, the existence of national standards and strong national practices, renders reaching a consensus difficult. In particular, currently there are differing opinions across the EU regarding the fitting of *EPRVs [FEVs]* on tankers containing petroleum products. The UK and, it is understood, other EU members, such as Sweden, Spain and France, fit these valves, but other member states, including Germany, Austria and Belgium, do not require them to be fitted. Conversely, there appears to be a common approach to pressure relief for tankers carrying other Class 3 flammable liquids. Table 1 summarises our understanding of the current practices adopted across Europe for the pressure relief of tankers (see section 2.3).

In order to resolve these differences in philosophy for emergency pressure relief, work may be required to study the effect of fire engulfment on flammable liquid tankers fitted with differing pressure relief devices.

NOTE: Throughout this report, unless otherwise stated, the term emergency pressure relief valve (EPRV) is used, as a more accurate term, to signify a fire engulfment valve (FEV).

Table 1. Current European practice

	*UK Approach**		*Non-UK Approach (no EPRV) ***	
	Petroleum (and derivatives) e.g. Diesel, Kerosene, etc. (EPRV fitted)	***Other Class 3 flammable liquids (e.g. acetone, methyl alcohol, etc.)***	***Petroleum (and derivatives) e.g. Diesel, Kerosene, etc.***	***Other Class 3 flammable liquids (e.g. acetone, methyl alcohol, etc.)***
Tank shape, e.g. Box (1), Elliptical (2), Cylindrical (3)	Can have all three types, but normally box section	Normally cylindrical	Can have all three types, but normally box section	Only cylindrical
Material of construction. e.g. aluminium, steel, stainless steel	Aluminium alloy (Type 5083) for box type Steel for box type (can have steel for cylindrical)	Stainless steel (or mild steel with liner if required)	Aluminium alloy (Type 5083) for box and elliptical type Steel for cylindrical	Stainless steel (or mild steel with liner if required)
Tank wall thickness (mm)	Aluminium box section; 5.12 mm shell + ends (all compartments < 7600 litres) (old formula - see Appendix C) (Pre-2001, most tanks are 4 mm aluminium)	Steel cylindrical 4 mm minimum	Aluminium box section and aluminium elliptical section; 5.12 mm shell and 7.7 -8.0 mm ends, if protected (i.e. fitted with belly belts etc, or if compartment < 7500 litres) otherwise 7.8 mm (old formula - Appendix C)	Steel cylindrical Stainless - 3.0 mm Mild - 4.0 mm Aluminium - 5.12 mm (for diameter > 1.8 m, add protection)
Design pressure of tank	350 mbar	4 bar upwards (e.g. to 10 bar)	250 mbar	4 bar upwards (e.g. up to 10 bar)
Type and size of pressure relief valve	38 mm pressure relief (also EPRV will be fitted)	65 mm pressure relief (No EPRV fitted)	65 mm vacuum relief valve 12 mm pressure relief (No EPRV fitted)	65 mm pressure relief (No EPRV fitted)
Operating pressure of relief valve	70 - 120 mbar pressure	Design rating for a 4 bar tank	50 - 120 mbar pressure down to 30 mbar	Design rating for a 4 bar tank.

Note: * UK approach = UK and other EU countries currently fitting EPRVs to petroleum (and derivative) tanks.
** Specifications taken from data provided for typical tanks used in Germany.

1.3 Scope and objectives of review

The scope of the report is limited to road tankers and does not, therefore, cover rail tankers (however, see section 3.2) and multimodal portable tank containers. In particular the report relates to those road tankers that are non-cylindrical (i.e. of BOX or MAX section geometry) and used for the carriage of petrol and petroleum derivatives (e.g. diesel, kerosene, aviation fuel).

This review aims to provide information on the following areas:

- Tanker design codes/legislation and approach to tanker design;
- Vent requirements;
- Fire engulfment;
- Emergency Pressure Relief Valves (EPRV);
- Prevention of spillage from EPRVs in the event of a tanker roll-over;
- Accidents and incidents; and
- Research undertaken in this area.

2. FLAMMABLE LIQUID ROAD TANKERS

A road tanker is defined in ADR as a 'tank vehicle'. Flammable liquids are defined in ADR as substances which:

- are liquids [according to subparagraph (a) of the definition for "liquid" in ADR Chapter 1.2.1]; and
- have, at 50 °C, a vapour pressure of not more than 300 kPa (3 bar) and are not completely gaseous at 20 °C and at standard pressure of 101.3 kPa (1.013 bar); and have a flash-point of not more than 61 °C (see ADR, Chapter 2.3.3.1 for the relevant test).

There are certain exceptions to this definition, the most relevant of which are:

- Non-toxic and non-corrosive substances, having a flash-point above 35 °C, which, under the sustained combustibility test conditions given in subsection 32.5.2 of Part III of the UN Manual of Tests and Criteria, do not sustain combustion, are not substances of Class 3;
- Diesel fuel, gas oil, heating oil (light), having a flash-point above 61 °C and not more than 100 °C, shall be deemed substances of Class 3, UN No. 1202.

The substances which account for the largest quantity of movements of dangerous goods in this category are petroleum products. According to the market situation report for CEN/TC296, petroleum products represent 75% of the total tonnage of dangerous goods transported within Europe.

In the UK, flammable liquid tankers may be cylindrical (pressure) or non-cylindrical (low pressure) in design. Petroleum is traditionally transported in vented tankers of the latter type.

Tankers carrying flammable liquids are normally fitted with pressure/vacuum vent valves (see Figure A5, Appendix A). These valves allow pressure/vacuum changes during normal filling, discharge and transport operations, including environmental temperature and pressure changes.

Under the national regulations of some countries, EPRVs are also required on BOX / MAX shaped tanks, although this requirement is not universal. Where EPRVs are not fitted, the tankers are fitted with pressure/vacuum vent valves, but may additionally be constructed as vessels with a greater inherent strength. This is designed to reduce the risk of failure or, at least, to increase the time to failure, thereby allowing emergency response measures to be implemented.

2.1 Emergency Pressure Relief Valves (fire engulfment valves)

When a tanker containing flammable liquids is heated by fire engulfment, the pressure inside the vessel will increase as the temperature of the liquid increases. If the pressure is not relieved, the tank may fail when the internal pressure exceeds the strength of the vessel walls, or the walls melt.

Where fitted, the normal method of providing emergency relief venting capacity is through the use of a spring loaded fill cap closure, incorporated into the manway at the top of the tank compartment. Examples of manhole covers containing an emergency relief vent are shown in Appendix A. When the tank becomes engulfed in fire and the contents heated, the EPRVs open to relieve the pressure produced by the heated liquid, thereby preventing the vessel from failing catastrophically. However, because the pressure at which the venting must be provided is low (thereby reducing the differential pressure which drives vapour through the vent), a large diameter vent is required to obtain the necessary venting capacity. Unfortunately, this large diameter opening in the top of the tank, or tank compartment, becomes a potential source of a major leak of product should the tanker roll over. For this reason, it is necessary to design the valve such that leakage is prevented in the event of roll-over. For example, leakage could occur due to a pressure surge created when the liquid contents impact on the underside of the EPRV. Some national standards include type-tests for EPRVs. These are intended to ensure that, in the event of tanker roll-over, any leakage of product is minimised. Physical protection from damage caused during roll-over is also normally required in order to protect tank-top fittings and thus prevent potential leakage in the event of an accident. The specifications for emergency engulfment valves, where they are required, are discussed in Section 3.

The majority of petroleum road tankers have tanks which are constructed from aluminium, although steel is also allowed under most design standards. Aluminium is used because of its light weight, which allows more cargo to be carried for a vehicle of a given gross weight.

2.2 Tanker shell thickness

The thickness of material used for the construction of tank walls depends on the material and the tank size and shape. ADR gives a method for calculating the minimum shell thicknesses allowable but also states that the minimum shell thickness shall not be less than 5 mm thick mild steel for tanks not more than 1.8 m in diameter and not less than 6 mm mild steel for tanks having a diameter greater than 1.8 m. For tank construction from other materials it gives a formula that can be used to obtain a steel-equivalent thickness. If a tank is provided with certain protection against impact damage (for example, if strengthening members, comprising partitions or double wall construction are used) these thicknesses may be reduced to “not less than the values given in Table 2 below.” For flammable liquid tankers, ADR does not deal with any provisions for protection against fire engulfment, and consequently any reduction in thickness for the cases where tankers are fitted with EPRVs is not considered.

Table 2. Tank shell thicknesses as defined in ADR

Minimum thickness of shells □	**Diameter of shell**	**[1.80 m**	**> 1.80 m**
	Stainless austenitic steels	2.5 mm	3 mm
	Other steels	3 mm	4 mm
	Aluminium alloys*	4 mm	5 mm
	Pure aluminium of 99.80%	6 mm	8 mm

* Note: Until recently, most aluminium alloys used have been ‘Type 5083’. Currently there is a move to using ‘Type 5186’ alloy.

There are also other requirements for double wall tanks and tanks divided into compartments of less than 5000 litres capacity, but the overall requirement is that in no case shall the thickness of the tank shell be less than 3 mm mild steel or an equivalent thickness of other material, as determined by the equivalent thickness formula given in ADR chapter 6.8.2.1.19. If a tank is required to withstand higher pressures, the ADR design codes can be used to determine the tank wall thicknesses that are required.

2.3 Philosophy of tanker design

Within Europe, in general, there are two philosophies adopted for the design of flammable liquid (including petroleum and derivatives) tanks. These differ based on the pressure at which the tank is designed to operate.

Firstly, there is an approach whereby the tanks are designed not to operate at pressures significantly above ambient i.e. a low pressure tank. These tanks are of BOX / MAX section geometry and are usually used for the carriage of petroleum and derivatives, although they may be used for other Class 3 flammable liquids. Because the tank does not need to withstand high pressures, the walls of the tank can be constructed of relatively thin material (in accordance with ADR). The pressure in the tank is controlled by a pressure/vacuum valve, operating during delivery and in case of pressure changes due to climatic changes. Additionally, in some countries (see section 1.2), the tanks are also fitted with an EPRV, which prevents the pressure in the tank from increasing if the tanker becomes engulfed in fire. Relieving the pressure in the tank reduces the risk of explosion. However, the tanker is usually still destroyed because the metal above the liquid-level in the tank melts, but the tank is unlikely to fail catastrophically. As the level of liquid falls, due to the fuel burning, more of the tank walls melt. This continues until the fuel is exhausted or the fire extinguished. In situations where an EPRV is not fitted to this type of tank it is possible/probable that over-pressurisation will occur under fire engulfment conditions.

Those low pressure tanks, used for the carriage of petroleum, that are not fitted with an EPRV (i.e. non-UK design in Table 1) are protected by pressure/vacuum valves which vent into the vapour recovery manifold, in accordance with EN 13082. The function of these valves is only to relieve pressure (into the vapour manifold) in case of thermal expansion/contraction within the tank. These valves typically open at ~ 0.05 bar over-pressure and ~ 0.025 bar vacuum. They are held open during charging/discharging, and in transit they are normally closed and operate according to their set pressures. The vapour manifold itself is protected by a combination valve which is open during voyage, but operates at over-pressures of ~ 0.08 bar and a vacuum of 0.015 bar during charging/discharging. In the case of a roll over, the set pressure of the main pressure relief valve is mechanically/pneumatically increased (activated by a float or weight, depending on the design) to ~ 0.25 bar in order to add the liquid head to the valve set pressure.

The alternative approach is to design a cylindrical tank having a pressure/vacuum vent valve and greater inherent strength, such that the tank can withstand internal pressures which are significantly greater than the ambient pressure. The integrity of the tank is provided by having a greater wall strength, which allows differences between internal and external pressure, due both to changes in ambient conditions and, to an unknown degree, due to engulfment by fire. During fire-engulfment, the vapour pressure in the tank increases due to an increase in the temperature of the liquid contents. At the same time, however, the strength of the metal tank walls decreases with an increase in temperature. The integrity of the tank will fail if the temperature of the metal exceeds its melting point or if the pressure in the vessel exceeds the strength of the walls. The time to failure and mode of failure for this design are unknown.

The different approaches result in the design and manufacture of significantly different tanks for the transport of flammable liquids. Whilst the approach to design differs, the designs themselves still follow the ADR code. Under existing and draft European Standards[5-10], for each type of tanker, the venting requirements of the EPRV, if fitted, must meet criteria similar[9] to those shown in Table 4 (see page 15). The venting requirements of the EPRV must be achieved at pressures less than the test pressure of the vessel to which it is attached. It should be noted that the specified venting rates will therefore be achieved at different internal tank pressures, because the test pressures for the two tanker designs are significantly different. For any tanker the minimum “Maximum Working Pressure” (MWP) shall be 25 kPa[10]. The actual required performance of the pressure/vacuum valves and EPRVs (with respect to lifting pressures, etc.) are still under discussion[8-10] in the drafting committees.

3. LEGISLATION AND CODES OF PRACTICE

The legislation and codes of practice governing the design and construction of flammable liquid tankers are considered below. It should be noted that the applicability of the provisions of ADR vary dependent upon the precedence afforded by national legislation in each participating country. For example, currently in the UK, national legislation takes precedence over ADR for national based carriers.

3.1 ADR

ADR gives extensive details of the basic design of tanks and tank vehicles. This includes the materials of construction and required wall thickness of tanks. It does not mention the provision of emergency pressure relief valves in the context of flammable liquid tankers. Under the dangerous goods listing in Chapter 3.2 of ADR, a tank code is given for petroleum distillate (UN1267). This tank code is LGBF; the ADR tank codes have the meanings shown in Table 3, below.

The ADR definition of a safety valve is:

‘ a spring-loaded device which is activated automatically by pressure the purpose of which is to protect the tank against unacceptable excess internal pressure;’

It is not clear how this differs from ‘pressure relief valves’ as no definition for these is provided in ADR. It is clear, however, from the lack of discussion of vent capacity, that these vents are not intended for fire-engulfment relief.

In section 4.3.4.1.2 of ADR, other, lower tier tank codes are permitted for each primary tank code. The other permitted codes for LGBF are LGBH; L1.5BN; L1.5BH; L4BN; L4BH; L4DH; L10BH; L10CH; L10DH; L15CH and L21DH. In effect, this means that any type of tank approved under national standards may be used for domestic carriage of petroleum without contravening the provisions in ADR.

Therefore, any European states which base their flammable liquid tanker regulations on the provisions of ADR will not generally have a requirement for emergency relief venting. However, the provision of such a vent is not precluded by ADR (ADR is a transport document and therefore fire engulfment is not considered).

Table 3. Description of ADR tank codes.

Part	Description	Tank code
1	Types of tank	L = tank for substances in the liquid state (liquids or solids handed over for carriage in the molten state); S = tank for substances in the solid state (powdery or granular).
2	Calculation pressure	G = minimum calculation pressure according to the general requirements of 6.8.2.1.14; or 1.5, 2.65, 4, 10, 15, or 21= minimum calculation pressure in bar (see 6.8.2.1.14).
3	Openings (see 6.8.2.2.3)	A = tank with bottom-filling and discharge openings with 2 closures; B = tank with bottom-filling and discharge openings with 3 closures; C = tank with top-filling and discharge openings with only cleaning openings below the surface of the liquid; D = tank with top-filling and discharge openings with no openings below the surface of the liquid.
4	Safety valves/devices	V = tank with a venting system but no flame trap; or non-explosion-pressure proof tank; F = tank with a venting system fitted with a flame trap according to 6.8.2.2.6; or explosion-pressure proof tank; N = tank with a safety valve according to 6.8.2.2.7 or 6.8.2.2.8 and not hermetically closed; these tanks may be fitted with pressure relief valves; H = hermetically closed tank (see 1.2.1).

Paragraphs 6.8.2.1.14, 6.8.2.2.3, 6.8.2.2.6, 6.8.2.2.7, 6.8.2.2.8 and 1.2.1 of ADR are reproduced in Appendix B.

3.2 UK legislation

The main regulations covering the transport of flammable liquids in road tankers within the UK are:

- *The Carriage of Dangerous Goods by Road Regulations 1996* (CDGRoad Regulations)[11]; and
- *The Carriage of Dangerous Goods (Classification, Packaging and Labelling) and Use of Transportable Pressure Receptacles Regulations 1996* (CDGCPL Regulations) [12].

The Carriage of Dangerous Goods by Road Regulations 1996 fully revoke the previous regulations applying to road tankers (Statutory Instrument 1992 no.743 *The Road Traffic (Carriage of Dangerous Substances in Road Tankers and Tank Containers*) *Regulations 1992)* (RTR) [13].

Several guidance documents are available, although only one is directly applicable to road tankers, namely:

- *The Carriage of Dangerous Goods Explained part 2: Guidance for road vehicle operators and others involved in the carriage of dangerous goods by road* (HS(G)161)[14].

This guidance contains information previously issued as an Approved Code of Practice (ACOP); *Design and construction of vented, non-pressure road tankers used for the carriage of flammable liquids*. This ACOP was revoked following the introduction of the CDGRoad Regulations 1996 and the subsequent withdrawal of RTR'92. Although CDGRoad do not impose requirements for EPRVs, the above guidance recommends that they are fitted to those types of tankers.

It is worthy of note that for rail tank wagons, which carry flammable liquids in the UK, Railway Group Standard GM/RT2101 sets out the requirements for safety valves to meet fire engulfment conditions. These tanks are always designed as cylindrical pressure tanks.

3.3 Germany

The relevant German legislation[15] is *'Gefahrgutverordnung Straße GGVS 1996'*, or *'Act on the transportation of hazardous materials by road'*. The part of this which refers to construction and testing of tank vehicles (i.e. Appendix B1a of the legislation) is almost identical to the regulations specified under ADR. As such, as far as is understood, the use of EPRVs for flammable liquid tankers in Germany is neither required nor are they in general use. However, this does not exclude the use of EPRVs on tankers for the transport of petroleum. In practice, a number of other European countries adopt the same approach as outlined in the German legislation.

NOTE: Because of the relative ease in obtaining information, Germany has been used as an example of an EU country where the fitting of EPRVs is not required.

3.4 United States

In 1990 the United States Department of Transportation's (DOT) Research and Special Programs Administration (RSPA) issued rules which established three new cargo tank specifications for the bulk transport of dangerous goods. These rules became fully effective in 1995. The specification for flammable liquid tankers is designated DOT 406 and is codified into US federal regulations (CFR49 part 178.346)[(16)]. The specification and regulations state that EPRVs must be fitted to these tanks. There is also an additional requirement which specifies the maximum leakage tolerated from the relief valves. Discussion with representatives from the American petroleum industry[(17)] also confirms that flammable liquid tankers without EPRVs would not be permitted in the US.

3.5 Australia

Australian requirements for flammable liquid tankers are covered in Australian Standard AS2809.2 1999[(18)]. Compliance with the standard is mandatory except for tankers covered by the following statement :

"any novel materials, designs, method of assembly, procedures, etc. which do not comply with specific requirements of this standard, or are not mentioned in it, but which give equivalent results to those specified are not necessarily prohibited....... but the specific approval remains the prerogative of the authority".

Under this standard, emergency relief venting is mandatory and for the EPRVs there is also a leak test, which is intended to simulate a pressure surge such as would occur when a vehicle rolls over.

4. VENT REQUIREMENTS

The vent requirements for UK, US and Australian tank specifications are compared below. Figures given in brackets have been converted to SI units. It should be noted that the SI unit for pressure (Pa) is strictly an absolute unit. However, in the interest of clarity, all references to pressure in SI units have been given as pressure above atmospheric.

4.1 UK Guidance document HS(G) 161

The relevant sections of Annex 5 of HS(G) 161 are reproduced below. These requirements are the same as those given in the Approved Code of Practice under the old Road Traffic (Carriage of Dangerous Substances in Road Tankers and Tank Containers) Regulations 1992.

Pressure relief devices

32 Each tank or tank compartment should be fitted with pressure relief devices as outlined in paragraphs 33-37. Any such device should communicate directly with the vapour space. No intervening shut off valve should be fitted between the tank and any pressure relief device.

33 Pressure relief devices should be fitted to provide for normal and emergency venting as described in paragraphs 34-37. Each device should be designed to minimise leakage of liquid, including that due to initial surge, past the device in the event of the vehicle rolling over. Excepting the loss due to initial surge, the maximum leakage rate should not exceed 15 ml in 30 minutes. This should not prevent the emergency venting device required in paragraph 36 from commencing to vent due to excess pressure at the designed pressure setting when the tank is in any position, even rolled over.

*36 Each compartment should be fitted with a venting device (or devices) which will limit the internal gauge pressure to not more than 0.35 bar when the tank is subjected to fire engulfment conditions. The venting device(s) should, at an internal gauge pressure not exceeding 0.35 bar have a capacity of not less than 240*m^3 *per hour of air for every square metre of exposed external surface area of the compartment.*

Another point which affects the venting requirements is that in the UK flammable liquid tankers for liquids with a flash point of less than 21 °C (this includes petrol) are required to be divided into compartments having a maximum nominal capacity of 7.6 m^3 (HS(G)161 Annex 5, para. 19).

Australian Standard AS 2809-2 1990 Road Tank Vehicles for Dangerous Goods; Part 2: *Tankers for flammable liquids*, Appendix B - *"Testing of vents, hatches and other tank top fittings for tank vehicles for dangerous goods*" contains details of drop tests for equipment fitted to tanker tops. These tests have been integrated into British and European Standards including; BS EN 13082:2001[(5)], *"Tanks for transport of dangerous goods - Service equipment for tanks - Vapour transfer valve"* (approved as a European Standard (EN 13082:2001) by CEN on 4 February, 2001), and two draft European Standards prEN 13314[(6)] ("*Tanks for transport of dangerous goods - Service equipment for tanks - Fill hole cover*") and prEN 13317[7] *("Tanks for transport of dangerous goods - Service equipment for tanks - Manhole cover assembly")*.

At least 50% of the total required[14] venting capacity must be provided by spring loaded, self-closing valves. The remainder may be provided by fusible venting devices. These should be actuated by elements which operate at a temperature not exceeding 120 °C.

4.2 United States DOT 406

The DOT 406 specification succeeded the old DOT MC306 specification in 1995. Pressure relief systems for road tankers (described as cargo tank motor vehicles in US legislation) are covered generally (for all types of cargo tank vehicles DOT 406, DOT 407, DOT 412) in 49 CFR part 178.345-10 and specifically, for pressure/vacuum vented flammable liquid tankers, (DOT 406) in part 178.346-3. The DOT 406 specification states that relief devices are required to:

- communicate directly to the vapour space in the tank, i.e. there should be no intervening shut off valve between the pressure relief device and the tank.
- open at not less than 110% of maximum allowable working pressure (MAWP) or 3.3 psig (22.75 kPa), whichever is greater and not more than 138% MAWP. The DOT 406 specification states that the MAWP (of the tank) must be no lower than 2.65 psig (18.3 kPa) and no higher than 4.0 psig (27.6 kPa). This gives a opening range for the relief valves of 3.3 to 5.5 psig (22.75 to 38 kPa).
- close at not less than the MAWP and remain closed at lower pressures.
- limit the tank internal pressure to not more than the tank test pressure.
- provide a minimum emergency vent capacity, as specified in a table in 49CFR. This table relates a vent capacity, in cubic feet of air per hour, to the exposed area of the tank, in square feet. For DOT 406 tanks, this capacity may be calculated at a pressure of not greater than 3 psig above the MAWP. For exposed tank areas below 200 square feet (18.6 m^2) the tabulated values equate to 790 cubic feet per hour vent capacity for each square foot of exposed tank area. This is equivalent to 240 m^3 for each square metre of exposed tank area.
- be able to withstand a dynamic pressure surge which reaches 30 psig (2.07 bar/206.8 kPa) above the design set-pressure and which is sustained above the set-pressure for at least 60 ms, with the total volume of liquid released not exceeding 1 litre, before the relief valve closes to a leak tight condition. This requirement must be met regardless of vehicle orientation.

There is also a requirement that the ability of valves to meet this requirement is demonstrated by type testing. An acceptable test procedure is referenced in the regulations. This test procedure is published by the Truck & Trailer Manufacturers Association (TTMA) as a recommended practice and it is known as; RP No. 81-97 (July 1, 1997) *Performance of Spring Loaded Pressure Relief Valves on MC 306, MC 307, MC 312, DOT 406, DOT 407 and DOT 412 Tanks*. This test is intended as a guide for determining the reseating capability of MC 306, MC 307, MC 312, DOT 406, DOT 407 and DOT 412 cargo-tank pressure relief valves in a roll-over condition.

4.3 Australia AS 2809-2 1999

The relevant Australian Standard is *"Road Tank Vehicles for dangerous goods Part 2: Tankers for flammable liquids".* The venting requirements under these regulations differ depending on whether the tanker in question is a 'small' or 'large' compartment tanker. These are defined as:

Small Compartment Tank A bulk container of one or more compartments, none of which exceed 8600 litres capacity.

Large Compartment Tank A bulk container of one or more compartments, having any one compartment which exceeds 8600 litres capacity.

The requirements applicable to both sizes of tank are as follows:

- Vents shall be connected to the vapour space.
- Shut-off valves shall not be installed between the tank opening and the vent.
- Vents shall be designed and installed to prevent leakage of liquid past the vent in the event of surge or vehicle overturn. There is a specified type and check test for vent valve compliance with this requirement as an appendix to the standard. In this test procedure no limits are given for leakage on initial surge but subsequent leakage is required to be less than 10 ml per minute.

Emergency vent requirements specifically for small compartment tanks are:

- The vent should open at 30 ±3 kPa (4.4 ± 0.4 psig) and should be fully open at a maximum pressure of 45 kPa (6.5 psig).

Emergency vent requirements for large compartment tanks are:

- The vent should open at 45 ± 3 kPa (6.5 ± 0.4 psig) and should be fully open at 60 kPa (8.7 psig).

In both cases, the vent capacities are given in a table, which relates vent capacity in $m^3 hr^{-1}$ to the exposed area of tank compartment. These capacities are at the vent fully-open pressure given above.

[Blank]

5. COMPARISON OF VENT REQUIREMENTS

The minimum required vent capacities given in the Australian and US requirements have been converted to SI units, where necessary, and plotted on a graph together with the straight line of 240 $m^3 h^{-1}$ per m^2 of exposed surface area from the UK Code of Practice (described in section 4.1). These are shown in Figure 1.

From this graph it is evident that the three are very similar except that the UK guidance does not show a change in vent capacity at an exposed tank surface area of 20 m^2. In practice, however, the UK code would never be used for exposed tank areas larger than 20 m^2 because the limit for the volume of the tanker compartment is 7.6 m^3. Most tank compartment geometries of this volume would have a surface area, which could be exposed to fire, of significantly less than 20 m^2. It can be concluded, therefore, that the UK guidance, in the region where it is applied, is identical to the other two. The Australian standard is effectively the same for their small compartment tanks, in that the maximum size is 8.6 m^3. For large compartment Australian tanks, the standard is identical to that used by the US in their regulations. The fact that all these vent capacity requirements are effectively the same, leads one to the conclusion that they are likely to be based on data from the same source. This does appear to be the case, with the source of the data being API 2000[(19)] (*Venting Atmospheric and Low-Pressure Storage Tanks, Non-refrigerated and Refrigerated*). In this document there is a table which gives the total rate of emergency venting required against the wetted surface area, for fire exposure of non-refrigerated, above ground tanks (The API 2000 code is applicable to tanks designed for operation at pressures ranging from vacuum to 15 psig (103.4 kPa)). This table is reproduced below with additional columns for conversions to SI units.

The data shown in Table 4 (for areas up to 1000 square feet (92.9 m^2)) have been plotted on the graph in Figure 2 along with the figures obtained from the specific road tanker venting requirements in the various codes. It can be seen that the API data require a significantly higher venting capacity for a given surface area. This discrepancy is due to the use of 'exposed wetted area' in the API document and the simplified use of 'exposed tank area' in the specific road tanker documents. Exposed wetted area means the area of the tank which is both exposed to fire and also in contact with the liquid inside the tank - it does not, therefore, include the area of the tank surface which bounds the ullage space. The API 2000 table also includes several notes on its applicability. One of these is relevant to a road tanker situation, namely:

The wetted area of a tank or storage vessel shall be calculated as follows:
.... for a horizontal tank the wetted area is equal to 75 percent of the total surface area ...

Since road tanker tanks are invariably horizontal, this can be seen to apply in all cases. Consequently, the road tanker vent requirements based on total tank area in the codes have been reduced by 25% from that specified in the API 2000 document. When this adjustment is applied to the API figures, they are nominally (subject to rounding and unit conversion) the same as the road tanker codes.

Table 4. Total rate of emergency venting required against the wetted surface area, from API2000

Wetted area		Venting requirement		Wetted area		Venting requirement	
ft^2	m^2	SCFH	m^3 h^{-1}	ft^2	m^2	SCFH	m^3 h^{-1}
20	1.9	21,100	597	350	32.5	288,000	8,155
30	2.8	31,600	895	400	37.2	312,000	8,835
40	3.7	42,100	1,192	500	46.5	354,000	10,024
50	4.6	52,700	1,492	600	55.7	392,000	11,100
60	5.6	63,200	1,790	700	65	428,000	12,120
70	6.5	73,700	2,087	800	74.3	462,000	13,082
80	7.4	84,200	2,384	900	83.6	493,000	13,960
90	8.4	94,800	2,684	1,000	92.9	524,000	14,838
100	9.3	105,000	2,973	1,200	111	557,000	15,772
120	11.1	126,000	3,568	1,400	130	587,000	16,622
140	13	147,000	4,163	1,600	149	614,000	17,387
160	14.9	168,000	4,757	1,800	167	639,000	18,094
180	16.7	190,000	5,380	2,000	186	662,000	18,746
200	18.6	211,000	5,975	2,400	223	704,000	19,935
250	23.2	239,000	6,768	2,800	260	742,000	21,011
300	27.9	265,000	7,504	>2,800	>260	-	-

Because these data are intended for static tanks, the figures continue into a range covering larger tank areas than those needed to be considered for road tanker sizes.

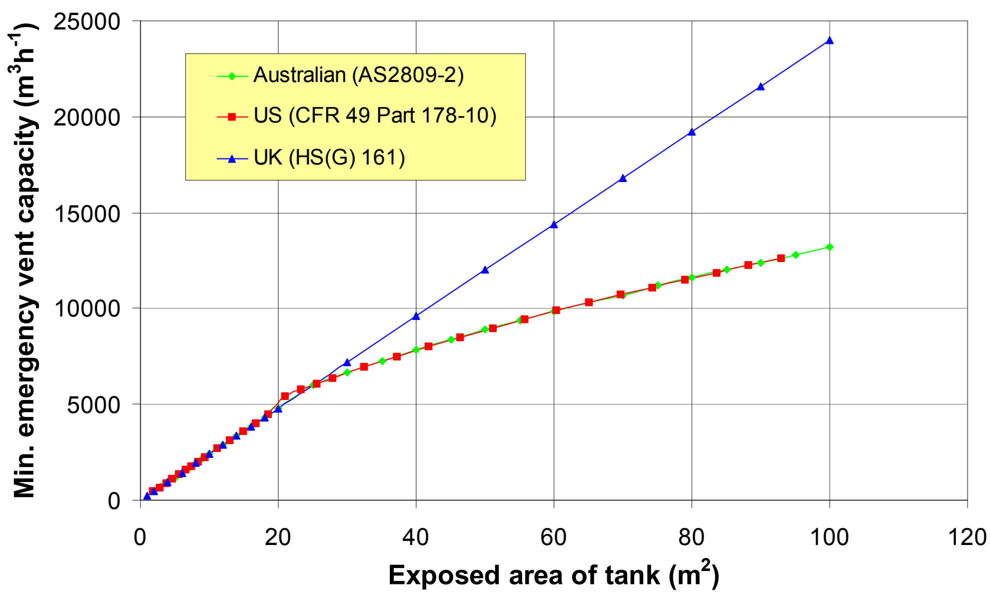

Figure 1. Comparison of minimum vent requirements

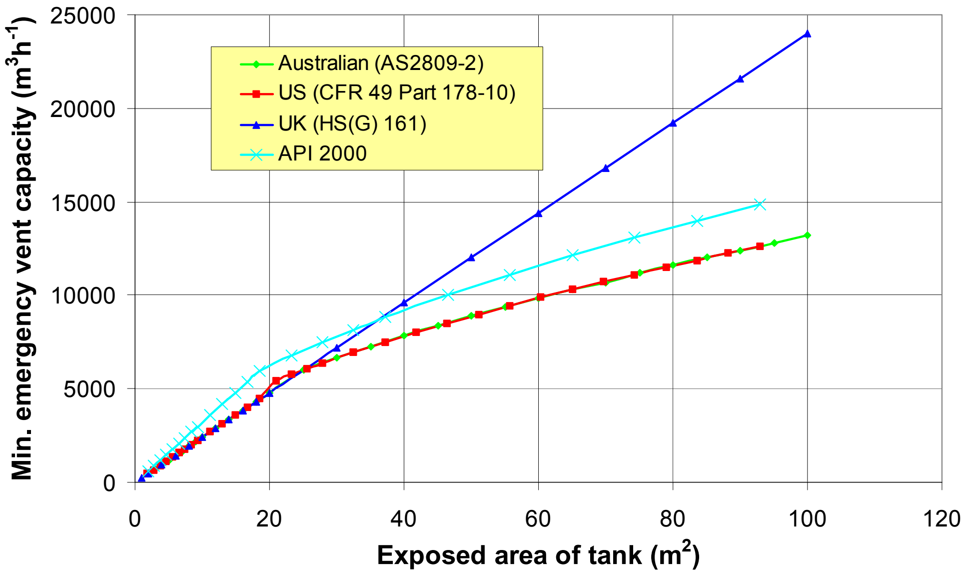

Figure 2. API 2000 vent capacities compared with road tanker codes.

5.1 Derivation of API venting requirements

Since all the vent requirements examined for road tankers are essentially derived from the same source, it is useful to consider what type of fire or heat input was envisaged when the figures for venting requirements in API 2000 were derived. The current venting requirements in API 2000 are based on large scale tests carried out in 1961, in which a horizontal tank measuring 8 feet x 26 feet 10 inches (2.4 m x 8.2 m) was subjected to fire engulfment and the pressure in the tank measured. The data for heat absorbed (Q) by an atmospheric, or low pressure, tank in the event of fire engulfment were derived from these tests. When the results are plotted against wetted surface area on a log-log graph, the plot takes the form of three straight lines. For the sizes of tank carried on road tanker vehicles, only the first two of these are applicable. The first line is drawn between 400,000 BTU h^{-1} (117 kW) at 20 square feet (1.86 m^2) and 4,000,000 BTU h^{-1} (1172 kW) at 200 square feet (18.6 m^2). The equation for this line is:

$$Q = 20{,}000 \times A \text{ (imperial units) or}$$

$$Q = 63 \times A \text{ (SI units),}$$

where A is the wetted surface area. The second line is between 4,000,000 BTU h^{-1} at 200 square feet (18.6 m^2) of wetted surface and 9,950,000 BTU h^{-1} at 1000 square feet (92.9 m^2) of wetted surface area. The equation for this portion of the correlation is:

$$Q = 199{,}300\ A^{0.566} \text{ (Imperial units) or}$$

$$Q = 224.1\ A^{0.566} \text{ (SI units).}$$

It can be seen, therefore, that the assumption in the API code is that, for fire engulfment, the heat absorbed by a tank of up to 18.6 m^2 wetted surface area will be 63 kWm^{-2}. In the case of larger surface areas, the figure for heat absorbed ranges from 63 kWm^{-2} at 18.6 m^2 to 31 kWm^{-2} at 92.9 m^2 of wetted surface area. These heat values, in kW, are then converted to a venting requirement, calculated in cubic metres of air, based on the assumption that the stored liquids will have the characteristics of hexane and the venting will occur at 15.5 °C. The formula given is:

$$Q_a = 70.5\ Q/LM^{0.5}$$

where	Q_a	=	Required flow capacity in SCFM of air
	70.5	=	Factor converting pounds of vapour to cubic feet of air
	Q	=	Total heat input in BTU h^{-1}
	L	=	Latent heat of vaporisation for hexane in BTU lb^{-1} = 144 kJ kg^{-1}
	M	=	Molecular weight for hexane = 86.17

The factor 70.5 is given in API 2000 and is based on the vapour density of hexane at 15.5°C. All other values given are also taken directly from API 2000.

Converting this equation to SI units gives:

$$Q_a = 4.39\ Q/LM^{0.5}$$

where	Q_a	=	Required flow capacity in m^3s^{-1}
	4.39	=	Factor converting kg of vapour to m^3 of air
	Q	=	Total heat input in kW
	L	=	Latent heat of vaporisation for hexane in kJ kg^{-1} = 334 kJ kg^{-1}
	M	=	Molecular weight for hexane = 86.17

The values of physical constants used in this conversion are those given in imperial units in API 2000. These values do not always agree with current literature values for physical constants for hexane.

The values calculated for the venting capacity have then been reduced by 25% in the road tanker codes to account for the use of total tank area as opposed to the wetted area used in API 2000.

6. FIRE SCENARIOS

The fire scenarios which could be envisaged to involve a road tanker are:

- Spillage of some of the contents, followed by ignition, resulting in full or partial pool-fire engulfment;
- Limited fire-impingement, caused by a vehicle fuel fire or cab fire whilst the tractor - semi-trailer unit is jack-knifed;
- Brake or bearing failure, partial or full tyre deflation, followed by tyre/mudwing fire; or
- Jet fire, caused by fracture of a tank compartment when contents are already above their boiling point.

These fire scenarios are considered further below.

6.1 Pool fires

The heat input to a tank from total engulfment in a pool fire is the fire scenario primarily addressed in the road tanker codes and is quantified, as stated earlier, as 63 kW for each square metre of wetted surface area. The actual heat which can be produced by engulfment by a pool fire can, however, be higher than this. Moodie(20) performed experiments on fire engulfment of a 5 tonne horizontal LPG tank, with dimensions 1.7 m diameter x 4.88 m length, from a road tank vehicle. The tank was engulfed in flames from a kerosene pool fire contained in a deep tray measuring 6.8 m x 3.8 m. The tank was supported approximately 0.15 m from the surface of the pool and calorimeter tubes were positioned at three heights (0.5, 1.0 and 1.5 m above the pool) and 1.35 m from the vertical centreline of the tank in order to measure the heat flux from the fire. The directly measured heat fluxes in these experiments peaked at approximately 85 kW. The authors state that if this value is corrected for the absorptivity of the surfaces of the calorimeter loop, then the maximum average flux densities were 105 kWm^{-2} and that this is fully consistent with other measurements. The most likely scenario involving complete fire engulfment of a flammable liquid tanker is as follows; an accident, which causes the rupture of one compartment of a multi-compartment tanker, with the spilt product igniting, producing a pool fire, which engulfs the remaining intact compartments.

6.2 Limited engulfment

The case of limited fire impingement from burning fuel and tyres from a jack-knifed tractor-trailer is one in which the presence of relief valves is likely to have the most effect. This is because the tanker is still upright and most probably intact. There is unlikely to be enough heat available from this type of fire to compromise the integrity of the tank wall, although there may be sufficient heat input to raise the temperature of the contents of the tank. This would subsequently cause opening of EPRVs, if fitted.

6.3 Tyre fires

It is stated by the Institute of Petroleum that there have been a number of incidents where the tyres on petroleum tankers have caught fire[(21)]. These fires may be caused, for example, by the failure of a wheel bearing or brake or possibly by full or partial deflation of the tyre. A tyre fire on a petroleum tanker is perhaps the most likely cause of a fire threatening the integrity of an undamaged cargo tank and its contents. A report by the Warrington Fire Research Centre[(22)] investigated the burning behaviour and heat output of fires involving tyres from large tankers. In these tests, burning was initiated by the application of an external flame and the fire was found to extend over an area of the tanker surface of approximately 0.15 m^2 and gave a heat output of between 100 and 150 kW. However other tests showed that when the tyre was ignited from the inside (such as may occur from brake or bearing seizure, leading to ignition of the inner-tyre material), larger fires, in which the heat output exceeded 900 kW, could be obtained. The Institute of Petroleum has made recommendations, as a result of the fire tests carried out by the Warrington Fire Research Centre, that mudwings located under the cargo tank on petroleum road tankers should provide a minimum of 20 minutes fire protection to allow sufficient time for the emergency services to reach the incident and deal with the fire.

6.4 Jet fire

Jet-fire impingement on the cargo tank of a petroleum road tanker is considered to be extremely unlikely. It is also impractical to size relief vents on a mobile tank for this scenario. This is due to the very high heat fluxes produced with jet-fire impingement. It has been shown that for a 1.7 kg s^{-1} flashing liquid (LPG) jet the heat flux can be as high as 200 kW m^{-2} [(23)]. At this level of heat input, the wall of a road tanker with a thin shell, particularly one constructed from aluminium, would fail at a point above the liquid fill level very quickly.

7. RESEARCH

As stated earlier, nearly all legislation relating to the requirements of EPRVs is based on information contained within API 2000. This information was obtained in a series of tests undertaken in Tulsa, Oklahoma, in 1961. The details of these tests are given in Section 5.1.

Little information relating to any subsequent testing has been discovered in the course of this work. However, two series of tests relating to the behaviour of flammable liquid tankers in fire-engulfment scenarios have been found.

Firstly, tests were undertaken on a Glass Reinforced Plastic (GRP) tanker at the Health and Safety Laboratory, in 1980 [(24)]. In these tests, a single compartment from a GRP tanker was exposed to engulfment by a pool fire. However, the compartment was not sealed with an EPRV and the vessel was only fitted with a limited number of instruments. The results do not add any additional information with respect to the behaviour of EPRVs.

In 1975, a series of tests was carried out at the Fire Research Establishment, on behalf of the Ministry of Defence (Royal Armament Research and Development Establishment (RARDE))[(25)]. In these tests, compartments made from aluminium, steel and GRP, taken from tankers, were part filled with flammable liquid and exposed to pool fires. However, limitations on the trials restricted the exposure to fire to a maximum of 15 minutes. This, combined with the compartments only being fitted with 4 thermocouples, does not provide any significant, additional information.

The largest series of tests involving tankers for the transport of flammable liquids was undertaken at the Federal Institute for Materials Research and Testing (BAM) in Germany. These tests were undertaken under the THESEUS [(26)] project (1995), entitled *"Tank-Vehicles with Maximum Attainable Safety through Experimental Accident Simulation"*. The main theme of these tests was the behaviour and response of tankers as the result of impacts, either from the sides or ends, and roll-overs. The test series did not involve any fire-engulfment trials. However, limited information relating to the behaviour of tanks was obtained in relation to their behaviour during roll-over. The report, which included a statistical survey of release occurrences, states that 25 % of the main causes of releases of dangerous substances are due to leaking domed lids and only 2 % due to open domed lids. The remaining releases are due to damage to the walls of the tanks. In this case, however, domed covers are for filling or inspection purposes and do not include EPRVs.

From the information obtained, it appears that the behaviour of tankers fitted with EPRVs, or even those without, has not been tested under fire-engulfment scenarios. Thus, the current legislation adopted in many countries is generally without suitable scientific support, other than a limited number of trials undertaken in 1961.

[Blank]

8. ACCIDENTS

Database searches were made in order to compile information on accidents involving road tankers with flammable loads. However, a large number of returned references were unusable for one of the following reasons;

- there were insufficient details of the type of accident or tanker;
- the accident occurred in a developing country where the tanker specification is unclear; or
- there was a large quantity of detail provided but this mostly concentrated on fire fighting and control of run-off.

The tanker accidents for which relevant details were available are discussed below.

8.1 MHIDAS

The Major Hazard Incident Data Service, operated by AEA Technology on behalf of HSE, was searched for incidents involving flammable liquid road tankers. 13 relevant entries were identified and the records obtained. Many of these records contain few details of the incidents, other than press reports at the time of the incident, making it difficult to arrive at any conclusions regarding the circumstances. The reliability of most reports of tanker fires is further compromised by the use of the term “explosion” interchangeably with “flash-over”, particularly in press reports of accidents. However, it would appear that most of the incidents for which records have been obtained involve a tanker in a road accident, subsequent spillage of petrol due to tank rupture, followed by ignition of the spilled fuel. It is this ignition and resulting flash fire which is usually referred to as an explosion in these reports and not an explosive rupture of the tank container.

Of the records which contain a reasonable level of detail, two of them indicate that the contents of the tankers were spilled immediately on impact of the tanker with street furniture. In both cases the tankers were carrying petrol. These two incidents were a tanker fire at Herborn, Germany, in July 1987 and a tanker fire at Johnson City, New York, US, in September 1986. Both of these incidents were attributed to excessive speed during cornering and both resulted in total loss of the tanker contents due to rupture or collapse of the cargo tank.

Two of the other records seem to indicate that the presence of fire engulfment relief valves was important in the safe resolution of the incident. The first of these is the Sunderland, Tyne & Wear, UK tanker fire on 26 August 1992, in which, initially, only the front part of the tanker was engulfed in flame. Fire crew at the scene reported hearing muffled explosions, followed by the rest of the tanker becoming engulfed. This is consistent with ignition of petrol vapour as EPRVs on compartments of the tanker opened. Another factor which is evident from the Sunderland incident is that the sections of the tanker walls which were above the liquid level, and hence not subject to cooling by the tank contents, were melted and burnt away, although it is not clear at what point during the fire this occurred. The second incident in which the presence of fire engulfment relief valves may have had an influence on the outcome was a collision between an articulated lorry and a petrol tanker at Immingham on Humberside, UK. The petrol tanker was carrying 14,000 litres of petrol and caught fire after being shunted up the highway embankment. When interviewed by the press after the fire, the deputy chief fire officer for Humberside indicated that the fire engulfment relief devices fitted to the tanker were instrumental in preventing an explosion.

8.2 Other accident data

In a report by the Advisory Committee on Dangerous Substances (ACDS)[27], the two main causes of spillage from road tankers carrying dangerous goods and rail tank wagons were identified as puncture or damage to the tanker/wagon following an accident and failure or mal-operation of the tanker/wagon equipment.

In 1984, the Traffic Accident Unit, Traffic Authority of New South Wales, Australia, produced a research report[28] on accidents involving road tankers with flammable loads. This study covered 15 months during 1979-1980 and investigated 42 incidents involving vehicles carrying bulk flammable liquids. Of the 42 incidents investigated, roll-over occurred in 18 cases. In 10 of these substantial liquid leakage occurred from hatch gear or vents, punctures, dislodged caps and one from a hole burnt by a fire. Two of the tankers which did not roll over were punctured and burnt out. This study showed significant incidence of leakage from tank venting equipment. However, the study was carried out before the implementation of the stringent rules and test for leakage from these devices introduced in AS2809 - 2 1990.

In 1992, a paper was published in Fire Engineering, entitled *"Flammable Liquid Releases from MC306 Tankers: an overview"* [29]. The MC306 is an old US tank specification which was replaced by the DOT 406 specification. A general description of the MC306 is:

"Tanks built after December 1, 1967 and prior to April 21, 1994, meeting US DOT specification MC 306 as defined in 49 Code of Federal Regulations 178.341. This tank is typically used to carry gasoline, fuel oil, alcohol, or other liquid flammables. This tank is typically constructed of aluminum and designed for atmospheric pressure. This tank is a predecessor of the DOT 406 cargo tank."

Under MC306, fire engulfment relief valves were also required to be designed 'so as to prevent leakage of liquid past the device in case of surge or vehicle upset' but no test procedure was specified.

The paper referred to above lists the typical causes of liquid releases from this type of tank. It states that rollovers are the most common cause of releases of liquid through tank gear, including vents and manways, and by damage to the shell of the tanker. US DOT information is also cited and indicates that one third of reported incidents to tankers involve a rollover and that if the rollover involves an MC306 tanker there will be a release of product in two thirds of cases.

This document also gives a detailed account of the effects of limited fire engulfment on this type of tanker by reference to an incident which occurred on Highway 65 in the United States. This incident involved a jack-knifed tractor-trailer unit which remained in an upright position. The tractor fuel, tyres and glass reinforced plastic cab caught fire and engulfed one end of the tanker. The EPRVs on the tanker operated and produced a high pressure plume of ignited vapour from the vents, the radiant heat from these plumes melted the top of the aluminium tanker, resulting in a larger fire but no danger of over-pressurisation of the tank. It should be noted however that the MC306 specification, in common with the current DOT406 specification and most other regulations and codes, allows the construction of tanks from various steels as well as from aluminium. The radiant heat from an ignited EPRV plume would not melt the top of a steel tank, but the total heat input to the tank and its contents would be increased significantly.

In 1995, a tanker carrying petrol was involved in a rollover accident near Gatwick Airport (UK). The fire engulfment valves in the manlids failed and the entire load of the vehicle was lost. The failure of the valves, which were of a design which had successfully prevented such incidents for several years, was attributed to an increase in surge pressure acting on the valves during rollover. This was shown to be due to the particular design of the tanker, which was much stiffer than the usual UK designs.

In 1999, a 35 tonne petrol tanker caught fire on the A34 near Oxford, UK and was effectively destroyed. The investigation into the incident indicated that one of the wheel bearings on the triple axle, single wheel, semi-rigid trailer overheated and caught fire. The fire melted a 100 mm fill-line which was located under the tanks and appeared to have been filled with petrol. The fuel in the fill-line added to the fire, which melted foot valves in the leading compartments. The escalating fire engulfed the tanker, leading to the destruction of the tanker body. The EPRVs are believed to have activated, preventing an explosive rupture of the tanker. The body was destroyed when the fuel in the tanker burnt and the tanker walls melted. It is thought that the fire in the wheel bearing spread so rapidly because there was no heat barrier between the wheels and the feed-pipe. Analysis of material from the tanker indicated that the body was made from 5083 Grade aluminium, the outer walls were 5.5 mm thick and the compartmental walls had a thickness of 4 mm.

8.3 Emergency pressure relief valves (fire engulfment valves) and product containment in the event of rollover

All of the standards examined have specifications for the prevention of leakage from tank top fittings such as emergency pressure relief valves. Several tank equipment manufacturers offer valves which pass the various national tests (the most severe of which is the US DOT 406 requirement). However, the ability of a spring operated relief valve to contain a pressure surge and reseat depends on the magnitude of the pressure surge within the tank. As a result of the tanker rollover in 1995 (discussed above) where relief devices failed due to a pressure surge, allowing the loss of the entire load of the vehicle, research was conducted on behalf of the Health and Safety Executive[30]. This research involved finite element analysis of two tanker designs and indicated that the magnitude of the pressure surge could be directly correlated with the stiffness of the tank construction. One of the tanker designs examined had a tank that was considerably higher in lateral stiffness than the more usual UK designs. In this study, it was estimated that in the stiffer design of tanker the pressures due to surge on rollover would be at least 4 - 5 bar and could be more if the tank walls moved. This pressure was in contrast to the estimated pressure surge in a typical UK design tanker of between 1.5 and 2 bar. It can be seen therefore that the construction of the tanker has an important effect on the performance of the relief valves and other tank top fittings.

Another concern in the event of tanker rollover is that the manlids or valves will be damaged by impact. All the standards examined require some type of protection to be fitted to the top of the tanker to prevent damage to the manlids in the event of rollover. The potential for damage to tank top fittings is present whether or not fire engulfment relief is fitted, as it is a requirement of ADR that manways are included in tank compartments to allow for inspection.

9. CONCLUSIONS

The following conclusions are drawn:

- The venting requirements for low and atmospheric pressure tanks in the various national codes are based on API 2000.

- The emergency venting recommendations in API 2000 are based on fire tests performed on a single tank geometry in 1961.

- No records of controlled fire engulfment of complete, low pressure road tanker tanks have been found. (Some tests have been undertaken on compartments or sections of tankers, but not whole tankers.)

- There is evidence to suggest that thermal radiation from burning fuel vapour from an open EPRV may result in the top of an aluminium tank melting (but there would be no explosion due to internal tanker pressure).

- Emergency pressure relief provision is universally recognised as being desirable on static tanks, but the situation for low pressure road tankers used for flammable liquids is less clear.

- EPRVs which pass containment tests on rollover are required in US and Australian codes. (Note: The containment test of the Australian code is largely adopted by the UK, and contained within current EN standards.)

- EPRVs which pass containment tests are readily available from a number of manufacturers.

- The US DOT 406 specification has the most stringent product containment requirements.

- The ability of EPRVs to contain product on tanker rollover may be affected by the strength of the tank.

- In the available literature, no reports have been found of catastrophic low pressure tanker rupture, where relief valves have not been fitted,   However, this may simply reflect the limited number of reports, rather than incidents not occurring.

- Steel tanks (if used) may perform differently from aluminium in the event of fire engulfment.

- No validation trials have been undertaken in order to confirm the efficiency of EPRVs fitted to tankers, or the behaviour of tankers not fitted with EPRVs, when engulfed in fire.

- Evidence from reported incidents suggests that EPRVs do offer protection for tankers engulfed in fire and limit the consequences of the incident.

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10. RECOMMENDATIONS

The following recommendations are made:

- Carry out trials to investigate the effect of fire engulfment on non-cylindrical (especially BOX / MAX section), low pressure tankers used for the carriage of petrol, when fitted with either EPRVs, or other pressure relief devices as currently used in Europe.

- Provide relevant information from these studies to TC296 Working Group 9 to assist in producing a unified approach across the EU.

- Consideration should be given to a similar study to investigate the behaviour of cylindrical, pressure tankers .

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11. ACKNOWLEDGEMENTS

The authors gratefully acknowledge contributions from the following organisations:

Alfons Haar.

Collins Youldon Ltd.

Emco Wheaton UK Ltd

F.A. Sening.

Federal Institute for Materials and Testing ((Bundesanstalt für materialforschung und -prüfung)BAM) in Berlin.

Hoyer UK Ltd.

Physikalisch-Technische Bundesanstalt (PTB), Germany.

Shell U.K. Oil Products Ltd.

TC296/WG9 Committee.

TKS (Sweden).

[Blank]

12. REFERENCES

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5) BS EN 13082:2001, "*Tanks for transport of dangerous goods - Service equipment for tanks - Vapour transfer valve*", British Standards Institute.

6) prEN 13314, "*Tanks for transport of dangerous goods - Service equipment for tanks - Fill hole cover*", European Committee for Standardization (CEN; Comité Européen de Normalisation).

7) prEN 13317, "*Tanks for transport of dangerous goods - Service equipment for tanks - Manhole cover assembly*", European Committee for Standardization (CEN; Comité Européen de Normalisation).

8) prEN WI 296009, "*Tanks for transport of dangerous goods - Service equipment for tanks - Pressure and vacuum breather valve*", European Committee for Standardization (CEN; Comité Européen de Normalisation).

9) prEN WI 296010, "*Tanks for transport of dangerous goods - Service equipment for tanks - Emergency pressure relief valve*", European Committee for Standardization (CEN; Comité Européen de Normalisation).

10) CEN/TC 296WG9 N27, "*Tanks for transport of dangerous goods - Service equipment (including dimensions) for tanks*", European Committee for Standardization (CEN; Comité Européen de Normalisation).

11) *The Carriage of Dangerous Goods by Road Regulations 1996*, Statutory Instrument 1996 No. 2095, ISBN 0 1106 2926 4

12) *The Carriage of Dangerous Goods (Classification, Packaging and Labelling) and Use of Transportable Pressure Receptacles Regulations*, 1996 (CDGCPL Regulations). Statutory Instrument 1996 no.2092, ISBN 0 1106 2923 X

13) *The Road Traffic (Carriage of Dangerous Substances in Road Tankers and Tank Containers) Regulations 1992*, Statutory Instrument 1992 no.743, ISBN 0 1102 3743 9

14) *The Carriage of Dangerous Goods Explained part 2: Guidance for road vehicle operators and others involved in the carriage of dangerous goods by road* (HS(G)161), Annex 5 Guidance on the design and construction of the tanks of road tankers. HSE Books, ISBN 0 7176 1253 8.

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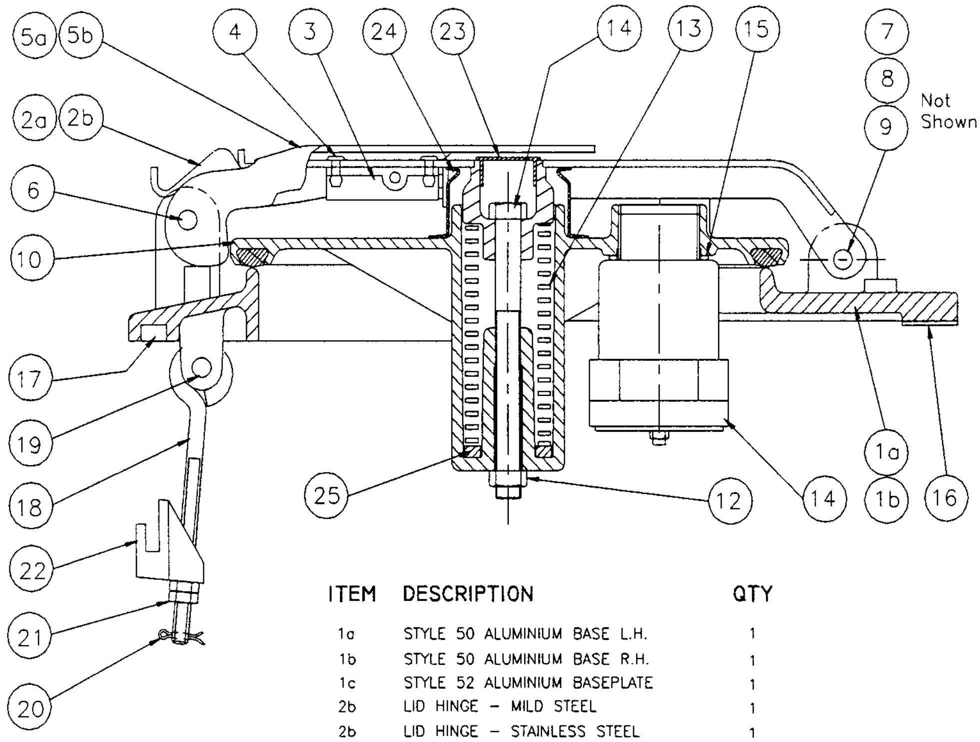
APPENDIX A

EXAMPLES OF PRESSURE RELIEF VALVES

A1 MANHOLE WITH EMERGENCY PRESSURE RELIEF



ITEM	DESCRIPTION	QTY
1a	STYLE 50 ALUMINIUM BASE L.H.	1
1b	STYLE 50 ALUMINIUM BASE R.H.	1
1c	STYLE 52 ALUMINIUM BASEPLATE	1
2b	LID HINGE – MILD STEEL	1
2b	LID HINGE – STAINLESS STEEL	1
3	STAINLESS STEEL LOCK	1
4	STAINLESS STEEL RIVET	4
5a	LID CLAMP – MILD STEEL	1
5b	LID CLAMP – STAINLESS STEEL	1
6	HINGE PIN for CLAMP	1
7	HINGE PIN for HINGE	1
8	3/8" DIA.PLAIN WASHER	4
9	3/8" PLIER TYPE CIRCLIP	4
10	FILL COVER AND GASKET	1
11	CENTRE BOLT	1
12	1/2" UNC AEROTITE NUT	1
13	STYLE 50 SPRING	1
14	PPV VENT – 4.5mbar	1
14	PPV VENT – 20 mbar	1
15	'O'RING	1
16	STYLE 50 FLANGE GASKET	1
17	STYLE 52 BASEPLATE GASKET	1
18	STYLE 52 EYEBOLT	6
19	STYLE 52 CLEVIS PIN	6
20	STYLE 52 SPLIT PIN	12
21	STYLE 52 LOCK NUT	12
22	STYLE 52 HOOK CLAMP	6
23	POLYTHENE PLUG	1
24	RUBBER BELLOWS	1
25	STYLE 50 SPRING SPACER	1

Figure A1. Example (1) of a manhole cover with emergency pressure relief valve. Picture courtesy of Collins Youldon Ltd.

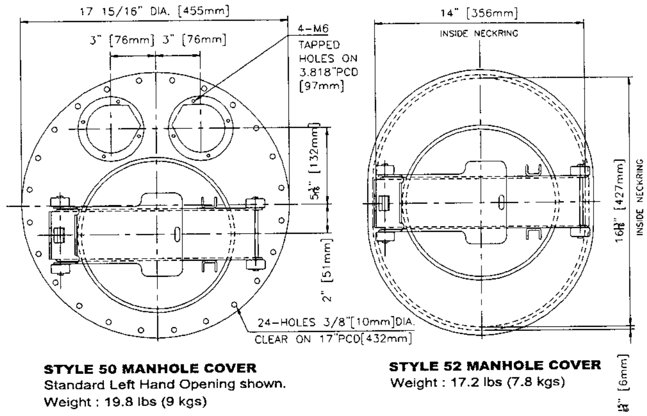
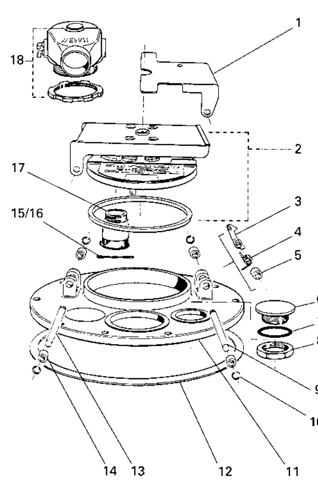


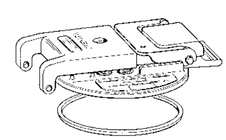
Figure A2. Two examples of manhole covers with emergency pressure relief valves. Picture courtesy of Collins Youldon Ltd.



REF	DESCRIPTION	PART NO. F0355-003	PART NO. F0355-004	QTY
1	Cover Arm Lever	618835	618835	1
2	Fillcap & Coverarm Assy	619474	619474	1
3	Latch Plate	618746	618746	1
4	Latch Spring	618825	618825	1
5	Spacer	618765	618765	3
6	Plug	619366	619366	1
7	O-Ring	619367	619367	1
8	Backnut 2" BSPP	619409	619409	1
9	Latch Pin	618763	618763	1
10	Circlip	419358	419358	4
11	Baseplate	619403	619281	1
12	Gasket	619431	619431	1
13	Hinge Pin	618762	618762	1
14	Spacer	618764	618764	2
15	Vent Lockwire	RM09940	RM09940	1 ft
16	Seal	367793	367793	1
17	P.V. Vent	614310	614310	1
18	Vapour Vent	F0592-301	F0592-301	1

Items 6 to 8 and 18 optional

Note: Variants illustrated are fitted with a standard 70/20 P/V vent suitable for bottom loading vapour recovery. Please consult Emco Wheaton if alternative variants are required.



Optional aluminium coverarm available.

Figure A3. Typical parts breakdown of manhole cover with emergency pressure relief valve. Picture courtesy of Emco Wheaton UK Ltd.

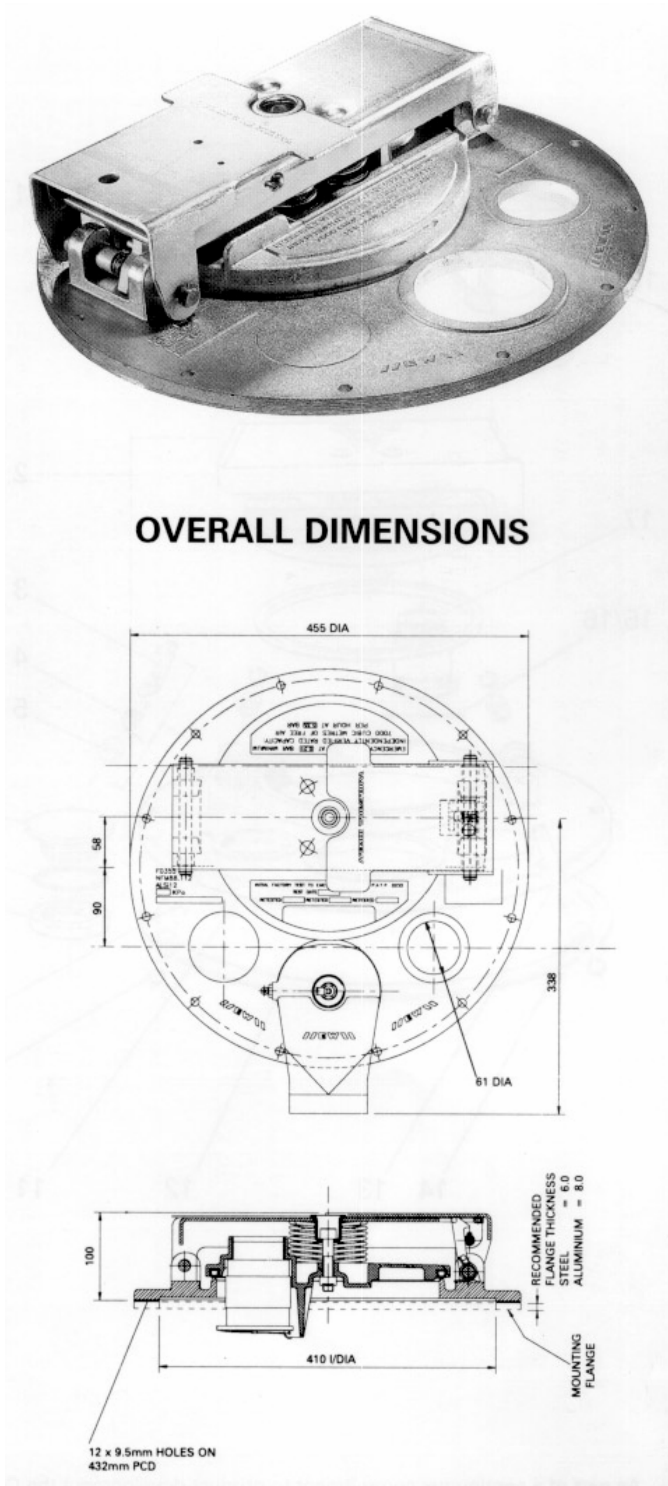


Figure A4.

Detail of a manhole cover with emergency pressure relief valve.
Picture courtesy of Emco Wheaton UK Ltd.

A2 PRESSURE/VACUUM VENT

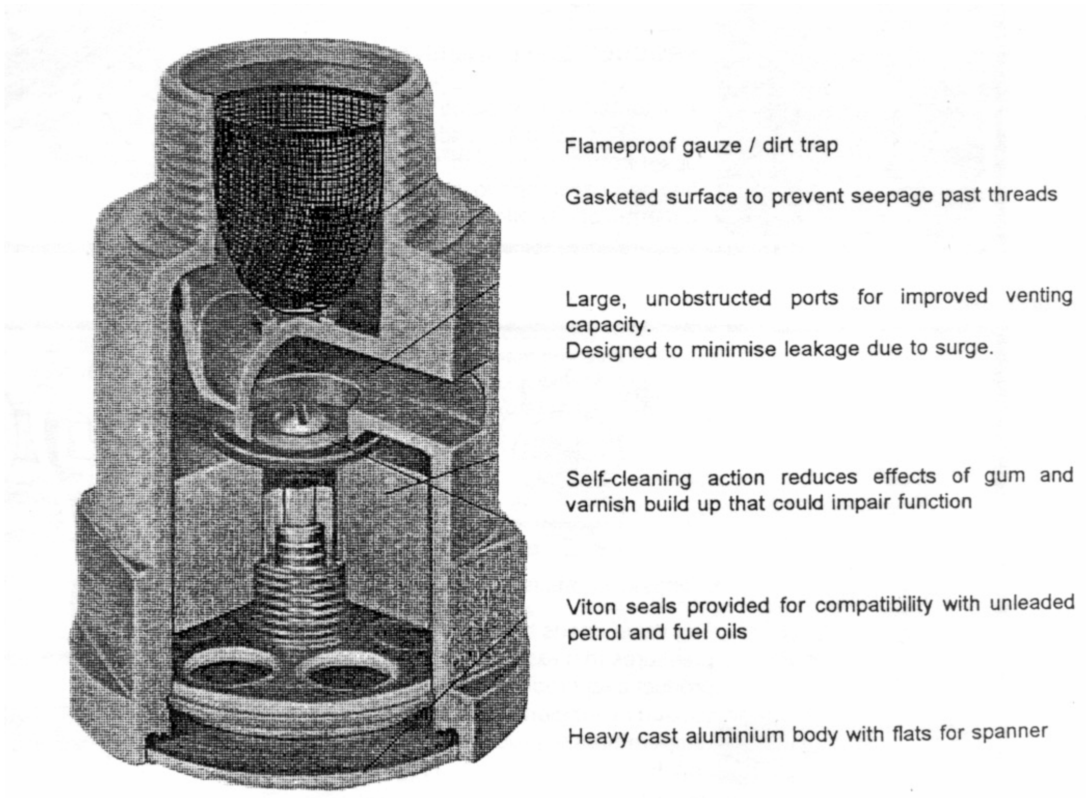
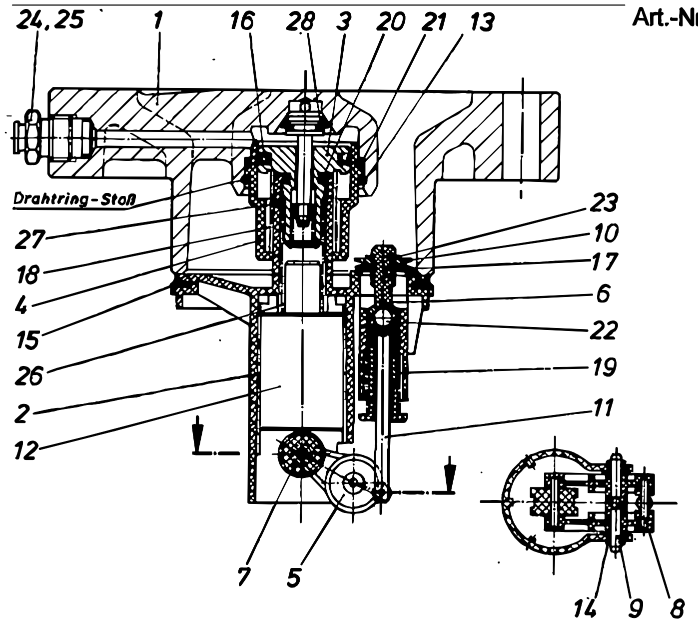


Figure A5. Example of a pressure/vacuum vent valve. Picture courtesy of Collins Youldon Ltd.

Report No. PS/OI/09 Revision 2

Pos.
Item



Art.-Nr / Part no.: 231 398

Pos Item	Bezeichnung Description	StOck Qty	Art. **Nr .** Part No
1	Befestigungsflansch *I* flange	1	230 340
2	Ventilkorper kompl. *I* valve body compl.	1	239 640
5.1	Hebel *I* lever ‚A”	1	052 558
5.2	Hebel / lever B”	1	052 566
6	Fuhrungsbolzen *I* guidance	1	052 523
7	Rolle / pulley	1	052 515
8	Bolzen *I* bolt	2	052 507
9	Bolzen *I* bolt	1	052 493
10	Scheibe *I* washer	1	052 485
11	Stößelstange *I* push rod	1	052 469
12	Gewicht *I* weight	1	172 642
13	Drahtring *I* wire ring	1	052 442
14	Lagerbuchse *I* bushing	2	052 434
15	Hauptdichtung *I* main seal viton	1	052 626
16	Nutring *I* key groove seal viton	1	052 418
17	Dichtung *I* seal viton	1	172 650
19	Druckfeder / pressure spring 0,7x9,2x38	1	172 626
21	O-Ring *I* O-ring	1	052 655
22	Kugel / ball 5mm	1	052 663
23	Sicherungsring / circlip	1	100 188
24	PSA 6/1 A Schlauchanschluβ / tube connector	2	069 922
26	Druckfeder *I* pressure spring O,4x12x83	1	172 618
27	Ring *I* ring	1	231 355
28	Dichtung *I* seal	1	053 155

Figure A6 Example of a pneumatic vent valve as used on German tankers. Picture courtesy of Alfons Haar.

Note:- The illustrations shown in Figures A1 - A6 are examples of equipment used on different designs of road tankers. Their inclusion in this document is for illustrative purposes only and does not constitute an endorsement or recommendation by either the Health and Safety Executive (HSE) or the Health and Safety Laboratory (HSL).

The authors of this report are grateful to each of the manufacturers featured for providing illustrations and allowing their reproduction in this document.

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APPENDIX B

ADR TANK REQUIREMENTS

B1 ADR TANK REQUIREMENTS.

The following requirements are taken from the ADR agreement:

6.8.2.1.14 The calculation pressure is in the second part of the code (see 4.3.4.1) according to Column (12) of Table A of Chapter 3.2.

When "G" appears, the following requirements shall apply:

(a) Gravity-discharge shells intended for the carriage of substances having a vapour pressure not exceeding 110 kPa (1.1 bar) (absolute pressure) at 50 ºC shall be designed for a calculation pressure of twice the static pressure of the substance to be carried but not less than twice the static pressure of water.

(b) Pressure-filled or pressure-discharge shells intended for the carriage of substances having a vapour pressure not exceeding 110 kPa (1.1 bar) (absolute pressure) at 50 ºC shall be designed for a calculation pressure equal to 1.3 times the filling or discharge pressure.

When the numerical value of the minimum calculation pressure is given (gauge pressure) the shell shall be designed for this pressure which shall not be less than 1.3 times the filling or discharge pressure. The following minimum requirements shall apply in these cases:

(c) Shells intended for the carriage of substances having a vapour pressure of more than 110 kPa (1.1 bar) but not more than 175 kPa (1.75 bar) (absolute pressure) at 50 °C shall, whatever their filling or discharge system, be designed for a calculation pressure of not less than 150 kPa (1.5 bar) gauge pressure or 1.3 times the filling or discharge pressure, whichever is the higher.

(d) Shells intended for the carriage of substances having a vapour pressure of more than 175 kPa (1.75 bar) (absolute pressure) at 50 °C shall, whatever their filling or discharge system, be designed for a calculation pressure equal to 1.3 times the filling or discharge pressure but not less than 0.4 MPa (4 bar) (gauge pressure).

6.8.2.2 ***Items of equipment***

6.8.2.2.3 Suitable non-metallic materials may be used to manufacture service and structural equipment.

The items of equipment shall be so arranged as to be protected against the risk of being wrenched off or damaged during carriage or handling. They shall exhibit a suitable degree of safety comparable to that of the shells themselves, and shall in particular:

- be compatible with the substances carried; and

- meet the requirements of 6.8.2.1.1.

As many operating parts as possible shall be served by the smallest possible number of openings in the shell. The leak-proofness of the service equipment including the closure (cover) of the inspection openings shall be ensured even in the event of overturning of the tank, taking into account the forces generated by an impact (such as acceleration and dynamic pressure). Limited release of the tank contents due to a pressure peak during the impact is however allowed.	The leak-proofness of the service equipment shall be ensured even in the event of the overturning of the tank-container.

The gaskets shall be made of a material compatible with the substance carried and shall be replaced as soon as their effectiveness is impaired, for example as a result of ageing.

Gaskets ensuring the leak-proofness of fittings requiring manipulation during normal use of tanks shall be so designed and arranged that manipulation of the fittings incorporating them does not damage them.

6.8.2.2.3 Unless otherwise prescribed in the provisions of 6.8.4, tanks may have valves to avoid an unacceptable negative internal pressure, without intervening bursting discs.

6.8.2.2.6 Tanks intended for the carriage of liquids having a vapour pressure of not more than 110 kPa (1.1 bar) (absolute) at 50 ºC shall have a venting system and a safety device to prevent the contents from spilling out if the tank overturns; otherwise they shall conform to 6.8.2.2.7 or 6.8.2.2.8.

6.8.2.2.7 Tanks intended for the carriage of liquids having a vapour pressure of more than 110 kPa (1.1 bar) but not exceeding 175 kPa (1.75 bar) (absolute) at 50 ºC shall have a safety valve set at not less than 150 kPa (1.5 bar) (gauge pressure) and which shall be fully open at a pressure not exceeding the test pressure; otherwise they shall conform to 6.8.2.2.8.

6.8.2.2.8 Tanks intended for the carriage of liquids having a vapour pressure of more than 175 kPa (1.75 bar) but not exceeding 300 kPa (3 bar) (absolute) at 50 ºC shall have a safety valve set at not less than 300 kPa (3 bar) gauge pressure and which shall be fully open at a pressure not exceeding the test pressure; otherwise they shall be hermetically closed.

APPENDIX C

EQUIVALENT THICKNESS FORMULA

C1 EQUIVALENT THICKNESS FORMULA

The following is taken from ADR 2001:-

These requirements apply to fixed tanks (tank-vehicles), to demountable and battery-vehicles.

6.8.2.1.18 Shells of circular cross-section not more than 1.80 m in diameter other than those referred to in 6.8.2.1.21, shall not be less than 5 mm thick if of mild steel, or of equivalent thickness if of another metal.

Where the diameter is more than 1.80 m, this thickness shall be increased to 6 mm except in the case of shells intended for the carriage of powdery or granular substances, if the shell is of mild steel, or to an equivalent thickness if of another metal.

The "Equivalent thickness" means the thickness obtained from the following formula:

$$e_1 = \frac{464\, e_0}{\sqrt[3]{(Rm_1 A_1)^2}}$$

which is derived from the general formula;

$$e_1 = e_0 \sqrt[3]{\left(\frac{Rm_0 A_0}{Rm_1 A_1}\right)^2}$$

where

e_1 = minimum shell thickness for the metal chosen, in mm;
e_0 = minimum shell thickness for mild steel, in mm, according to 6.8.2.1.18 and 6.8.2.1.19;
Rm_0 = 370 (tensile strength for mild steel, see definition 1.2.1, in N/mm^2);
A_0 = 27 (elongation at fracture for reference steel, in %);
Rm_1 = minimum tensile strength of metal chosen, in N/mm^2; and
A_1 = minimum elongation at fracture of the metal chosen under tensile stress, in %.

APPENDIX D

SOURCES OF INFORMATION

D1 SOURCES OF INFORMATION

Information sources used and organisations contacted during this review are given below:

Library and Internet search for:

Incidents.
Valve manufacturers.
Standards (UK, European and international).
Design codes (UK, European and international).

Searches of:

Major Hazard Incident Data Service (MHIDAS) database.
World Standards Index.
Internet web pages of Institute of Petroleum (I.P) and American Petroleum Institute (A.P.I.).
Internet web pages of Department of Transportation (DOT) Research and Special Programs Administration and US Environmental protection Agency (EPA).
HSE website (including WEBCAT).
Health and Safety Laboratory (HSL) internal reports for jet and pool fire data.
Database of Home Office files.

Information supplied by:

Alfons Haar.
Collins Youldon Ltd.
Department of Minerals and Energy Western Australia.
Emco Wheaton UK Ltd
Exxon.
F.A. Sening.
Federal Institute for Materials and Testing ((Bundesanstalt für materialforschung und -prüfung)BAM) in Berlin.
Hoyer UK Ltd.
Institute of Petroleum (I.P).
P & O TransEuropean Ltd.
Phillips 66 Company.
Physikalisch-Technische Bundesanstalt (PTB), Germany.
Shell U.K. Oil Products Ltd.
TC296/WG9 Committee.
TKS (Sweden).
Tread Corporation.