

# Flat-bottomed, vertical, cylindrical storage tanks for low temperature service —

**Part 1: Guide to the general provisions  
applying for design, construction,  
installation and operation**

# Committees responsible for this British Standard

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 British Compressed Gases Association  
 British Gas plc  
 Concrete Society  
 Energy Industries Council  
 Engineering Equipment and Materials Users' Association  
 Institution of Gas Engineers  
 Institution of Mechanical Engineers  
 Process Plant Association  
 Thermal Insulation Contractors' Association  
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## Foreword

This Part of BS 7777 has been prepared under the direction of the Pressure Vessels Standards Policy Committee.

Flat-bottomed, vertical, cylindrical, storage tanks for refrigerated liquefied gases have traditionally been of the single containment design where the liquid is contained in a single shell surrounded by a conventional low bund wall at a considerable distance. Where a double shell construction was used, the outer shell was mainly there to contain the insulation.

These tanks were built in accordance with two British Standards:

BS 4741:1971, *Specification for vertical cylindrical welded steel storage tanks for low temperature service: single wall tanks for temperatures down to – 50 °C.*

BS 5387:1976, *Specification for vertical cylindrical welded storage tanks for low-temperature service: double-wall tanks for temperatures down to – 196 °C.*

Until the 1970s it was normal practice to store all refrigerated products in single containment tanks. Since that time it has increasingly become the practice for the inner tank for hydrocarbons or ammonia to be surrounded by an outer tank or wall. It is still the practice to store liquid oxygen, liquid nitrogen or liquid argon in single containment tanks. The outer tank or wall is intended to prevent the release of the liquefied products into the surrounding area in case of leakage from or damage to the inner tank. This philosophy results in increased safety for the surrounding area. Such constructions are known as double containment tanks and full containment tanks.

Depending on the lowest service temperature, the inner tank may be made from carbon-manganese steel, low nickel steel, 9 % nickel steel, aluminium or stainless steel. The double containment tanks and full containment tanks generally have outer tanks or walls made from prestressed concrete, reinforced concrete with an earth embankment or one of the metals specified for the inner tank. BS 4741 and BS 5387 specified requirements for single containment tanks only and consequently did not include the requirements for material selection, design, construction, loading cases, etc. that are necessary for double containment tanks and full containment tanks.

To redress this situation, the Storage Tank Committee of The Engineering Equipment and Materials Users' Association (EEMUA) published in 1986 *Recommendations for the design and construction of refrigerated liquefied gas storage tanks*, Publication No. 147[1]. The intention of EEMUA was that this document would form the basis of a British Standard to be published a few years later. Together, BS 7777-1 to BS 7777-4 supersede BS 4741:1971 and BS 5387:1976, which are withdrawn.

Although experience has demonstrated that the risk of failure of a single containment tank designed and fabricated in accordance with British Standards is very low, this can be further reduced by more stringent requirements for material selection, design, construction, inspection and testing. For certain stored products, however, the consequences of failure may be considered so great that an outer tank or wall is deemed necessary. Thus a further reduction of risk of failure can be achieved through the use of a double or full containment storage concept. The definitions of single, double and full containment tanks are given in **3.1** of this Part of BS 7777.

The selection of the storage concept should take into account the location, the operational conditions and the environmental conditions. This standard covers only flat-bottomed, cylindrical, stand-alone storage tanks. However, it is not intended to exclude the use of other storage concepts and designs which have been proven in service.

This British Standard comprises four Parts:

- *Part 1: Guide to the general provisions applying for design, construction, installation and operation;*
- *Part 2: Specification for the design and construction of single, double and full containment metal tanks for the storage of liquified gas at temperatures down to  $-165\text{ }^{\circ}\text{C}$ ;*
- *Part 3: Recommendations for the design and construction of prestressed and reinforced concrete tanks and tank foundations, and for the design and installation of tank insulation, tank liners and tank coatings;*
- *Part 4: Specification for the design and construction of single containment tanks for the storage of liquid oxygen, liquid nitrogen or liquid argon.*

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

**Compliance with a British Standard does not of itself confer immunity from legal obligations.**

#### Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 28, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

## 1 Scope

This Part of BS 7777 provides guidance on design conditions, criteria for the selection of a storage concept, loading cases, internal positive pressure and internal negative pressure relief, testing, commissioning and decommissioning, inspection and monitoring for single, double and full containment tanks for above ground installation at service temperatures down to  $-165\text{ }^{\circ}\text{C}$ , and for single containment tanks down to  $-196\text{ }^{\circ}\text{C}$ . Guidance on operation, seismic analysis and safety is given in Annex A to Annex C.

Tanks are intended to contain liquid products to be stored at temperatures equal to or just above their boiling points at atmospheric pressure. The liquids stored in tanks covered by this standard typically include liquid petroleum gas, ethylene, ethane, liquid natural gas and similar hydrocarbons, as well as ammonia, oxygen, nitrogen and argon.

For the purposes of this standard, it is intended that tanks for the storage of hydrocarbons and ammonia are selected from three types (single, double and full containment tanks) taking into account local circumstances and particular needs. For tanks storing liquid oxygen, liquid nitrogen or liquid argon, it is intended that single containment tanks should be used.

This standard does not address the detail design of ancillary equipment such as pump tubes, pumps, valves and instrumentation, but it does refer to these components where there is an effect on mechanical design. Information regarding ancillary equipment is conventionally part of the purchaser specification.

## 2 References

### 2.1 Normative references

This Part of BS 7777 incorporates, by reference, provisions from specific editions of other publications. These normative references are cited at the appropriate points in the text and the publications are listed on the inside back cover. Subsequent amendments to, or revisions of, any of these publications apply to this Part of BS 7777 only when incorporated in it by updating or revision.

### 2.2 Informative references

This Part of BS 7777 refers to other publications that provide information or guidance. Editions of these publications current at the time of issue of this standard are listed on the inside back cover, but reference should be made to the latest editions.

## 3 Definitions

For the purposes of this Part of BS 7777, the following definitions apply.

### 3.1 Types of containment

#### 3.1.1

##### single containment tank

either a single tank or a tank comprising an inner tank and an outer container designed and constructed so that only the inner tank is required to meet the low temperature ductility requirements for storage of the product

the outer container (if any) of a single containment storage tank is primarily for the retention and protection of insulation and to constrain the vapour purge gas pressure, but is not designed to contain refrigerated liquid in the event of leakage from the inner tank

a single containment tank is normally surrounded by a low bund wall (see 3.2.1) to contain any leakage

NOTE Examples of single containment tanks are given in Figure 1.

#### 3.1.2

##### double containment tank

a double tank designed and constructed so that both the inner tank and the outer tank are capable of independently containing the refrigerated liquid stored. To minimize the pool of escaping liquid, the outer tank or wall is located at a distance not exceeding 6 m from the inner tank

the inner tank contains the refrigerated liquid under normal operating conditions. The outer tank or wall is intended to contain the refrigerated liquid product leakage from the inner tank, but it is not intended to contain any vapour resulting from product leakage from the inner tank

NOTE Examples of double containment tanks are given in Figure 2. Figure 2 does not imply that the outer tank or wall is necessarily as high as the inner tank.

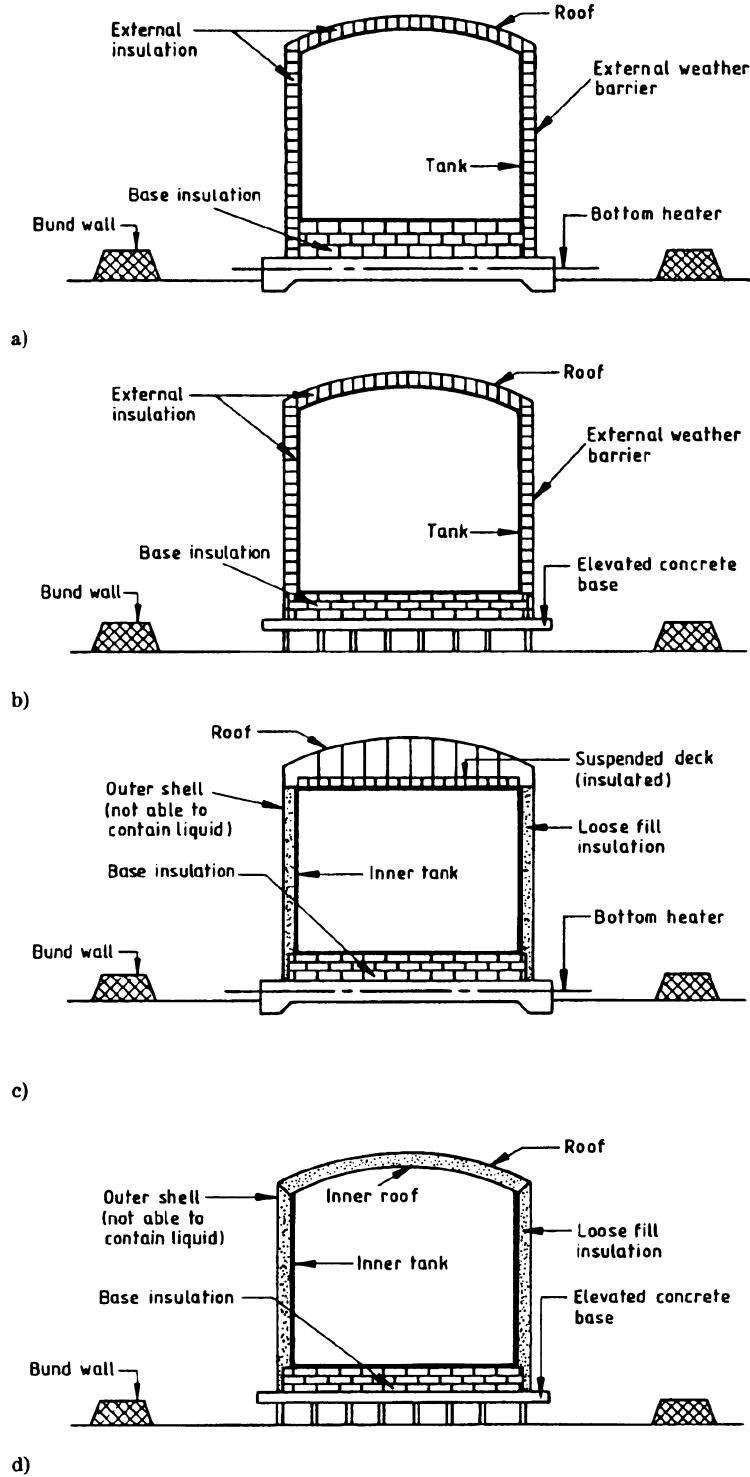
#### 3.1.3

##### full containment tank

a double tank designed and constructed so that both the inner tank and the outer tank are capable of independently containing the refrigerated liquid stored. The outer tank or wall should be 1 m to 2 m distant from the inner tank

the inner tank contains the refrigerated liquid under normal operating conditions. The outer roof is supported by the outer tank. The outer tank is intended to be capable both of containing the refrigerated liquid and of controlled venting of the vapour resulting from product leakage after a credible event

NOTE Examples of full containment tanks are given in Figure 3.



NOTE. For a definition of single containment tank, see 3.1.1

Figure 1 — Examples of single containment tanks



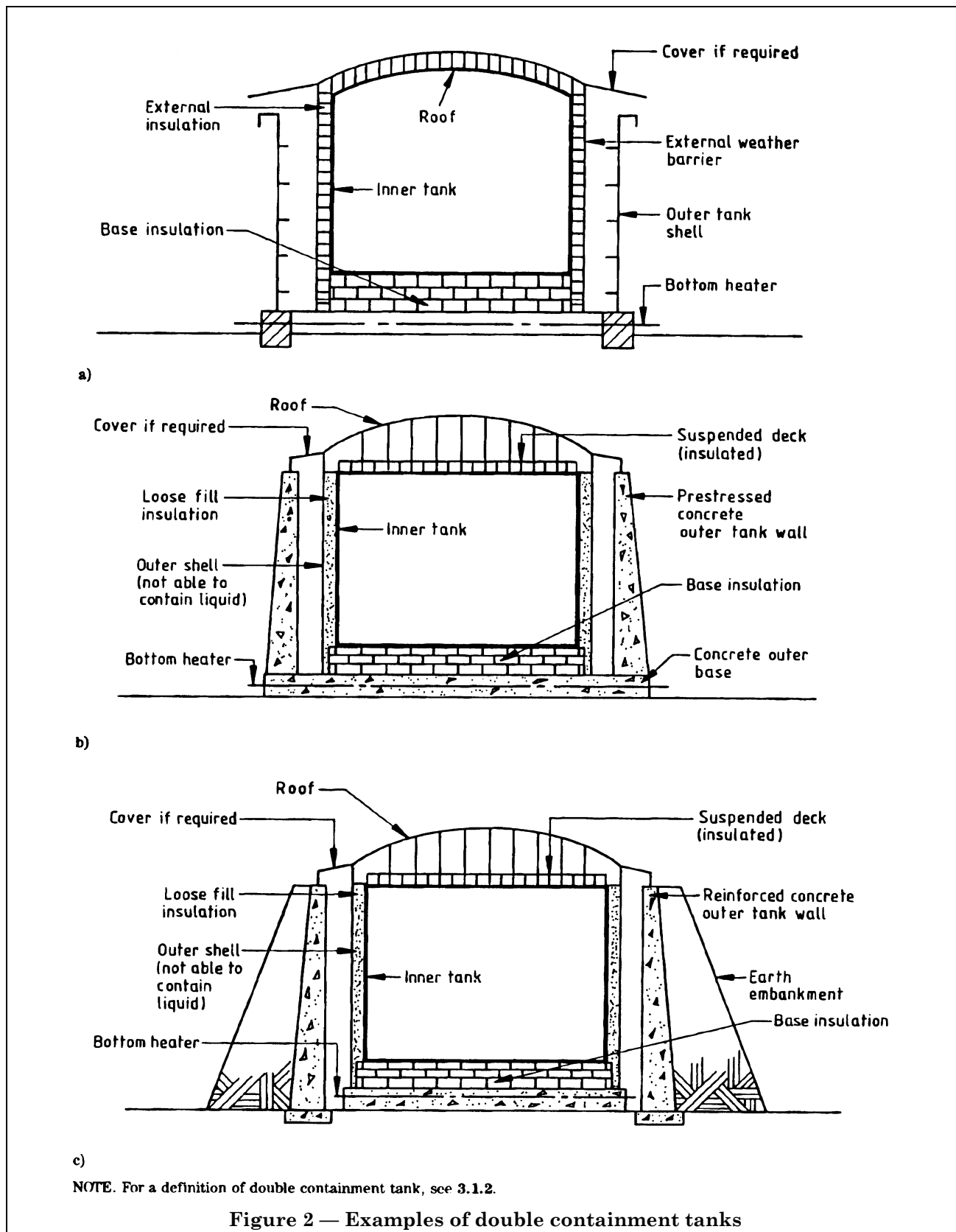
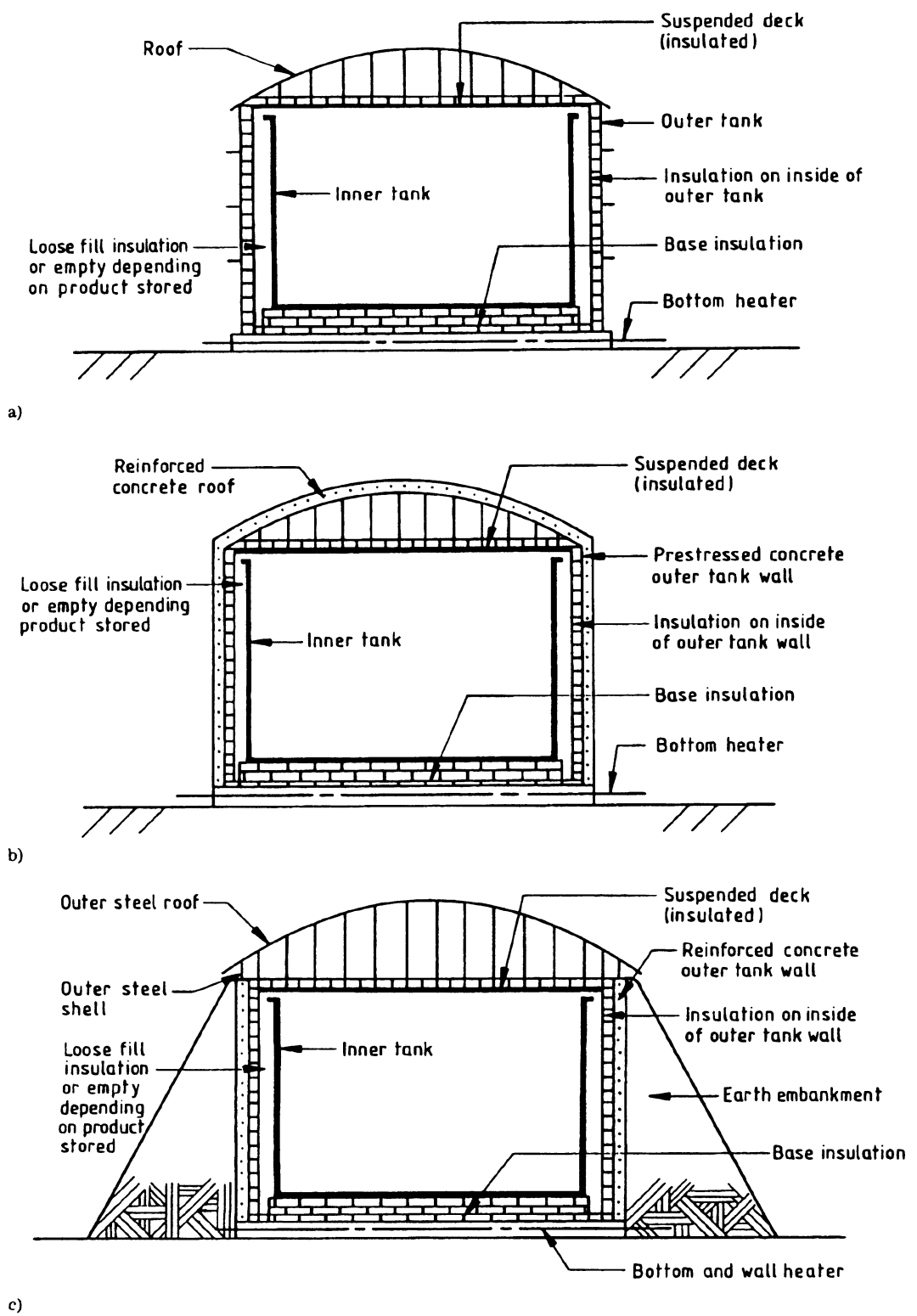


Figure 2 — Examples of double containment tanks



NOTE. For a definition of full containment tank, see 3.1.3.

Figure 3 — Examples of full containment tanks

## 3.2 Other terms

### 3.2.1

#### **bund wall**

a low construction of earth or concrete surrounding the storage tank, at a considerable distance from the tank, to contain spilled liquid

NOTE Illustration of a bund wall is given in Figure 1.

### 3.2.2

#### **boil-off**

a process of vaporization of very small quantities of refrigerated liquid by heat conducted through the insulation surrounding the storage tank

### 3.2.3

#### **embankment**

a bank of selected earth and other material placed against the outer face of a reinforced concrete wall

### 3.2.4

#### **roll-over**

an uncontrolled mass movement of a stored liquid, correcting an unstable state of stratified liquids of different density

NOTE Roll-over results from differences in temperature or composition throughout the depth of the liquid. It is generally accompanied by a large release of vapour inside the tank.

### 3.2.5

#### **purchaser**

the company or its agent which prepares and agrees a proposal with a contractor (or contractors) for the design, construction, testing and commissioning of a tank for storing refrigerated liquefied gas

NOTE It is not the purpose of this standard to define terms of reference or to allocate responsibilities between contracting parties when the purchaser is not the owner or operator of the storage facility.

### 3.2.6

#### **contractor**

the company with which the purchaser agrees a proposal for the design, construction, testing and commissioning of a tank for storing refrigerated liquefied gas

### 3.2.7

#### **inner tank**

a flat-bottomed, vertical, metallic cylinder, with or without a roof, designed to store liquid during service

### 3.2.8

#### **outer tank**

a flat-bottomed, vertical cylinder designed to contain liquid from the inner tank in the event of leakage

### 3.2.9

#### **shell**

a general term used to describe any metallic vertical cylinder

### 3.2.10

#### **cover**

a device providing weather protection for the annular space of a double containment tank

### 3.2.11

#### **roof**

a member on top of a shell or wall, sealing off the contents from the atmosphere

### 3.2.12

#### **suspended deck**

a structure for supporting the internal insulation under the roof

### 3.2.13

#### **wall**

a general term used to describe any concrete, vertical, cylindrical structure

### 3.2.14

#### **container**

a non-liquid-containing metallic, flat-bottomed cylinder, including the roof, to hold insulation and vapour or purge gas, or the metallic upper part above the concrete wall of a full containment tank

## 4 Design conditions

Tanks should be designed to suit the pressures that are met in service. The internal positive pressure should be not greater than 140 mbar<sup>1)</sup> (gauge), and the internal negative pressure should be not greater than 6 mbar (gauge).

NOTE 1 The internal positive pressure of 140 mbar (gauge) may be exceeded subject to agreement between the purchaser and contractor, but for large diameter tanks the design of the roof to shell joint and anchorage might be limiting (see BS 7777-4).

NOTE 2 For tanks with concrete roofs the internal positive pressure of 140 mbar (gauge) may be exceeded because of increased dead weight.

The lowest service temperature permitted is – 165 °C for tanks conforming to BS 7777-2 and – 196 °C for tanks conforming to BS 7777-4.

<sup>1)</sup> 1 mbar = 10<sup>-3</sup> bar = 100 N/m<sup>2</sup> = 100 Pa.

## 5 Information to be exchanged between the purchaser and the contractor

### 5.1 Information to be supplied by the purchaser

The following basic information should be fully documented.

- a) Geographical location of the tank.
- b) Selected storage concept (see 3.1 and clause 6).
- c) Diameter and height or capacity of the tank including ullage.

NOTE 1 Where only the capacity of the tank is specified, ground conditions should be included.

- d) Diameter and height of outer tank, container or wall.
- e) Type of foundation and detail of bottom heating (see A.6).
- f) Areas of responsibility between tank contractor, foundation contractor and contractor responsible for the construction of the concrete outer wall, where these are not the same.
- g) Loadings, conditions and considerations to be taken into account in the design of the storage concept (see clause 6).
- h) Relevant properties of the contained fluid, including relative density, temperature, corrosion allowance (as appropriate), and permissible boil-off.
- i) Design internal positive pressure and design internal negative pressure of the inner tank and/or the outer tank or wall or container, as appropriate.
- j) Minimum and maximum design metal temperatures for the tank.
- k) Minimum and maximum ambient temperatures.
- l) Predicted maximum total and differential foundation settlement during water testing and during service lifetime of the tank [see 7.2.2 f)].
- m) Size, number and type of all mountings and accessories, and their locations.
- n) Maximum filling and emptying rates and any special venting arrangements.
- o) Quality of the water to be used for the hydrostatic test.
- p) Other specifications to be read in conjunction with this standard.

NOTE 2 The purchaser should consider the tank, insulation and foundation designs together to achieve the most economical purchase arrangement.

### 5.2 Optional and/or alternative information to be supplied by the purchaser

The following optional and/or alternative information should be fully documented, as appropriate.

- a) Intensity and duration of reflected blast pressure [see 7.3.2 a)].
- b) Weight and velocity of flying objects [see 7.3.2 b)].
- c) Impact loading resulting from the sudden failure of the inner tank (see 7.3.5).
- d) Seismic loading conditions (see 7.3.1 and Annex B).
- e) Precautions to prevent roll-over (see 7.3.7).
- f) Facilities to be provided for the detection and removal of liquid in the annular space (see Annex A).

### 5.3 Information to be agreed between the purchaser and contractor

The following information should be fully documented.

- a) Nature and magnitude of significant loads or moments applied to the tank from piping, valves, or other aspects including tank and pipe support settlement [see 7.2.2 g)].
- b) Design and operation of the internal positive pressure/internal negative pressure relief systems (see 8.1).
- c) Conditions for determining the minimum capacity of the internal positive pressure/internal negative pressure relief systems (see 8.5.1).
- d) Combination of flows to be used for determining the minimum capacity of the internal positive pressure/internal negative pressure relief systems (see 8.5.2).
- e) Use of isolating valves between pressure relief valves and tank (see 8.2 and C.2.4).
- f) Commissioning procedure (see 9.1).
- g) The materials to be used.

NOTE 1 It is essential that relevant information is exchanged between the purchaser and contractor before implementing the provisions of this standard.

NOTE 2 It is essential that all relevant provisions of this standard, and other documented data, are satisfied before a claim of compliance is made.

## 6 Storage concepts

### 6.1 General

The purchaser should select the storage concept, taking into account national or local authority requirements and the influence of loadings, conditions and considerations that are appropriate for the location (see 6.2 and Annex C).

The possibility of sudden failure of the inner tank is not a normal design consideration, but in cases where the purchaser specifies that it should be taken into consideration, it is essential that the outer tank or wall is designed to withstand the consequent impact loading (see 7.3.5).

## 6.2 Criteria for the selection of storage concept

The following list summarizes a number of loadings, conditions and considerations that influence the selection of the storage concept.

- a) *Criteria not subject to control:*
  - 1) earthquake;
  - 2) wind, snow, climate;
  - 3) hazard from outside the plant.
- b) *Criteria subject to limited control:*
  - 1) in-plant flying objects;
  - 2) pressure waves from internal plant explosions;
  - 3) maintenance hazards;
  - 4) fire in bund or at adjacent tank or plant;
  - 5) overfill;
  - 6) process overpressure;
  - 7) roll-over;
  - 8) major metal failure, e.g. brittle fracture;
  - 9) minor metal failure, e.g. leakage;
  - 10) metal fatigue;
  - 11) corrosion;
  - 12) failure of pipework attached to bottom, shell or roof;
  - 13) foundation behaviour.
- c) *Criteria subject to full control:*
  - 1) proximity of other plant;
  - 2) proximity of control rooms, offices and other buildings within plant;
  - 3) proximity of habitation outside plant;
  - 4) requirements of national or local authority;
  - 5) requirements of the applied design codes.

## 7 Loading cases and design considerations

### 7.1 General

The loading cases and design considerations for single, double, or full containment tanks, should conform to 7.2 and 7.3. (For the application of 7.2 and 7.3 to the different types of tank, see Table 1 and Figure 1 to Figure 3.)

### 7.2 Normal loading cases

#### 7.2.1 Dead loads

The most significant dead loads of the normal loading cases are designated as follows:

- a) tank weight;
- b) insulation weight;
- c) roof weight;
- d) suspended deck weight (where applicable) including the weight of insulation and support structure;
- e) weight of accessories, e.g. pipes, valves, platforms, walkways and hand rails;
- f) weight of concrete foundations;
- g) weight of concrete walls (where applicable).

#### 7.2.2 Imposed loads

The most significant imposed loads of the normal loading cases are as follows.

- a) *General loads.* A uniformly distributed load of 1.2 kN/m<sup>2</sup> over the projected fixed roof area should be applied.

The roof should be able to carry a concentrated load of 5 kN over a square area of 300 mm × 300 mm placed at any location.

A uniformly distributed load of 2.4 kN/m<sup>2</sup> acting on the roof platform and access-way areas should be applied.

NOTE 1 This includes both snow loading and internal negative pressure loading.

NOTE 2 It is recommended that the minimum uniformly distributed load on a suspended deck should be 1.0 kN/m<sup>2</sup> during erection and maintenance. This may be regarded as a temporary or permanent loading, but in any event this loading should be applied to the fixed roof.

- b) *Snow loads.* The loading cases and design considerations of item a) should apply.

- c) *Internal negative pressure loads.* For tank components other than the fixed roof, the design should be based on 6 mbar gauge.

NOTE 3 Loads on the fixed roof are taken into account in general loads [see item a)].

- d) *Insulation pressure loads.* Where appropriate, both inner and outer tanks, walls or containers should be designed for the pressure exerted by loose powder insulation in the annular space.

NOTE 4 The loose powder insulation exerts an external pressure on the inner tank and internal pressure on the outer tank, wall or container.

NOTE 5 The loose powder insulation pressure can be reduced by the presence of resilient blankets on the outside of the inner tank.

- e) *Loads due to internal pressure.* Depending on the design, loads due to internal pressure can act on either the inner tank or the outer tank, wall or container, and can be due to either the product vapour pressure or the purge gas pressure.

NOTE 6 A value should be specified by the purchaser and should be consistent with the design condition for vapour pressure (see clause 4).

f) *Settlement loads.* The storage tank and its foundation should be designed to take account of the maximum total and differential foundation settlements predicted to occur during the life of the tank (see BS 7777-3).

**Table 1 — Loading cases associated with the tank types shown in Figure 1 to Figure 3**

Clause number	Loading case	Tank type	Figure 1				Figure 2			Figure 3		
			a)	b)	c)	d)	a)	b)	c)	a)	b)	c)
<b>7.2</b>	<i>Normal loading cases</i>											
<b>7.2.1</b>	Dead load	Inner tank	×	×	×	×	×	×	×	×	×	×
		Steel outer tank	—	—	—	—	×	—	—	×	—	—
		Concrete outer tank	—	—	—	—	—	×	×	—	×	×
		Steel outer container	—	—	×	×	—	×	×	—	—	×
<b>7.2.2</b>	Imposed loads											
<b>7.2.2 a)</b>	General loads	Inner tank	×	×	—	×	×	—	—	—	—	—
		Steel outer tank	—	—	—	—	—	—	—	×	—	—
		Concrete outer tank	—	—	—	—	—	—	—	—	×	—
		Steel outer container	—	—	×	×	—	×	×	—	—	×
<b>7.2.2 b)</b>	Snow load	Inner tank	×	×	—	—	×	—	—	×	—	—
		Steel outer tank	—	—	—	—	—	—	—	×	—	—
		Concrete outer tank	—	—	—	—	—	—	—	—	×	—
		Steel outer container	—	—	×	×	—	×	×	—	—	×
<b>7.2.2 c)</b>	Internal negative pressure	Inner tank	×	×	—	×	×	—	—	—	—	—
		Steel outer tank	—	—	—	—	—	—	—	×	—	—
		Concrete outer tank	—	—	—	—	—	—	—	—	×	×
		Steel outer container	—	—	×	×	—	×	×	—	—	×
<b>7.2.2 d)</b>	Insulation pressure	Inner tank	—	—	×	×	—	×	×	×	×	×
		Steel outer tank	—	—	—	—	—	—	—	×	—	—
		Concrete outer tank	—	—	—	—	—	—	—	—	×	×
		Steel outer container	—	—	×	×	—	×	×	—	—	—
<b>7.2.2 e)</b>	Internal pressure	Inner tank	×	×	—	×	×	—	—	—	—	—
		Steel outer tank	—	—	—	—	—	—	—	×	—	—
		Concrete outer tank	—	—	—	—	—	—	—	—	×	×
		Steel outer container	—	—	×	×	—	×	×	—	—	×
<b>7.2.2 f)</b>	Settlement	Inner tank	×	×	×	×	×	×	×	×	×	×
		Steel outer tank	—	—	—	—	×	—	—	×	—	—
		Concrete outer tank	—	—	—	—	—	×	×	—	×	×
		Steel outer container	—	—	×	×	—	—	—	—	—	—
<b>7.2.2 g)</b>	Applied load	As applicable					As applicable					
<b>7.2.3</b>	Product liquid load	Inner tank	×	×	×	×	×	×	×	×	×	×
		Steel outer tank	—	—	—	—	×	—	—	×	—	—
		Concrete outer tank	—	—	—	—	—	×	×	—	×	×
		Steel outer container	—	—	—	—	—	—	—	—	—	—
<b>7.2.4</b>	Wind loading	Inner tank	×	×	—	—	—	—	—	—	—	—
		Steel outer tank	—	—	—	—	×	—	—	×	—	—
		Concrete outer tank	—	—	—	—	—	×	×	—	×	×
		Steel outer container	—	—	×	×	—	×	×	—	—	×

Table 1 — Loading cases associated with the tank types shown in Figure 1 to Figure 3

Clause number	Loading case	Tank type	Figure 1				Figure 2			Figure 3		
			a)	b)	c)	d)	a)	b)	c)	a)	b)	c)
7.2.5	Hydrostatic and pneumatic testing	Inner tank	×	×	×	×	×	×	×	×	×	×
		Steel outer tank	—	—	—	—	×	—	—	×	—	—
		Concrete outer tank	—	—	—	—	—	—	—	—	—	—
		Steel outer container	—	—	×	×	—	×	×	—	—	×
7.2.6	Additional loading cases	As applicable				As applicable						
7.2.7	Induced loads											
7.2.7.1	Thermal	Inner tank	×	×	×	×	×	×	×	×	×	×
		Steel outer tank	—	—	—	—	×	—	—	×	—	—
		Concrete outer tank	—	—	—	—	—	×	×	—	×	×
		Steel outer container	—	—	×	×	—	×	×	—	×	×
7.2.7.2	Condensate	—	—	×	—	—	×	×	×	×	×	
7.3	<i>Abnormal loading cases</i>											
7.3.1	Seismic loads	Inner tank	×	×	×	×	×	×	×	×	×	×
		Steel outer tank	—	—	—	—	×	—	—	×	—	—
		Concrete outer tank	—	—	—	—	—	×	×	—	×	×
		Steel outer container	—	—	×	×	—	×	×	—	—	×
7.3.2	External explosions and their effects	Inner tank	×	×	—	—	×	—	—	—	—	—
		Steel outer tank	—	—	—	—	×	—	—	×	—	—
		Concrete outer tank	—	—	—	—	—	×	×	—	×	×
		Steel outer container	—	—	×	×	—	—	—	—	—	×
7.3.3	Fire hazards	Inner tank	×	×	—	—	—	—	—	—	—	—
		Steel outer tank	—	—	—	—	×	—	—	×	—	—
		Concrete outer tank	—	—	—	—	—	×	×	—	×	×
		Steel outer container	—	—	×	×	—	×	×	—	—	×
7.3.4	Leakage of inner tank	Inner tank	—	—	—	—	—	—	—	—	—	—
		Steel outer tank	—	—	—	—	×	—	—	×	—	—
		Concrete outer tank	—	—	—	—	—	×	×	—	×	×
		Steel outer container	—	—	—	—	—	—	—	—	—	—

NOTE 1 Table 1 gives a summary of the loading cases appropriate to those tank configurations shown in Figure 1 to Figure 3. The relevance of a clause is marked “×”. For tank configurations not shown, as well as for uses where additional loading are specified by the purchaser, the appropriate clauses have to be established, for which use can be made of the table.

NOTE 2 From the loading cases, listed under clause 7, the selection of the appropriate loadings is made for all structural components. So, for example, for tanks shown in Figure 1 a) and Figure 1 b) the outer shell is not a load carrying structure, but merely a lagging container. All loads are, therefore, applied to the inner tank roof.

NOTE 3 For tanks shown under Figure 1 c) and Figure 1 d) the outer shell and roof are designed to carry the vapour or purge gas pressures as well as all external loads. The liquid loads are carried by the inner tank.

g) *Applied loads.* Pipes, valves and other items connected to the shell, bottom or roof should be designed such that no significant additional loads or moments are applied to the shell, bottom, or roof. Where such loads or moments are unavoidable, the purchaser and the contractor should agree their nature and magnitude [see 5.3 a)]. Tank and pipe support settlements should also be taken into consideration.

### 7.2.3 Product liquid loading

There are three product liquid loadings which are as follows.

a) *Inner tank.* The inner tank should be designed for a product liquid loading at the minimum design temperature specified.

The design product level or the maximum product level should be not higher than 0.5 m below the top of the shell.

NOTE 1 The free board for earthquake sloshing need not be included in the design product level.

b) *Outer tank.* The outer tank should be designed to contain the maximum product liquid content of the inner tank at the minimum design temperature specified.

NOTE 2 Item b) applies to double or full containment tanks.

c) *Outer container.* The outer container should be designed to contain the insulation surrounding the inner tank and either the inert purge gas or the vaporized product.

NOTE 3 The outer container should not be designed to contain any stored liquid.

#### 7.2.4 Wind loading

Wind loadings are as follows.

a) *Steel tanks.* The wind speed used in the calculations is the maximum Class A, 3 s gust.

NOTE 1 This wind speed is estimated to be exceeded on average only once in 50 years.

b) *Concrete tanks.* The wind speed used in the calculations is the maximum Class B, 5 s gust for tanks up to 50 m diameter, and the maximum Class C, 15 s gust for tanks equal to or greater than 50 m diameter.

NOTE 2 For wind speed classification for UK conditions, see CP 3:Chapter V-2.

#### 7.2.5 Hydrostatic and pneumatic testing

The inner tank should be filled with water to a level equal to the maximum product level specified.

Steel outer tanks designed to contain the liquid product should be hydrostatically tested to the level reached when the volume of test water in the inner tank is contained by the outer tank.

NOTE Prestressed concrete and reinforced concrete tanks with earth embankments do not need to be hydrostatically tested unless this is specified by the purchaser.

During hydrostatic testing of the outer tank, the water level in the inner tank should always be above that of the water in the outer tank to prevent damage to the inner tank.

The roof of the inner tank, where appropriate, as well as the roof and shell of the outer tank should be pneumatically tested.

After either hydrostatic or pneumatic testing the anchorage, where present, should be checked when the tank is empty.

#### 7.2.6 Additional loadings

Any additional loads resulting from the proposed methods of construction, commissioning and decommissioning should be taken into account.

#### 7.2.7 Induced loads

##### 7.2.7.1 Thermal loads

The effects of tank movement due to differential thermal expansion of the outer tank components should be assessed.

All tank attachments should be designed to minimize the thermal loads and moments on the tank components.

##### 7.2.7.2 Loads due to condensate formation

Increases in the effective weight of the suspended deck should be considered in the design.

NOTE In locations where the ambient temperature falls below storage content temperature, condensation can occur on the inside of the outer tank roof and run onto the suspended deck.

#### 7.3 Abnormal loading cases

##### 7.3.1 Seismic loads

An assessment of the effect of seismic loadings should be made (see Annex B).

##### 7.3.2 External explosions and their effects

Depending on the location of the storage tank from an environmental aspect and in relation to associated or other plant items, either within the boundary of the owner or in adjacent third-party owned properties, consideration should be given to the possibility of explosion occurring, within the vicinity of the tank, with the following consequences.

a) **Resultant blast or pressure wave.** The blast or pressure wave produced by a nearby explosion could be “reflected” by the tank. Such pressure waves are of short duration and are site and time dependent. The dynamic response of the tank structure, including foundations, should be taken into account in the design calculations.

The values for the intensity and time duration of reflected blast pressure should be specified by the purchaser or his consultant, the purchaser being responsible for ensuring that they are taken into account in the design specification.

b) **Impact of flying objects on the tank.**

Storage tanks should be able to withstand flying objects that could hit the tank as a result of an external explosion. The mass and velocity of a missile to be used in the calculation should be specified by the purchaser.

NOTE It may be considered reasonable to use the impact from a valve weighing 50 kg travelling at 45 m/s.

##### 7.3.3 Fire hazards

A fire occurring near a tank normally results in heat radiation and a temperature increase of the tank structure. The temperature rise should be limited to prevent strength reduction of the tank components.

NOTE 1 Credible fires to be considered may consist of:

- fire in catchment or banded area;
- fire from leaking flange joint;
- fire from atmospheric vent pipe;
- fire from neighbouring tank.

The radiation heat flux from the assumed fire should be calculated. When the heat flux value has been ascertained, the structure temperature rise should be determined, taking into account the presence of an active fire protection system and considering the reliability of the system.



NOTE 2 If the temperature were to rise above 300 °C, the structural integrity of the roof and shell of steel tanks would be adversely affected.

Prestressed and reinforced concrete tanks should be designed to conform to the fire resistance requirements given in BS 7777-3:1993.

NOTE 3 The guidance given in 7.3.3 may affect the minimum spacing of tanks.

#### **7.3.4 Leakage of the inner tank of a double or full containment tank**

The outer tank should be designed and constructed in such a manner that it contains the maximum liquid content of the inner tank, assuming that the annular space between the shells is filled gradually.

The height of the outer tank or wall should be sufficient to contain a leak at any elevation.

#### **7.3.5 Sudden failure of the inner tank**

Provision for sudden rupture of the inner tank as the result either of material failure or of seismic action is not considered in this standard.

NOTE Where provision for such a sudden rupture is included as a design feature, the outer tank needs to be designed to withstand the consequent impact loading as evaluated by the purchaser (see clause 5).

#### **7.3.6 Overfill of the inner tank**

Multiple independent level controls should be provided to prevent overfill of the inner tank.

NOTE 1 The independent level controls utilized are level measuring devices, alarms and automatic shut-off valves.

NOTE 2 Provision of these controls means that overfill is not a design consideration (see Annex A).

#### **7.3.7 Roll-over**

Roll-over is not a design consideration of this standard.

NOTE Precautions such as mixing can be taken to prevent roll-over.

## **8 Pressure relief**

### **8.1 General**

Tanks designed and constructed in accordance with BS 7777-2:1993 and BS 7777-4:1993 should be provided with a system which ensures that the design internal positive pressure and design internal negative pressure are not exceeded. This system should consist of vapour control valves capable of withdrawing and injecting sufficiently large quantities of product vapour to prevent frequent lifting of the safety relief valves. Safety relief valves should vent to and from atmosphere.

NOTE The design and operation of pressure relief systems should be agreed between the purchaser and the contractor before the order is placed (see 5.3).

### **8.2 Primary internal positive and internal negative pressure relief system design**

For conditions outlined in 8.5.1 a) to 8.5.1 f), both inner and outer tanks should be protected by relief systems that prevent:

- a) the internal positive pressure at the top of the tank from exceeding the design internal positive pressure by more than 10 %;
- b) the internal negative pressure exceeding the design internal negative pressure by more than 2.5 mbar.

NOTE 1 In order to meet these restrictions, pressure relief valves may have to be set in such a way that they start to open at a lower pressure than design pressure.

For conditions outlined in 8.5.1 g) and 8.5.1 h), supplementary pressure relief capacity should be installed. These pressure relief valves should be capable of preventing the pressure from exceeding the design vapour pressure by more than 20 %.

Even where the size of a single pressure relief valve satisfies the provisions of this clause, to facilitate inspection and maintenance a duplicate pressure relief valve of the same capacity should be fitted.

When multiple pressure relief valves are needed for venting, those for each duty should be of the same capacity. At least one additional valve of the same capacity should be fitted as a standby.

NOTE 2 If more than one pressure relief valve is needed to give the venting duty, it is good practice to arrange the settings so that only one will operate in the event of a process upset.

The use of isolating valves installed between the pressure relief valve and the tank should be agreed between the purchaser and the contractor [see 5.3 e) and C.2.4].

The relief system should be designed and operated to ensure that the full internal positive and internal negative pressure relief is available at all times.

### **8.3 Location of pressure relief valves**

Pressure relief valves should be located on the tank so that they cannot be sealed off by the contents or by external sources such as snow.

Provision should be made for maintenance access.

Venting from pressure relief valves should be arranged so that cold products do not impinge on the outer tank.

### **8.4 Construction of pressure relief valves**

Pressure relief valves should be constructed of materials suitable for the intended service.

Pressure relief valve seats and moving parts should be so constructed that performance is not impaired by frost, ice or corrosion.

## 8.5 Determination of capacity of pressure relief systems

### 8.5.1 Maximum capacity

When determining maximum capacity, consideration should be given to the effects of the following:

- a) vapour displaced during filling;
- b) rate of withdrawal of liquid product;
- c) possible escape of product under emergency conditions;
- d) suction capacity of compressor;
- e) heat leakage to tank from atmosphere;
- f) barometric pressure variation;
- g) fire exposure;
- h) any other special circumstances.

NOTE 1 The minimum capacity should be agreed between the purchaser and contractor, but should not be less than that determined in accordance with the American Petroleum Institute (API) Standard 2000[2].

NOTE 2 Reference should be made to the relevant safety code in *Cryogenics safety manual — a guide to good practice*[3].

NOTE 3 For tanks with concrete roofs, the provision of additional emergency pressure relieving capacity should be considered to avoid over-pressurization under conditions outside the limits of this standard.

### 8.5.2 Single and combination flows

Pressure relief systems should be capable of relieving the flow capacity for the largest single flow or the largest possible combination of the flows as given in 8.5.1 a) to 8.5.1 h).

The determination of the combination of flows should be subject to agreement between purchaser and contractor [see 5.3 d) and note 1 to 8.5.1].

## 9 Commissioning and decommissioning

### 9.1 Commissioning

#### 9.1.1 General

Commissioning comprises the procedures involved in converting the tank from its finally erected condition to its cold condition where it contains an amount of stored product. The provisions of this clause are regarded as a minimum for stored products.

A tank is considered to be complete only after it has been satisfactorily commissioned. A comprehensive commissioning procedure should be agreed between the purchaser and contractor.

#### 9.1.2 Physical examination

Prior to final closing-up, the tank should be visually inspected to ensure that it is free from any obvious physical damage, that it is clean and free from any foreign matter and that all the fittings and instruments are correctly installed.

NOTE It should be ensured at this stage that the tank is physically isolated from entry of any external source of gas, liquid or product other than air, by the removal of spool pieces and the fitting of blank flanges. Reliance should not be placed on shut-off valves for tank isolation.

#### 9.1.3 Submerged pumps

Where discharge pumps are submerged in the product, the following precautions should be taken.

- a) The pumps should not be installed prior to the tank hydrostatic test.
- b) Before installation of the pumps, the direction of rotation should be checked against the known phase rotation of the incoming electricity supply, to ensure that the pumps rotate in the specified direction.
- c) The pumps should be thoroughly dried, preferably by blowing with heated dry oil-free air or nitrogen.
- d) After installation the pumps should be maintained in a dry pressurized atmosphere.

#### 9.1.4 Internal shut-off valves

Internal shut-off valves fitted to tanks, and located below liquid level, should be capable of being operated from outside the tank.

Prior to tank cooldown, the tank valves should be thoroughly dried and actuated a number of times to ensure that they operate.

Tank valves should be checked to ensure that they retain freedom of movement at all times during cooldown.

Valves should be actuated shortly after commencement of and during cooldown, and also when immersed in cold liquid.

Tank valves should be checked to ensure that they retain freedom of movement in subsequent service.

NOTE Failure of any valve to operate requires decommissioning and entry into the tank to correct the fault.

#### 9.1.5 Closing-up prior to purging

All access openings should be closed prior to the commencement of purging.

The tank should be vented to atmosphere to prevent the occurrence of pressure differentials.

#### 9.1.6 Purging and final drying

##### 9.1.6.1 Purging

For tanks used to contain combustible gases, the possibility of creating an explosive atmosphere should be avoided by purging.

NOTE Purging is normally undertaken with nitrogen.

Purging should be continued until the residual oxygen is insufficient to form an explosive mixture.

The safe oxygen level should be calculated and a safety margin allowed against the possibility of sampling error and non-uniformity of composition within the tank.

#### 9.1.6.2 Final drying

The tank should be dried out to ensure that it operates satisfactorily.

NOTE 1 Areas needing special attention include the insulation, instrument lines and pipework.

NOTE 2 The measurement of dew-point is normally the most appropriate means for the determination of the state of dryness.

#### 9.1.6.3 Precautions

The purging and drying procedure should be such that the purging of one section of the tank does not deposit moisture in another section.

NOTE 1 The annular space and the tank should be purged separately, to preclude the transfer of moisture from one to the other.

During the purge of the annular space, the maximum pressure differential across the bottom of the inner tank should be agreed between the purchaser and contractor.

NOTE 2 For an excessive differential pressure there is a tendency for the bottom to lift.

When a granular insulant is used, precautions should be taken to prevent it being fluidized by the purge gas.

#### 9.1.6.4 Completion of purging

Upon completion of purging all parts of the tank should remain under a positive pressure of purge gas until the next stage of commissioning.

#### 9.1.7 Cooldown

Prior to filling, the tank should be cooled at a controlled rate to prevent thermal overstressing and supercooling of the liquid.

The maximum rate of cooling should be specified by the tank designer.

NOTE 1 Cooldown is accomplished by spraying with the cold liquid.

Temperature gauges should be provided to monitor the cooldown process.

NOTE 2 Cooldown is complete when liquid accumulates in the base of the tank.

#### 9.1.8 Completion of commissioning

After completion of cooldown the tank should be visually inspected for any irregularities such as leakage, cold spots or physical defects.

After commissioning the condition of the tank should be monitored at regular intervals especially during the first filling and emptying.

## 9.2 Decommissioning

### 9.2.1 General

For new facilities, decommissioning at least once during the lifetime of the tank should be specified by the purchaser.

NOTE 1 Decommissioning of refrigerated liquid storage systems is not to be regarded as a normal operational requirement and should not be attempted on any routine basis.

NOTE 2 Decommissioning is necessary subsequent to an upset or failure of a component in the system, where there is a need for entry.

### 9.2.2 Safety

To ensure that decommissioning and entry into a tank can be conducted safely, the original system design should include equipment, instrumentation and safety facilities to permit entry by personnel for inspection and/or repair.

The facilities for decommissioning should be designed and organized to avoid the need for an inert atmosphere in the tank during the entry period and to simplify inspection and repair.

When planning shutdown entry into the tank and recommissioning, consideration should be given to the following.

a) Provision of instrumentation for monitoring and recording of gaseous and liquid content of the tank during emptying and purging operations.

b) Provision of tank purge connections for an effective purge operation based on the condition of a system which has been in operation for a specified period of years.

NOTE This is also based on individual plant design parameters.

c) Provision of sufficient monitoring and/or control devices to ensure that during the purge, the inner and outer tanks are not subjected to positive or negative pressures beyond the design limits.

d) Provision of instrumentation to permit regular sampling and monitoring of the atmosphere in the tank during inspection and repair to ensure freedom from hydrocarbons or any hazardous gases.

Before construction commences, a detailed procedure for decommissioning the tank should be made available.

## **10 Inspection and tank monitoring**

### **10.1 General**

Refrigerated storage tanks are not normally internally inspected during their lifetime but, as an example, checks might be made of bottom heating and settlement.

### **10.2 Equipment**

When monitoring is required only suitable equipment should be supplied and used.

## Annex A (informative) Guidance on operation

### A.1 Cooldown of the tank

Refrigerated storage tanks have an operating temperature at the atmospheric pressure boiling temperature of the refrigerated gas to be stored. This gives a temperature range of  $-5\text{ }^{\circ}\text{C}$  for butane tanks to  $-165\text{ }^{\circ}\text{C}$  for liquefied natural gas (LNG) tanks. Cooldown of the tanks is required and this work starts after the drying and purging of the tank. In general, purging of the tanks is undertaken with nitrogen. Hence the cooldown proceeds with nitrogen in the tank.

A gradual and constant rate cooldown of the inner tank results only in shrinkage of the inner tank, without unacceptable stress generation of the tank material. A local cool down results in temperature gradients, abnormal shrinkage and unacceptable stress. These stresses, combined with those already existing from fabrication and welding, result in cracking at a location of stress concentration.

The cooldown of the tank should be undertaken very carefully. Special cooldown skin thermocouples should be connected to the inner-tank bottom and inner-tank shell. The permissible temperature difference between adjacent thermocouples should be established by the designer.

The use of nitrogen in cooldown may result in sub-cooling of the tank below its design temperature, e.g. butane tank to  $-45\text{ }^{\circ}\text{C}$ , propane tank to  $-70\text{ }^{\circ}\text{C}$  and LNG tank to  $-180\text{ }^{\circ}\text{C}$ . This sub-cooling should always be avoided by the careful introduction of refrigerated gas into the tank, a slow cooldown and frequent, accurate temperature monitoring.

### A.2 Prevention of overfill

The normal maximum operating levels are calculated by using time intervals based on local operating conditions so that a stepwise overfill protection system exists. The typical levels to be noted are shown in Figure A.1. The distances  $a$ ,  $b$  and  $c$  should be determined on the basis of the selected time interval, e.g. 1 h, and the pump-in rate.

The level high, high alarm with cut out should have a trip function on the liquid supply line.

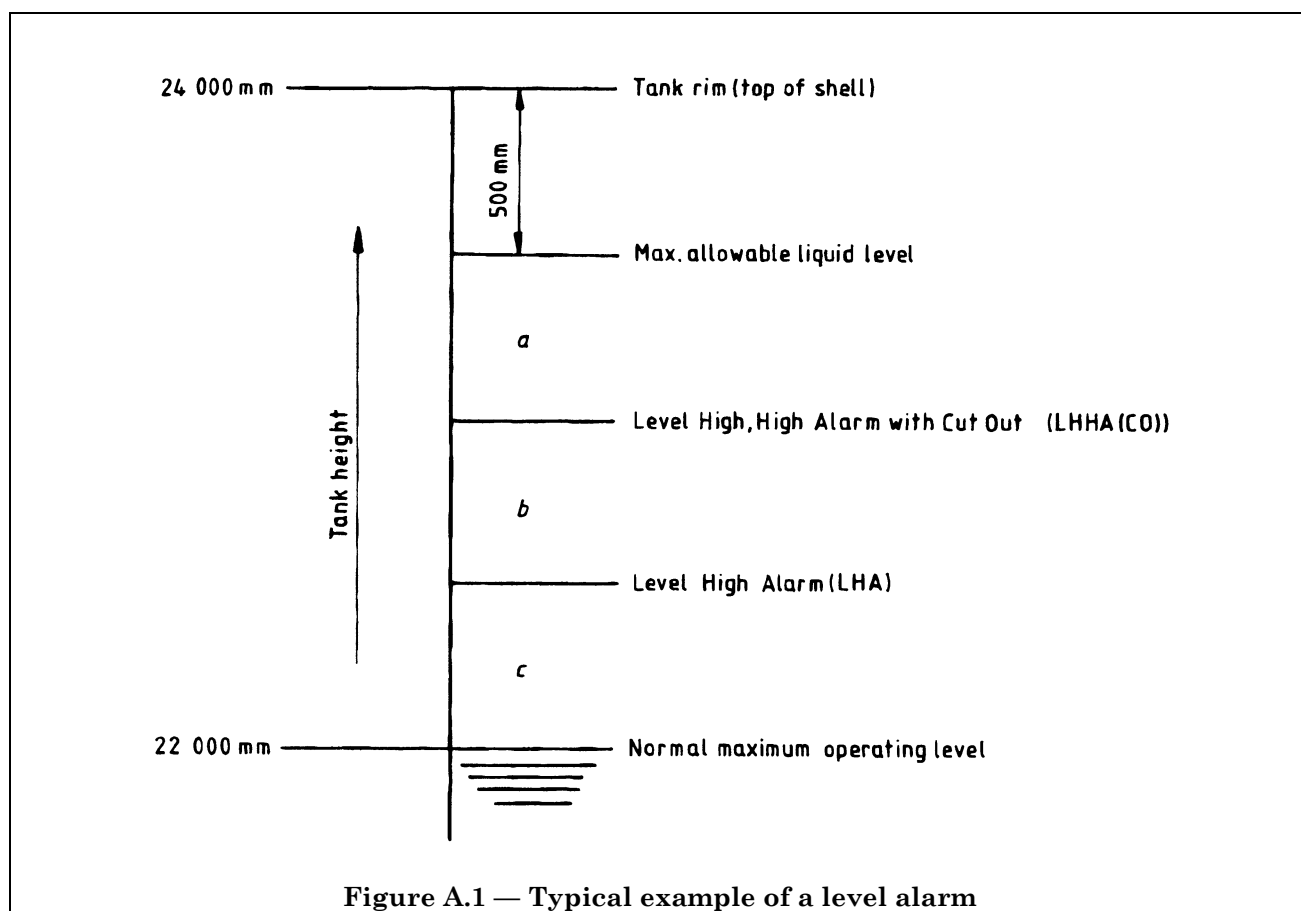


Figure A.1 — Typical example of a level alarm

### A.3 Prevention of overpressure

Refrigerated storage tanks normally operate at a pressure considerably lower than their design pressure, e.g. with an operating pressure in the range 20 mbar gauge to 50 mbar gauge. The design pressure would be approximately 75 mbar gauge. The normal operating pressure is maintained by the boil-off compressor and gas/liquid supply.

If the pressure increases to a value above the normal operating level, then gas will be released to the flare or vent. At a further increase of the pressure, the emergency-relief system will give a final protection. Where conditions allow, the emergency pressure release is to atmosphere.

### A.4 Prevention of excess internal negative pressure

The gas/liquid supply maintains the pressure at the normal operating pressure. Should the pressure drop, then the boil-off compressor is tripped and liquid removal from the tank stopped. In addition, an excess internal negative pressure-breaking gas supply system may be used, but at the final stage the internal negative pressure relief valves should open and allow air to enter the tank. This typically happens at a pressure of  $-5$  mbar gauge. This is, however, an emergency condition that in practice should never occur.

### A.5 Prevention of condensation

At certain locations, where the ambient temperature in winter drops below the atmospheric boiling point of the product, say  $-5$  °C for butane, condensation in the tank against the underside of the roof occurs (see Figure A.2). Due to the condensation the pressure in the tank drops.

All operating conditions are to be evaluated so that regular opening of the internal negative pressure relief valves is prevented. Gas injection into the dome, such as an injection of propane into butane, should be considered as an active protection system and should be carried out before each winter.

During the winter period, regular sampling should be undertaken to check the composition of the gas in the space between inner suspended roof and outer roof.

### A.6 Tank heating system

If the soil under the tank is allowed to become too cold, frost penetrates into the ground, ice lenses form in the soil (mainly in clay types of soil), and the growth of these ice lenses results in high expansion forces which lift and damage the tank or parts of the tank (e.g. the tank bottom connection). To prevent this, the heating system needs to operate in the foundation and also in the vertical outer wall for tanks with an earth embankment.

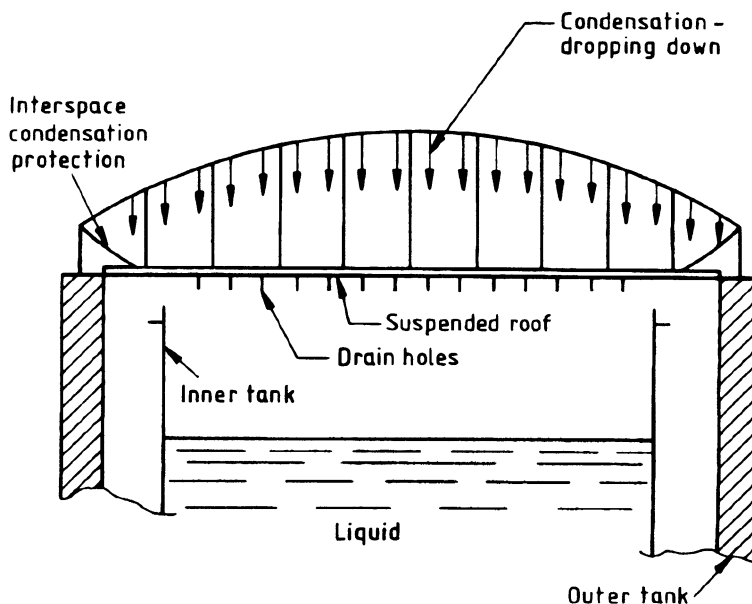


Figure A.2 — Typical example of condensation in dome roof for butane gas

An automatic on/off switch system should activate the heating system and ensure that the tank foundation, at its coldest location, is within a temperature range of + 5 °C to + 10 °C. Other areas of the tank foundation may have a higher temperature.

The performance of the whole heating system should be monitored by a number of sensors. These sensors should be evenly distributed over the whole tank base (see Figure A.3). If applicable, wall sensors should also be provided. One or more of these sensors should have an alarm function. Typically the set point for the "low temperature alarm" is 0 °C and for the "high temperature alarm" + 50 °C (see Figure A.4)

Proper and frequent control of the monitoring systems of the base and wall is essential because it provides the first indication of a tank leak. In the event of a leak the sensor located near this leak shows a sudden temperature drop. Daily recording of all bottom sensor readings is therefore recommended.

Another indication of an abnormal situation is a change in duty cycle or heating power consumption. This produces a change in on-off time. Normally the heating system is activated for 40 % to 60 % of the operating time and a sudden change to 100 % activation would indicate that there is something wrong with the system, or that a leak is present. It is recommended that a daily record is maintained of whether the heating is activated or not.

#### **A.7 Liquid in the annular space**

Liquid may be present in the annular space adjacent to the inner tank due to one of the following abnormal conditions:

- a) spillage from the inner tank;
- b) condensation at the outside of the inner tank;
- c) leak of the inner tank.

If liquid enters the annular space there is a danger of damage to the inner tank and the bottom insulation. Large quantities of liquid in the annular space may cause upward bulging of the tank bottom and ultimately flotation of the inner tank. In this condition, damage to the lower shell courses (e.g. buckling) is also likely to occur. In addition, the light foam glass blocks, located under the inner bottom, are caused to float so that the entire insulation system is disturbed and damaged (see Figure A.5).

If liquid is detected in the annular space it should be removed carefully. Pumping out should start in the annular space so that the level in the inner tank is always higher than in the annular space, to prevent the possibility of buckling of the inner tank shell. Small quantities of liquid in the annular space can be removed by the special venting system which may be located at the bottom of the annular space. Hot gas or nitrogen may be used to accelerate the evaporation.

Tanks with an open annular space and not filled with perlite insulation may have a pump to remove the liquid and a liquid detection system. This would consist of either a bubbler or a level measuring device. Either device should be set in such a way that it detects small depths of liquid. A typical depth might be 100 mm.

For tanks with a perlite filled annular space it is difficult to install liquid detection instruments to control leaks and hence a pump for the removal of liquid is not feasible. Liquid can only be removed by evaporation. The detection and control of leaks from the inner tank relies on monitoring of the heating system under the tank bottom. Temperature sensors may be used for detection.

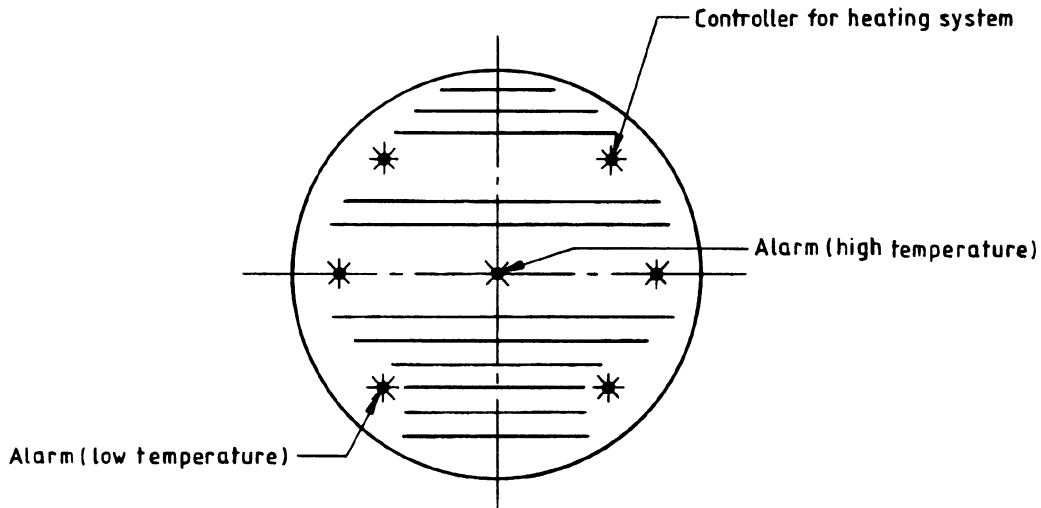


Figure A.3 — Arrangement of sensors under tank bottom

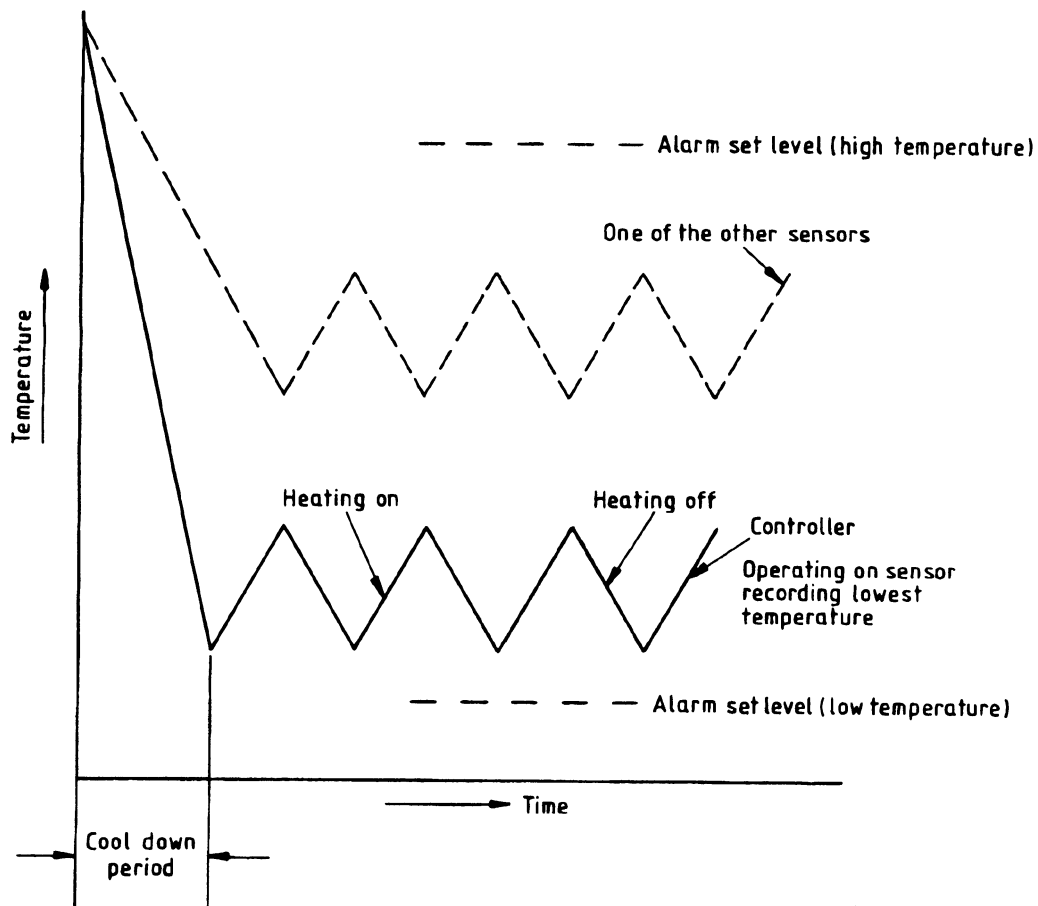


Figure A.4 — Typical heating time recording curve



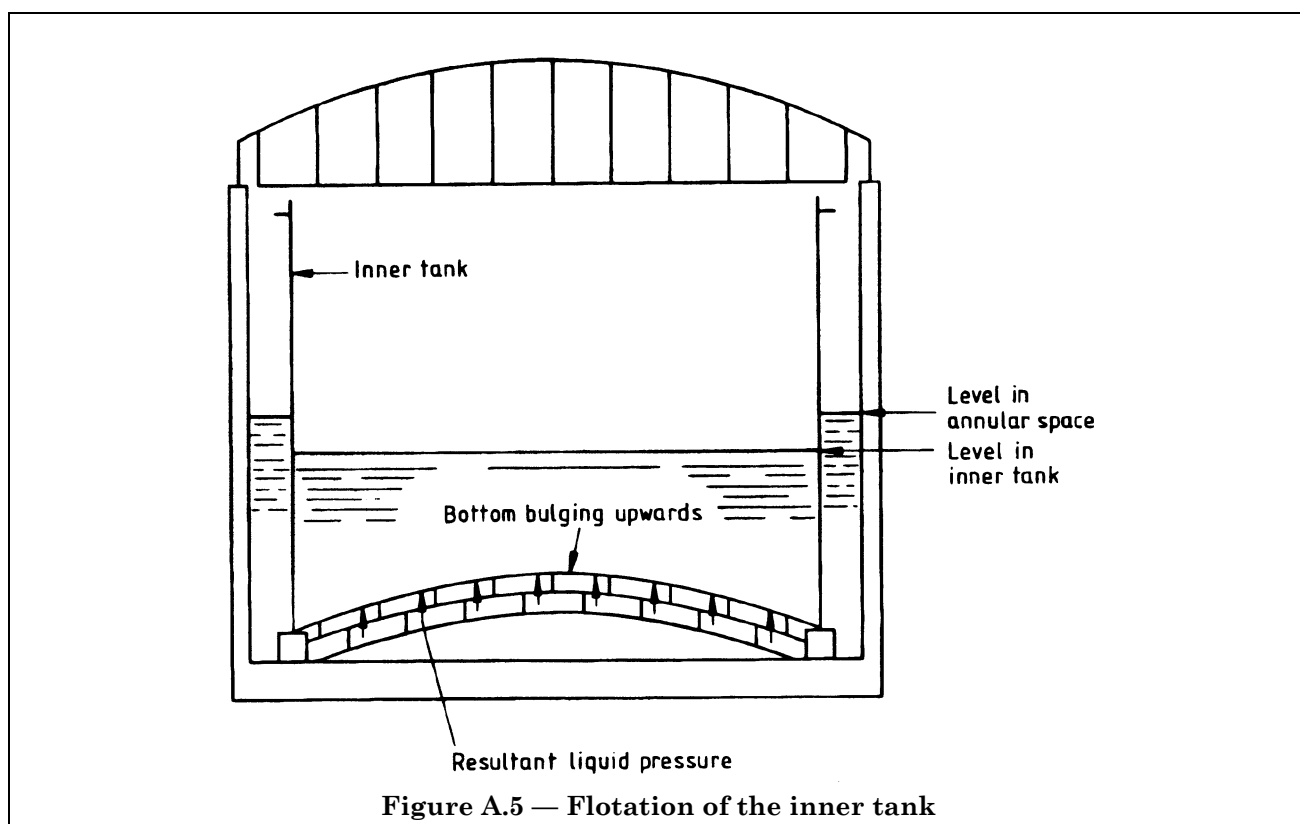


Figure A.5 — Flotation of the inner tank

## Annex B (informative) Guidance on a method of seismic analysis for refrigerated liquid gas tanks

### B.1 General

When historical evidence indicates that a particular site is subject to a significant risk of seismic activity, or when the local foundation conditions are known to be unfavourable, then a site specific review should be undertaken.

The objective of the site specific review is to establish peak ground accelerations for a given return period associated with the operating basis of the safe shutdown earthquake, together with free field site response spectra. This forms the basis for a seismic analysis of the tank shell and bottom plates.

NOTE For simple seismic loading cases, reference should be made to appendix G of BS 2654:1989.

### B.2 Analytical method

#### B.2.1 General

Guidelines for the seismic analysis method are given in B.2.2 to B.2.5. A distinction can be made between a static and a dynamic analysis of the tank structure.

#### B.2.2 Static analysis

A static analysis of the tank structure may be used in the following cases:

- for inner tanks of double and full containment systems;
- for outer tanks (steel or concrete) of double and full containment systems, for areas with low seismicity;
- for inner tanks and outer containers of single containment systems, for areas with low seismicity.

For the static analysis of concrete tanks, local building codes may be used (e.g. the US *Uniform building code*[4]). For the static analysis of steel tanks, appendix G of BS 2654:1989 should be used as a guideline.

Table B.1 — Component transient loading criteria

Component	Stress	Transient loading	
		Wind loading or OBE plus all other loading	SSE plus all other loading
Plate	Tensile stress	$0.85 \times$ yield of proof stress	Yield or proof stress
	Compressive stress	<b>G.3</b> of BS 2654:1989	Lesser of design stress to BS 7777-2 and $(0.4 \times Et/R)$
Anchor	Tensile or compressive stress	$0.85 \times$ yield or proof stress	Yield or proof stress
<b>Key to variables</b>		<b>Abbreviations</b>	
$E$ = Young's modulus;		OBE = operating basic earthquake;	
$t$ = thickness;		SSE = safe shutdown earthquake.	
$R$ = tank radius.			
NOTE Refer to appendix G of BS 2654:1989 for seismic provisions for storage tanks.			

### B.2.3 Dynamic analysis

A full dynamic analysis of the tank structure should be carried out in the following cases:

- for outer tanks (steel or concrete) of double and full containment systems, for areas with high seismicity;
- for inner tanks and outer containers of single containment systems, for areas with high seismicity.

For a dynamic analysis of the tank structure, a finite element programme with modal analysis or direct integration techniques can be used. The input for such calculation is a time-ground acceleration history or a design response spectrum.

They are based on certain recurrence intervals to be specified by the purchaser (see B.1). It is common practice to set the recurrence period for the outer tank of double and full containment systems one order of magnitude higher than the recurrence period for the inner tank.

### B.2.4 Sloshing

A method for calculating the height of the sloshing wave can be found in *Basis of design provisions for welded steel storage tanks* by R.S. Wozniak and W.W. Mitchell[5].

### B.2.5 Allowable stresses

The peak tensile and compressive stresses should be compared with code allowable values as defined in Table B.1. The tank bottom should be checked for lift-off.

## Annex C (informative)

### Guidance on safety and other aspects

#### C.1 General

Two aspects relating to the storage of refrigerated liquid gases (RLG) warrant particular attention. The first of these is that the liquid concerned is maintained in that state by virtue of artificially created thermal conditions. If it were to escape from its container it would revert to a much greater volume of gas. The second aspect is economic. The value of the contents of a large storage system can be several million pounds sterling. Thus there are strong incentives, both financial and environmental, to ensure that the contained liquid does not escape.

Long experience has shown that single containment systems, of concrete or metal, can be operated for many years without trouble. The safety record of RLG storage is very good.

However, modern requirements for environmental safety and the limitation of social risk involve enhanced safety measures, often to guard against events which are beyond the control of the owner or operator of the system.

Safeguards of this type are embodied in national and local authority requirements and regulations. These vary from country to country, and sometimes within the same country. The requirements for a particular site are determined by consultation between the owner/operator and the relevant authorities. It is the responsibility of the owner to ensure that they are included in the statement of design philosophy. The wide variations in specific site requirements make it difficult to lay down hard and fast rules, but guidance can be obtained from the British Standards and other references listed on the inside back cover.

It is becoming common practice for the owner/operator, in conjunction with the approving authority, to perform a hazard and systems analysis for proposed RLG storage sites and designs. The analysis includes a probability assessment of various accident scenarios and the effects of safety measures. The consequences of credible accidents are considered, and the physical implications of possible leaks and spills are derived.

Computational models, incorporating dynamic effects, and the response behaviour of the storage system and its components, are employed. The components considered include the support system and the foundation/soil interaction.

## **C.2 Pressure and vacuum relief**

### **C.2.1 Pressure relief safety valves**

For the purposes of relief of the inner tank, internal positive pressure relief valves should be entirely separate from the internal negative pressure relief valves. This requires the inlet piping to penetrate the suspended roof where applicable, thus preventing cold vapour from entering the warm space between outer roof and suspended roof under relieving conditions. The influence of this piping should be considered in relief valve capacity calculations.

Pilot-operated pressure relief valves are preferred to dead weight type pressure relief valves for refrigerated storage tanks. These valves stay tight up to the set pressure and open wide when this pressure is reached (see Figure C.1 and Figure C.2). This no-flow/full-flow characteristic prevents icing at the valve seats.

NOTE Icing is a cause of leakage in the shut position.

An advantage of pilot-operated pressure relief valves is that the valve pilot setting is verifiable in situ. Because the pilot operates against atmosphere, its set pressure does not vary with back-pressure. This is important in the case of discharge into a vent or flare system (see Figure C.3).

A disadvantage of this type of valve is that, if blockage occurs in the pilot sensing line with the tank pressure near set pressure, the relieving pressure of the valve can be as high as twice the set pressure. For all tanks an extra valve of the same capacity should be installed to allow for the possible maloperation of one of the valves.

### **C.2.2 Internal negative pressure safety valves**

Separate safety valves should allow air into the vapour space between the outer roof and the suspended roof for the following reasons:

- a) restricted flow, if there is a long inlet pipe and a low differential pressure available across the valve;
- b) condensation problems, if wet air is allowed to enter the cold inner tank.

Pilot-operated internal negative pressure relief valves are not acceptable for pressure protection because the valve action is not fail-safe against main valve diaphragm or bellows rupture.

Conventional pallet type internal negative pressure valves should be used. Since the tanks normally operate at a slight overpressure, there will be enough margin between operating pressure and valve setting to keep the valve tightly shut (see Figure C.4).

### **C.2.3 Valve setting for maximum relief pressures**

It is essential that the set pressure of relief valves does not exceed the design pressure of the tank. The relief valve capacity should be such that the maximum relief pressure does not exceed 1.1 times the design pressure for all emergencies, except an external fire. For fire conditions the maximum relief pressure should not exceed 1.2 times the design pressure.

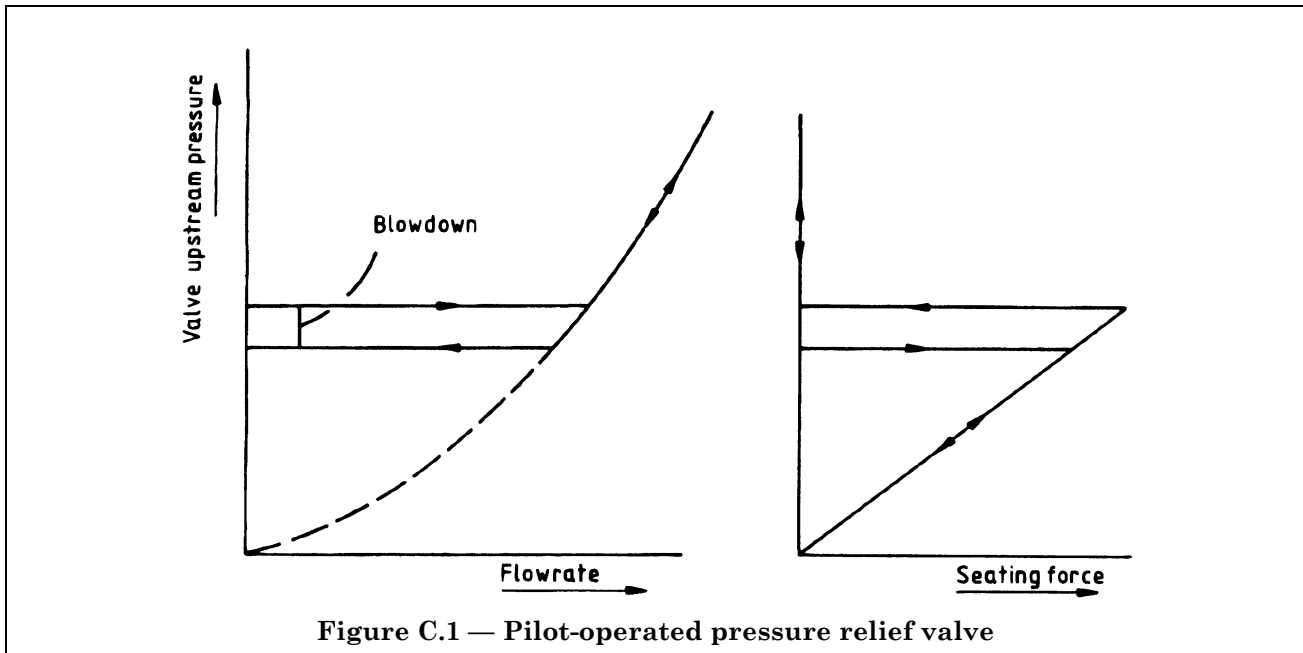


Figure C.1 — Pilot-operated pressure relief valve

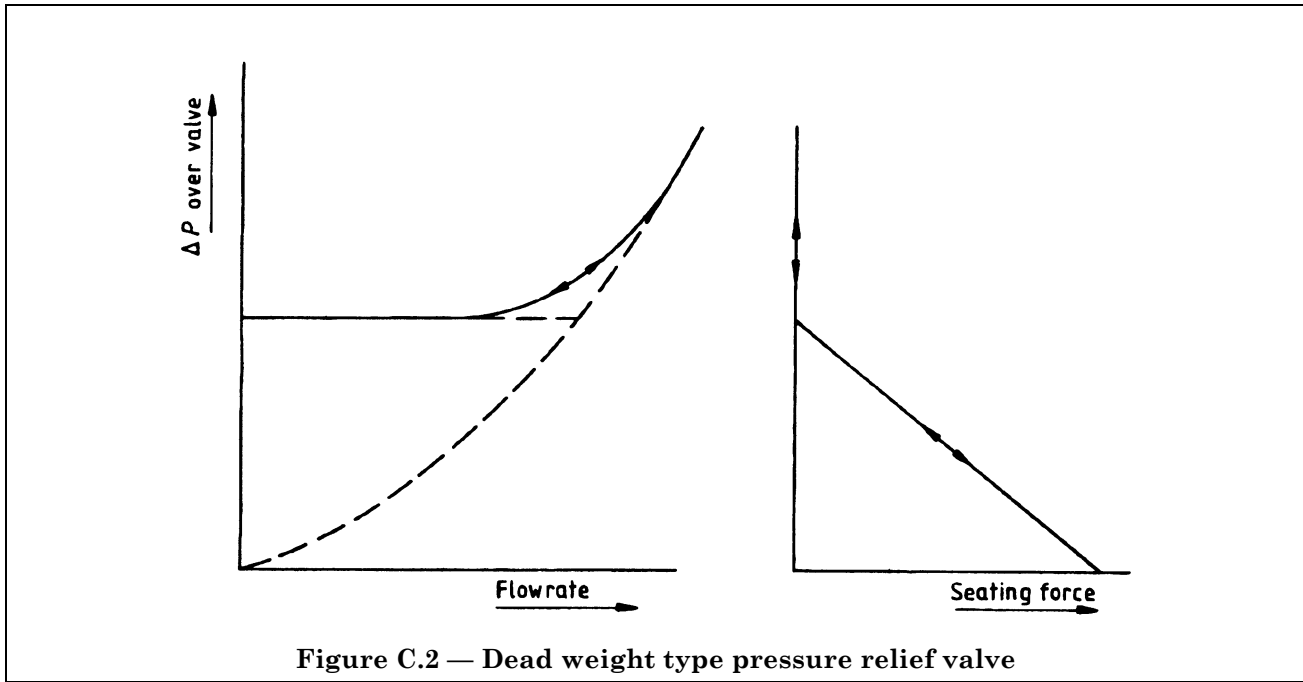
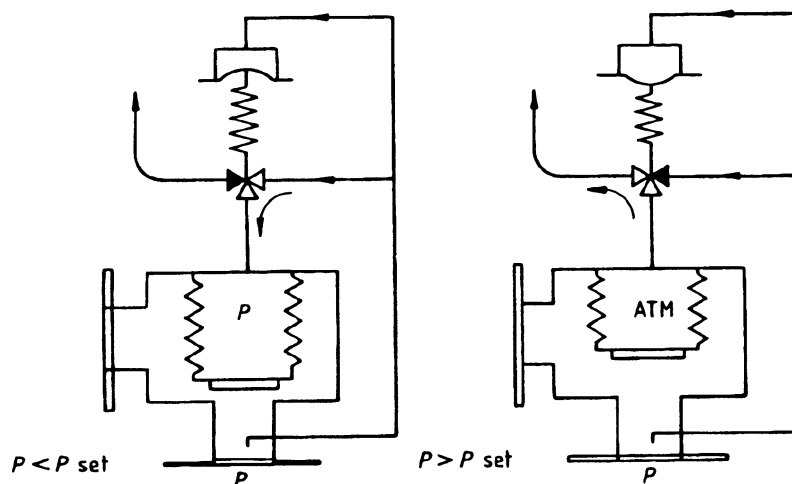
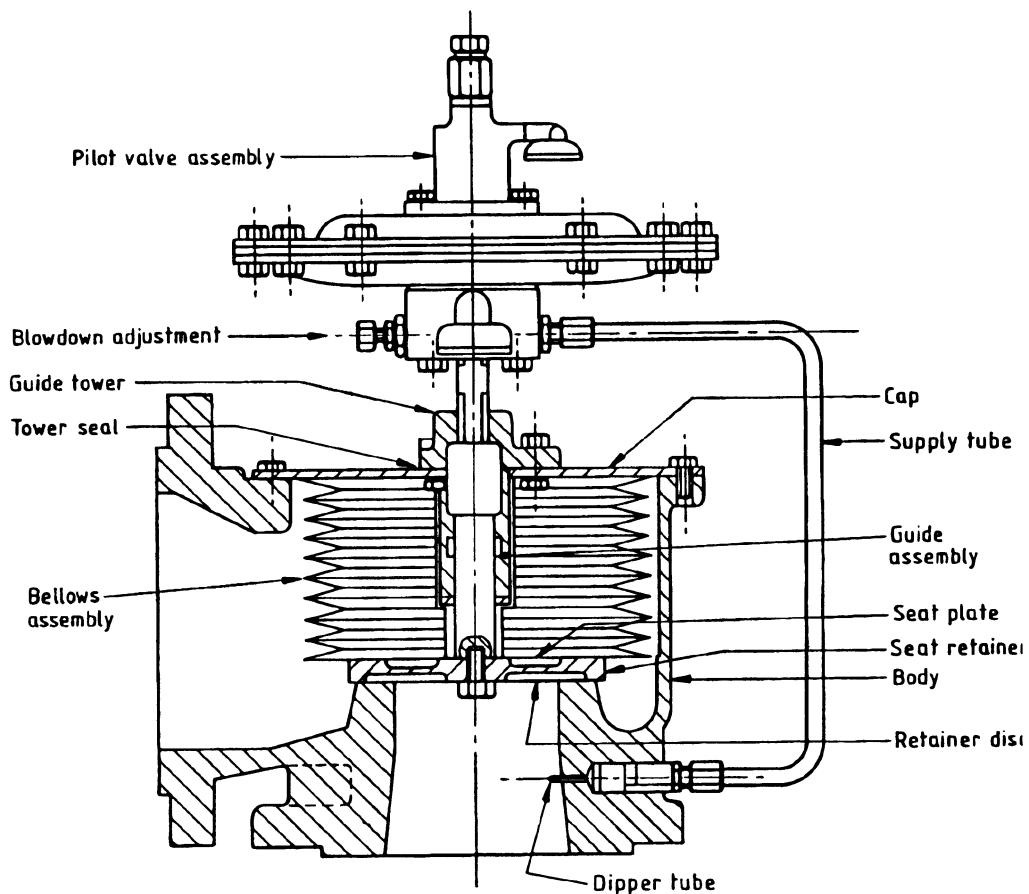
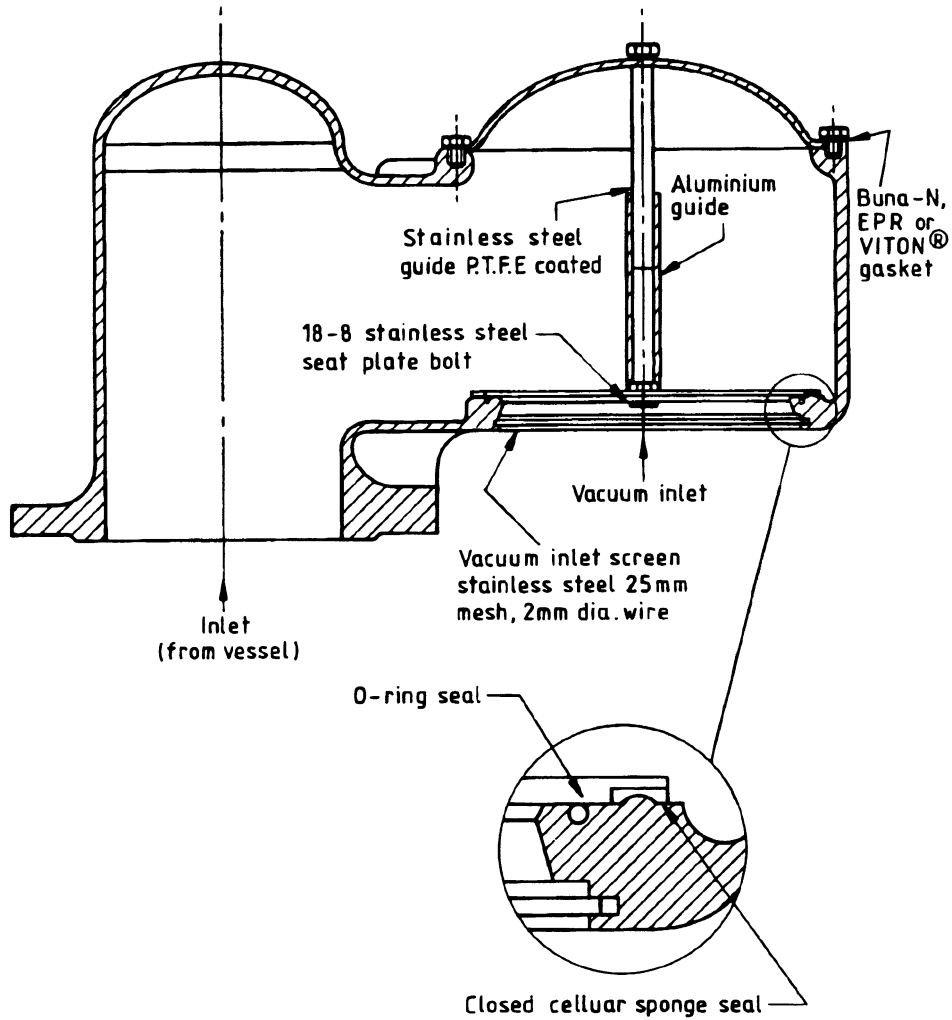


Figure C.2 — Dead weight type pressure relief valve



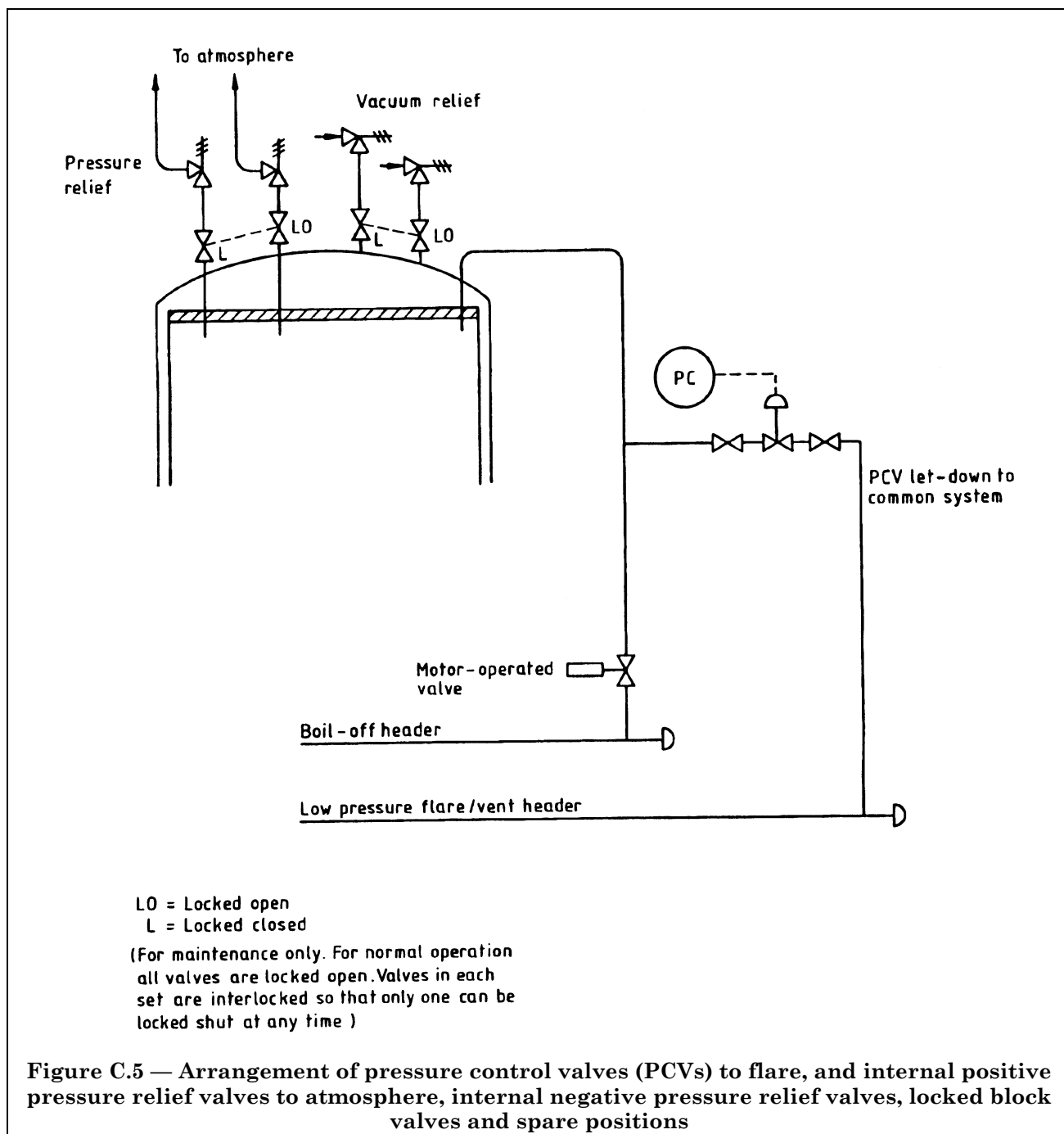
$P$  = Pressure inside tank  
 ATM = Atmospheric pressure

Figure C.3 — Pilot-operated low-pressure relief valve



NOTE. VITON is an example of a suitable product available commercially. This informative is given for the convenience of users of this Part of BS 7777 and does not constitute an endorsement by BSI of this product.

Figure C.4 — Dead weight type internal negative pressure relief valve



#### C.2.4 Spare venting capacity

Internal positive pressure relief valves and internal negative pressure relief valves for refrigerated storage tanks should be provided with interlocked block valves and spare positions, so that a faulty pressure relief valve can be exchanged without opening the tank to atmosphere (see Figure C.5).

#### C.2.5 Relief of compressed vapour

There are two means of relieving the compressed vapour of a tank system, as follows.

- a) *Relief to controlled system.* Vapour relieved from the pressure relief valve of a tank should be conducted to a location such as a flare system where it is safely discharged.

b) *Relief to atmosphere*. Vapour should be safely vented directly to atmosphere, provided that this is accomplished without creating the following problems:

- 1) formation of flammable toxic mixtures at ground level or on elevated structures where personnel are likely to perform their duties;
- 2) ignition of the relieved vapours at point of emission.

NOTE The hydrocarbon vapour outflow from internal positive pressure relief valves can be ignited by one of the following.

*i) Lightning*. Except for emergency relief associated with power failure or atmospheric pressure drop which may occur during a thunderstorm, the probability of lightning occurring simultaneously with the opening of a relief valve is negligible. Leaking relief valves increase the probability of lightning ignition.

The inert gas snuffing system connected to the discharge pipework may be used to extinguish the ignited vapours.

*ii) Adjacent tank fire*. The expansion of vapour in the dome of a tank subject to radiation from an adjacent tank fire could cause the atmospheric relief valve to open. If the venting vapour ignites, the additional radiation from the vent fire causes further expansion, thus requiring additional venting capacity, and results in high roof-plate temperature.

The inert gas snuffing system would not normally be designed to extinguish the flames and use should be made of adequate water spray/exposure protection facilities.

### C.3 Leakage and spillage

#### C.3.1 General

In considering the consequence of leakage or spillage, account should be taken both of the volume of the leak or spill and of the nature of the product. All refrigerated liquids when spilled evaporate at a rate which is directly related to the surface area of the spilled liquid.

Small leaks or spills may require forced ventilation of potential pockets of gas, for instance under the bases of above-ground tanks. This is particularly the case with heavy gases such as butane or propane. Gases, such as methane, which are lighter than air at ambient temperatures are usually denser than air when they are first evolved, and are thus capable of forming a low-lying vapour.

When larger spills are to be considered, measures are normally taken to limit the pool surface area of the spill, and hence the rate of vapour formation. These may take the form of concrete guard walls, earth bunds, or a system of channels leading to a remote collection area. Some tanks are located below ground level for similar reasons.

Vapour cloud generation should be avoided for reasons other than fire and explosion. Ammonia, for instance, is highly poisonous in comparatively small concentrations, and thus needs special consideration. Dense vapour clouds can also cause suffocation and the low temperature of the liquid and vapour is a hazard.

#### C.3.2 Risk of external leakage to atmosphere

The risk of external leakage to the atmosphere can be minimized by:

- a) avoiding all connections on the tank below the maximum liquid level;
- b) where such connections are unavoidable, limiting both their number and size;
- c) use of emergency remote control and/or automatic fail safe shut-off valves on liquid connections on the tank and other important locations;
- d) use of double valving for all liquid connections on the tank below the maximum liquid level, the first being as near to the tank shell as practicable;
- e) use of welded connections upstream of the first shut-off valve on each connection below the maximum liquid level.

#### C.3.3 Local internal leaks

The guidance given in this and related standards regarding prevention of leaks in storage tanks is to ensure that the tanks are liquid tight. It is important to highlight the need for attention to detail in the design, construction and testing of each tank bottom and its attachment to the lowest course of the shell. The recommendations made should be applied to both inner and outer tanks, leak-tightness being further confirmed by vacuum box testing of the welds in the inner tank after the hydrostatic test (see BS 7777-2:1993).

Any local cooling in the tank interbottom space could lead to unacceptably high local thermal stresses in the outer tank bottom. To prevent the possibility of outer bottom failure due to thermal stress, consideration should be given to suitable protective layers of liquid-proof thermal insulation over the outer tank bottom, or to the use of low temperature quality steel for the outer tank bottom and the lower shell course. In double containment tanks and full containment tanks (see BS 7777-2:1993) a suitable low temperature quality steel has to be provided for the outer tank bottom, shell or the liners, unless, in the case of outer concrete tanks, the concrete is designed for direct contact with the liquid.



### C.3.4 Internal condensation

In tanks containing product gas in the annular space, the possibility of condensation in the interbottom space and the intershell space exists. The presence of product liquid on the outer tank floor may result in flotation of the inner tank and significant damage to inner and outer tanks. Instrumentation enabling the operator to be warned of the existence of such condensation and a means for its removal should be considered and specified at the tank design stage.

At certain locations where the outside temperature in winter can drop below the atmospheric boiling point of the product, say  $-5\text{ }^{\circ}\text{C}$  for butane, condensation on the underside of the tank roof will occur. Large quantities of condensate, comparable with a very heavy rainfall, may drop down on the suspended deck. Thus drainage holes should be provided in the deck so that the liquid can enter the inner tank. A drain protection system should be provided above the annular space, so that the condensate is directed to the inner tank. No liquid should enter the annular space.

### C.3.5 Overfilling

To prevent overfilling, two separate independent level instruments should be provided. The level instruments should be equipped to provide remote readings and high level alarm signals in the control room. As backup to these level instruments, separate independent Level High Alarms (LHA) and Level High, High Alarms with Cut Out [LHHA (CO)] are recommended. The LHHA (CO) should be hard wired directly to close the motor-operated liquid inlet valves to the tank (see A.2).

### C.3.6 Accidental spillage

The outer tank should be protected from the adverse effects of any accidental spillage of the product onto the tank roof or shell.

Areas on the tank roof where the spillage is most likely to occur are flanged joints.

The tank areas where such spillage is possible need to be protected by low temperature steel roof plating, or product catchment trays, liquid proof insulation and suitable drainage directing the spillage to a safe disposal area. The size of these trays should take account of wind dispersion.

## C.4 Tank layout and spacing

### C.4.1 Distances

Various national and US standards include requirements for minimum distances between steel tanks, distances to property lines and secondary bunds (see American Federal Safety Standard (AFSS) 49 Code of Federal Regulations (CFR) Part 193[6], National Fire Protection Association (NFPA) Standards 59 and 59A[7,8] and Chemical Industries' Association *Code of practice for large scale storage of fully refrigerated anhydrous ammonia in the United Kingdom*[9]).

### C.4.2 Location and spacing

The containment system of tanks, and their associated bunds and impounding basins, should be located and spaced so that in the event of a tank fire, or a fire in a bund/impounding basin, which results from the ignition of spillage, radiation flux levels are in accordance with the recommendations of the *IP model code of safe practice in the petroleum industry* Part 9: Volume 1[10], hereafter referred to as the IP code.

NOTE For tank layout and spacing reference should be made to "Refrigerated storage" in the IP code[10].

### C.4.3 Radiation flux levels

The radiation flux levels laid down in the IP code[10] are based on the ignition of the product, either in the tank or spilling from it and forming a pool. The radiation flux level is determined by the spillage rate, evaporation rate and duration of the spillage, together with the topography/location of the bund/impounding basin.

NOTE An example of a calculation for radiation levels is given in "Refrigerated storage" in the IP code[10].

## C.5 Fire protection and loss control systems

For a concrete outer tank, the fire rating will be affected by such aspects as the thickness of the wall, slab or roof, the cover thickness over the reinforcement, and the position of the prestressing cables.

The installation of at least four combustible gas detectors equally spaced around a tank is recommended. Alarms should be located in the control room. In some cases these detectors should automatically close the tank liquid valves. Consideration should be given to the use of gas detectors for early warning, taking account of such aspects as points of potential leakage, drainage gullies, sumps, and tank and bund geometry.

Pumps and compressors should not be located within the storage tank bund for a single containment tank as they have a higher potential for leaks or fires than most other equipment.

NOTE For fire protection and loss control systems reference should be made to "Refrigerated Storage" in the IP code[10].

**C.6 Protection against explosion and impact**

In any industrial plant handling hazardous liquids, the possibility of an explosion cannot be ruled out. The credibility of such an event forms part of the hazard analysis. The physical implications should be assessed to provide the basis for the design philosophy.

Commonly, an external blast overpressure and external missile impact are included in the hazard analysis. Since the blast loading is time dependent, a full dynamic analysis should be considered to determine its effect on the complete storage system, and its individual elements. This includes the foundations.

**C.7 Lightning protection**

The structure should be provided with adequate protection to prevent damage and fire by lightning. The requirements of local codes should be observed in full.

Where tankage is required to be protected against lightning, the following guidance is given.

- a) Provided there is a minimum steel thickness of 5 mm, a lightning discharge should not penetrate the tank and the absolute value of the earthing of a vertical storage tank is not important as far as the tank is concerned.

Where it is necessary to earth a storage tank for other reasons, such as installed electrical equipment, static discharge, or protection of the supporting structures, the absolute value of the earthing resistance should be determined.

- b) Electrical appliances and cabling either on or in tankage should be electrically earthed.

Any metal part which may be electrically isolated from the tank, e.g. by a gasket or even by a rust layer, should be bonded to the tank by the shortest possible route.

- c) Where a tank or pipeline is cathodically protected, either spark arresters, enclosed spark gap devices or similar devices should be fitted across any insulated flanges.

**C.8 Effect of radio transmissions, static electricity and cathodic protection systems**

In certain circumstances a hazard may exist when a flammable substance is stored in the vicinity of certain types of high powered radio transmitters. Radio waves can induce sufficient energy in steel members to cause incendive sparks at distances up to 20 km.

**NOTE** This distance is based on an m.f. broadcast radio transmitter of 150 kW, and a Group IIC gas (see appendix B of BS 6656:1991).

Normal provision of on-site radio systems, amateur and CB radios should not create a hazard at distances above 200 m. If there is any doubt on the possibility of a hazard existing then expert advice should be sought (see BS 6656).

Static voltages can also be built up in unearthed metalwork with a danger of spark creation.

Cathodic protection systems for buffed steelwork can also give rise to break sparks. If any of these hazards are relevant to a particular location, a more detailed study should be undertaken. Enhanced earthing provisions may be necessary to overcome the danger arising.

# List of references (see clause 2)

## Normative references

### BSI standards publications

BRITISH STANDARDS INSTITUTION, London

BS 7777, *Flat-bottomed, vertical cylindrical storage tanks for low temperature service.*

BS 7777-2:1993, *Specification for the design and construction of single, double and full containment metal tanks for the storage of liquified gas at temperatures down to – 165 °C.*

BS 7777-3:1993, *Recommendations for the design and construction of prestressed and reinforced concrete tanks and tank foundations, and the design and installation of tank insulation, tank liners and tank coatings.*

BS 7777-4:1993, *Specification for the design and construction of single containment tanks for the storage of liquid oxygen, liquid nitrogen or liquid argon.*

## Informative references

### BSI standards publications

BRITISH STANDARDS INSTITUTION, London

BS 2654:1989, *Specification for manufacture of vertical steel welded non-refrigerated storage tanks with butt-welded shells for the petroleum industry.*

BS 6656:1991, *Guide to prevention of inadvertent ignition of flammable atmospheres by radio-frequency radiation.*

BS 8110, *Structural use of concrete.*

BS 8110-1:1985, *Code of practice for design and construction.*

BS 8110-2:1985, *Code of practice for special circumstances.*

CP 3, *Code of basic data for the design of buildings.*

CP 3:Chapter V, *Loading.*

CP 3:Chapter V-2:1972, *Wind loads.*

### Other references

[1] THE ENGINEERING EQUIPMENT AND MATERIALS USERS' ASSOCIATION (EEMUA). *Recommendations for the design and construction of refrigerated liquefied gas storage tanks.* EEMUA publication 147:1986<sup>2)</sup>.

[2] AMERICAN PETROLEUM INSTITUTE (API). *Venting atmosphere and low pressure storage tanks (non-refrigerated and refrigerated)*, 2nd edition. API Standard 2000:1987.

[3] BRITISH CRYOGENICS COUNCIL, SAFETY PANEL. *Cryogenics safety manual — a guide to good practice.* Rushden: Reed Book Services, 1991.

[4] *Uniform building code.* International conference of building officials, Whittier, CA, USA:1988.

[5] WOZNIAK, R.S., and MITCHELL, W.W. Basis of design provisions for welded steel storage tanks, *Proceedings of the refining department of the American Petroleum Institute*, Vol. 57:1978.

[6] American Federal Safety Standard (AFSS) 49 Code of Federal Regulations (CFR) Part 193.

[7] NATIONAL FIRE PROTECTION ASSOCIATION (NFPA). *Standard for the storage and handling of LPG at utility gas plants.* NFPA standard 59:1992.

[8] NATIONAL FIRE PROTECTION ASSOCIATION (NFPA). *Standard for the production, storage and handling of LNG.* NFPA standard 59A:1992.

[9] CHEMICAL INDUSTRIES' ASSOCIATION. *Code of practice for large scale storage of fully refrigerated anhydrous ammonia in the United Kingdom.* 1992.

[10] *IP model code of safe practice in the petroleum industry. Part 9: Liquefied petroleum gas.* Volume 1 *Large bulk pressure storage and refrigerated LPG.* Chichester: John Wiley, 1987.

<sup>2)</sup> Referred to in the foreword only.

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