

DEP SPECIFICATION

PRESSURISED BULK LPG STORAGE INSTALLATIONS AT PROCESSING FACILITIES

DEP 30.06.10.12-Gen.

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DESIGN AND ENGINEERING PRACTICE

DEM1



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1. INTRODUCTION

1.1 SCOPE

This DEP specifies requirements and gives recommendations for the layout, location, safety and operability aspects of above-ground and mounded storage of LPG in pressure vessels in processing facilities (e.g., in bulk storage facilities at Upstream gas and gas to liquid plants, Manufacturing refineries and Chemicals sites).

This DEP also specifies requirements and gives recommendations for main equipments (pumps, compressors, strainers, valves, flexible loading arms, quality measuring instruments and odorizing facilities) available for use in LPG processing installations (e.g., in bulk storage facilities at Upstream gas and gas to liquid plants, Manufacturing refineries and Chemicals sites).

This DEP is for LPG including commercial mixtures of propane, propylene, butane or butylene (normal or iso-).

Excluded from this DEP are the following:

- Facilities at terminals, bottling plants, customer sites and retail sites.
- LPG vessels inside the battery limits of process units.

This DEP contains mandatory requirements to mitigate process safety risks in accordance with Design Engineering Manual (DEM) 1 – Application of Technical Standards.

This DEP is a revision of the same number dated February 2018; see (1.5) regarding the changes.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by Shell GSI, the distribution of this DEP is confined to Shell companies and, where necessary, to Contractors and Manufacturers/Suppliers nominated by them.

Any authorised access to DEPs does not for that reason constitute an authorisation to any documents, data or information to which the DEPs may refer.

This DEP is intended for use in facilities related to oil and gas production, gas handling, oil refining, chemical processing, and gasification. This DEP may also be applied in other similar facilities.

When DEPs are applied, a Management of Change (MOC) process shall be implemented; this is of particular importance when existing facilities are to be modified.

If national and/or local regulations exist in which some of the requirements could be more stringent than in this DEP, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable with regards to the safety, environmental, economic and legal aspects. In all cases, the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned, the objective being to obtain agreement to follow this DEP as closely as possible.

1.3 DEFINITIONS

1.3.1 General definitions

The **Contractor** is the party that carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party that manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party that initiates the project and ultimately pays for it. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The capitalised term **SHALL [PS]** indicates a process safety requirement.

The word **should** indicates a recommendation.

The word **may** indicates a permitted option.

1.3.2 Specific definitions

Term	Definition
Adiabatic Flash Fraction	Flash (or partial) evaporation is the partial vapour that occurs when a saturated liquid stream undergoes a reduction in pressure.
Lower Design Temperature (LDT)	The LDT is the lowest temperature to which equipment can be safely subjected at its design pressure with respect to brittle fracture control.
LPG	Any material having a vapour pressure not exceeding that allowed for commercial propane that is composed predominantly of the following hydrocarbons, either by themselves (except propylene) or as mixtures: propane, propylene, butane (normal butane or isobutene), and butylenes
Maximum Operating Pressure (MOP)	The MOP is the vapour pressure of the commercial product concerned corresponding to the MOT.
Maximum Operating Temperature (MOT)	Refer DEP 01.00.01.30-Gen. for MOT definition.
Minimum Metal Temperature (MMT)	The MMT is the lowest temperature that equipment could possibly reach. It takes into account the normal lowest operating temperature, the lowest temperatures during startup or shutdown and exceptional cool down events caused by high rate depressurising (when applicable), upset and emergency conditions resulting in Joule-Thompson cooling, or cooling by evaporation or boiling of liquefied gas

1.3.3 Abbreviations

Term	Definition
ESD	Emergency Shutdown
LPG	Liquefied Petroleum Gas
PD	Positive Displacement
QMI	Quality Measuring Instruments

1.4 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section or clause number is shown in brackets ().

Other documents referenced by this DEP are listed in (12).

1.5 SUMMARY OF MAIN CHANGES

This DEP is a revision of the DEP of the same number dated February 2018. This is an administrative update only to correct references to DEPs that have been involved in either a merge or a split.

1.6 COMMENTS ON THIS DEP

Comments on this DEP may be submitted to the Administrator using one of the following options:

Shell DEPs Online (Users with access to Shell DEPs Online)	Enter the Shell DEPs Online system at https://www.shelldeps.com Select a DEP and then go to the details screen for that DEP. Click on the "Give feedback" link, fill in the online form and submit.
DEP Feedback System (Users with access to Shell Wide Web)	Enter comments directly in the DEP Feedback System which is accessible from the Technical Standards Portal http://www.shell.com/standards . Select "Submit DEP Feedback", fill in the online form and submit.
DEP Standard Form (other users)	Use DEP Standard Form 00.00.05.80-Gen. to record feedback and email the form to the Administrator at standards@shell.com .

Feedback that has been registered in the DEP Feedback System by using one of the above options will be reviewed by the DEP Custodian for potential improvements to the DEP.

1.7 DUAL UNITS

This DEP contains both the International System (SI) units, as well as the corresponding US Customary (USC) units, which are given following the SI units in brackets. When agreed by the Principal, the indicated USC values/units may be used.

1.8 NON NORMATIVE TEXT (COMMENTARY)

Text shown in italic style in this DEP indicates text that is non-normative and is provided as explanation or background information only.

Non-normative text is normally indented slightly to the right of the relevant DEP clause.

2. TYPES OF STORAGE VESSEL

2.1 GENERAL

1. LPG at ambient temperatures may be stored under pressure in two different types of vessels:

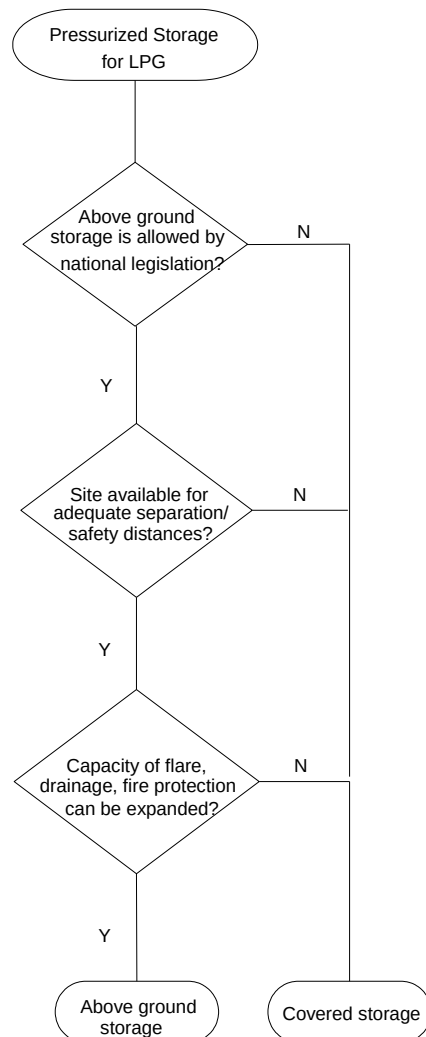
- a. Above ground storage vessels (spheres, bullets), and
- b. Covered storage vessels (mounded or submerged storage).

Mounded storage can provide additional safety compared with above ground storage. For instance, the occurrence of a BLEVE (boiling liquid expanding vapour explosion) is virtually impossible because of passive environment. However, the design of mounded storage is in general more complicated than for above ground spheres or bullets.

2. Refer to EEMUA 190, Chapter 3 for settlement issues as well as corrosion protection.
3. The flow chart for storage vessel selection in Figure 1 shall be followed to determine if above ground storage or covered storage is acceptable.

Above ground storage installations require adequate flare capacity, sufficient drainage systems and extended fire protection systems.

Figure 1 Flowchart for storage vessel selection



3. ABOVE-GROUND BULK STORAGE OF LPG IN PRESSURE VESSELS

3.1 LAYOUT AND LOCATION

3.1.1 General

1. Refer to DEP 80.00.10.11-Gen. for requirements for layout and selection of location.

3.1.2 Piping

1. Only piping directly associated with the storage vessels shall be located within the storage area; refer to (3.2.4), Figure 3 and Figure 4.
2. If the risk assessment indicates a need for active or passive fire protection for piping, then refer to Section 3.3.10 of DEP 80.47.10.30-Gen.

3.1.3 Grading and ground finish

1. Grading and ground finish SHALL [PS] be designed so that spills/escaped product drain away from equipment and cannot collect under vessels or remain in their immediate vicinity.

2. To facilitate the flow of escaped product and prevent its penetration into the soil, the ground shall be finished with concrete paving sloping towards the perimeter drain channels; refer to DEP 34.14.20.31-Gen.
3. For storage vessels in dedicated LPG service that always have an adiabatic flash fraction larger than 0.1 together with a resulting adiabatic flash temperature of 20 °C (36 °F) or more below the lowest ambient temperature, the following apply:
 - a. The concrete paving together with the perimeter drain channels may be omitted.
 - b. Omission of the sloping floor and the liquid collecting trench should be considered; refer to Section 6.5 of DEP 80.47.10.30-Gen.

The content of the vessel will vaporise sufficiently without danger of a pool fire.

3.1.4 Separation between the vessel and the pipe manifold

1. There shall be a positive separation/deflection between the storage vessels and the pipe manifold/track to prevent the flow of any leakage from one to the other.

For example, a wall of 0.6 m (2 ft) maximum height.
2. Deflection walls may be considered between vessels to prevent product escape from one vessel from flowing under another.

3.1.5 Confinement

1. Bund walls shall not be used.

Bund walls interfere with the ventilation of the site and impede the vaporisation/dispersion of escaped products.

3.1.6 Surface drainage

1. Refer to DEP 34.14.20.31-Gen. for surface drainage requirements.

3.2 VESSELS

3.2.1 Types of vessels

1. Pressure vessels for above ground storage of LPG shall be one of the following types:
 - a. horizontal cylindrical vessels;
 - b. vertical cylindrical vessels;
 - c. spherical vessels.
2. Portable tanks SHALL [PS] not be used for providing permanently installed storage facilities.

3.2.2 Applicable codes

1. LPG storage vessels shall comply with one of the following standards:
 - a. EN 12542 (vessels < 13 m³ (459 ft³));
 - b. DEP 31.22.00.31-Gen.
2. The Manufacturer/Supplier shall be responsible for obtaining the required certificates of acceptance for the storage vessels from the appropriate authorities.

3.2.3 Design temperature and pressure

3.2.3.1 Maximum Operating Temperature (MOT)

1. The MOT shall be the maximum temperature on receipt into storage or the assessed temperature for the relevant climate as follows, whichever is the higher:
 - a. The assessed temperatures are:
 - i. 35 °C (95 °F) for temperate climates;
 - ii. 40 °C (104 °F) for tropical climates;
 - iii. 45 °C (113 °F) for desert climates.
 - b. If assessed temperatures have been established by local regulations or in the design code specified by the Principal, then these shall be used for design purposes.

3.2.3.2 Maximum Operating Pressure (MOP)

1. Refer to Table 1 for the MOP corresponding to the MOT for commercial products.

3.2.3.3 Design Pressure (DP)

1. Refer to DEP 01.00.01.30-Gen. for the requirements for determining the design pressure.
2. The DP is defined for the top of the vessel; hence, the maximum liquid static head shall be taken into account to determine sizing/strength of the lower parts of the vessel.
3. A vapour return line and/or top spray filling (3.2.4.6) should be used as a means of limiting excessive back-pressure build-up in vessels during the filling operation.
4. If vapour return systems are not used, then the DP should be checked to ensure that the back-pressures generated when filling are adequately covered, in order to avoid product loss through spurious relief.

Vapour return systems prevent vacuum from developing during discharge.

The relationship between temperature and vapour pressure of commercial propane, commercial butane and propane/butane mixtures is shown in Figure 2.

3.2.3.4 Design Temperature (DT)

1. Refer to DEP 01.00.01.30-Gen. for further definition of DT.

3.2.3.5 Lower Design Temperature

1. With respect to the Lower Design Temperature (LDT):
 - a. Refer to DEP 01.00.01.30-Gen. for determining the LDT.
 - b. Refer to DEP 30.10.02.31-Gen. for the requirements associated with the LDT once it has been determined.

3.2.3.6 Minimum Metal Temperature (MMT)

1. Refer to Part II, Section 2.1.5 of DEP 01.00.01.30-Gen. for the definition and determination of the MMT.

3.2.3.7 Vacuum conditions (external pressure)

1. Above ground LPG storage vessels SHALL [PS] be designed for full vacuum conditions if any of the following conditions are met:
 - a. Ambient temperatures can be expected to fall below Atmospheric Boiling Point (ABP) of the commercial product stored.

- b. The rate of liquid withdrawal can exceed the capacity of the vapour return system resulting in sub atmospheric pressure.

These cases normally apply only to Butane storage.

2. Table 2 provides details of the pressure in a vessel containing pure n-butane at low temperatures, which shall be included in the design.

3.2.4 Connections

3.2.4.1 General

1. The number of nozzles on vessels, particularly below the liquid level, should be minimised.
2. Refer to ASME B16.5 for requirements for nozzle flanges.
3. Nozzles to which product transfer piping, product drains and pressure relief systems are connected shall be at least DN 50 (NPS 2).
4. Flanges in piping under vessels shall be avoided for safety reasons.

3.2.4.2 Bottom connections

See Figure 3 for typical bottom connection details.

1. There shall be only one bottom connection, to be used for filling, withdrawal and draining.
2. The bottom connection pipe SHALL [PS] be welded and not flanged to the vessel bottom nozzle, so that the vessel nozzle includes the pipe and terminates at the weld between the nozzle and the first valve.
3. All joints in the bottom pipe, up to and including the first valve (ESD valve) SHALL [PS] be welded and fully radiographed.
4. The minimum size of the bottom pipe shall be DN 100 (NPS 4).
5. The bottom pipe thickness shall be as determined by the pressure vessel code with the following minimum thickness:
 - a. Schedule 80 or thicker for DN 100 (NPS 4).
 - b. Schedule 40 or thicker for pipes larger than DN 100 (NPS 4).

Due to the fact that the pipeline is welded, it may be more vulnerable to mechanical damage during engineering work.

6. The product line should be as short as possible and sloping downwards from the vessel to the pump suction.
7. The product line shall be provided with a water drain system at the manifold, upstream of the operational valve(s), downstream of the ESD valve (see Figure 3). See (3.2.4.3).
8. The product line SHALL [PS] be provided with an ESD valve (3.4.2) welded to the upstream side of the product line and located downstream of the separation/deflection wall.
9. Only in locations subjected to moderate/severe earthquake conditions (refer to DEP 34.00.01.30-Gen., Section 3.8) or where local regulations dictate, may the ESD valve be internally mounted; refer to Figure 4.
10. The product line SHALL [PS] be provided with a shut-off valve directly downstream of the ESD valve.

11. The product line shut-off valve may be fitted with an actuator and be remotely controlled.
 - a. The product line shut-off valve should be capable of being manually operated, even if it is fitted with an actuator and can be remotely controlled.
12. The product line SHALL [PS] be provided with a flanged tee, to accommodate an elbow between it and a DN 50 (NPS 2) drain valve to provide a bypass in case of malfunction of the internal ESD valve for emptying of the vessel.
13. The product line bypass should be installed permanently by using a welded connection with a locked valve (subject to approval by the appropriate regulatory Authorities); refer to Figure 4.
14. The product line SHALL [PS] be fire-insulated at all flanges immediately beneath the vessel.

3.2.4.3 Drain system for sphere and mounded bullets

1. Each storage vessel shall be provided with a drain nozzle not larger than DN 50 (NPS 2) Schedule 80 welded to the bottom line (see Figure 3 and Figure 4).
 - a. A fire-safe ball valve not larger than DN 50 (NPS 2) (upstream drain valve) shall be connected to the drain nozzle.
2. The drain system SHALL [PS] meet the following requirements:
 - a. Have two manual shut-off ball valves separated by at least 600 mm (2 ft) of supported piping with a slope towards the drainage direction to ensure that both valves are never simultaneously blocked open by ice.

The separation is so that if flashing of LPG at the second valve (downstream) freezes, the valve in the open position is far enough away that it is still operable and can operate the drain.
 - b. The two drain valves positioned so that a single operator can operate both valves simultaneously.
 - c. The downstream drain valve a DN 20 (NPS 3/4), quick-acting, spring-loaded type (spring-to-close) valve, that will operate as a dead man's handle.
 - d. The discharge point lined up to flare or a vent in a safe location via a knock out vessel, with the size of the knock out vessel determined by the rate of draining and the volume of the piping contents between the bottom of the storage vessel and the drain connection.
3. Refer to DEP 80.45.10.10-Gen. for the design and sizing requirements of knockout drums and associated equipment.

Additional details on separation equipment can be found in DEP 31.22.05.12-Gen.
4. A risk assessment and dispersion analysis shall be carried out in order to determine if the use of a vent to atmosphere is acceptable instead of routing to the flare.
5. A vent to atmosphere shall meet the following requirements:
 - a. A DN 20 (NPS 3/4) pipe follows the downstream drain valve into a small separator vessel with discharge to atmosphere at a safe location. Refer to DEP 80.45.10.10-Gen.
 - b. The discharge point is in a freely ventilated area outside the periphery of the vessel.
 - c. Installed with knockout drums and associated equipment in accordance with DEP 80.45.10.10-Gen. and DEP 31.22.05.12-Gen.
6. The water drained from the vessel shall be routed to and collected at a safe location.

7. At locations where freezing can occur, the drain valves, separator/knockout vessel and lines shall be protected against freezing.
 - a. Tracing shall not be welded to the product drain line.
8. At low points in pipelines and equipment, drain points shall be fitted with a shut-off valve with a blind flange.

3.2.4.4 Top connections

1. Nozzles of all top connections shall be above the maximum liquid level.
2. Liquid and vapour lines terminating in the vapour space should be flange connected to a nozzle at the top of the vessel.
3. Liquid fill connections shall be provided with a remotely operated non-return valve directly connected to the vessel nozzle and a close coupled fire-safe shut-off valve preferably of the remotely operated type.
4. If flow can be bi-directional, the vapour connection shall be fitted with a remotely operated fire-safe shut-off valve.
 - a. Back flow protection shall be in accordance with DEP 80.45.10.11-Gen., Section 2.11.7.
5. To prevent the release of liquid in the event of a pipe leak, the internal pipe shall not extend below the maximum liquid level.
6. There should be only one (top mounted) manhole of minimum size DN 600 (NPS 24) for above-ground vessels.
7. For mounded vessels the manhole (top mounted) should be in accordance with DEP 34.51.11.30-Gen., except in very long horizontal vessels where two manholes may be required to facilitate access/escape for maintenance/inspection personnel and improve gas freeing.
8. The manhole cover should be used to its maximum extent for the location of connections/fittings, e.g., instruments.
9. Pressure Relief Valves (PRVs) shall be connected to the vapour space of the vessel. See also (3.4.8).

3.2.4.5 Instrument connections

Typically in industry, instrument connections are not more than 1.5 mm (0.05 in) bore.

1. Connections for instruments shall, where practicable, be above the maximum liquid level of the vessel to prevent the release of liquid in the event of a tubing leak.
2. Instrument connections should be located where impact damage and shearing off of the fittings are unlikely to occur.
3. A shut-off valve shall be installed for all instruments in open connection with the vessel.

3.2.4.6 Top spray filling system

Top spray filling is recommended as a means of limiting excessive back-pressure build-up during the filling operation.

The top spray filling system normally consists of a spray ring (for spheres) or straight pipe (for cylindrical vessels) with a sizing which is normally one size less than the inlet piping to the storage vessel, e.g., if the line to the storage vessel is 100 mm (4 in) diameter then the spray ring would be 80 mm (3.2 in) diameter.

1. The pressure drop across the spray ring should be a maximum of 1 bar (14.5 psi) at the maximum liquid flow rate.

Maximum liquid flow would normally occur when LPG is being transferred from one storage vessel to another by means of the loading pumps. As the LPG rundown rate is normally lower than this transfer rate, the pressure drop will normally be correspondingly lower.

2. The holes in the spray ring should be between 8 mm (0.32 in) and 10 mm (0.39 in) diameter to give a reasonable liquid distribution with minimal risk of blocking due to rust.
3. The top spray ring/pipe should be located as close to the top of the storage vessel as possible to avoid a significant reduction in vessel ullage.
 - a. The holes should be angled upwards in an arc of 120 degrees.
4. The top spray ring/pipe shall be provided with sufficient drain holes (6 mm (1/4 in) ID) to allow easy drainage of the LPG from the spray ring/pipe.
5. The spray shall not foul the level gauges or temperature gauges.
6. The top spray ring/pipe should be installed so that the need to weld onto the shell of the storage vessel is avoided.

The top spray ring/pipe will have to be fabricated in sections to allow it to enter the vessel via the top manhole.

- a. Significant stresses might be placed on the inlet nozzle of the storage vessel, and these should be calculated to confirm that they are within the acceptable limits.

It might be necessary to reinforce the nozzle.

3.2.5 Supports and foundations

3.2.5.1 Supports

1. Supports shall be capable of carrying the vessel full of water.
2. The vessels shall be anchored to the foundation.
3. Horizontal vessels shall have two steel saddle supports for mounting on concrete pedestals, one saddle being a fixed support and the other a sliding support to permit expansion and contraction of the vessel.
 - a. The fixed support shall be welded to the shell.
 - b. The fixed support shall be at the same end of the vessel as the bottom nozzle.
 - c. The sliding support shall have a wear plate welded to the outside of the vessel at the location of its support.
 - d. It may also be possible that the sliding takes place between the end of the support and the concrete plinth. The sliding support shall not permit the vessel to move in the transverse and vertical directions.
 - e. The supports shall incline the vessel at a minimum slope of 0.5 % for complete draining.
4. The concrete pedestals shall be high enough to protect the vessel from flotation in the event of flooding and to give adequate NPSH for pump suction.

3.2.5.2 Design of foundations

1. The Manufacturer/Supplier shall submit a loading diagram for the foundation design, including loads on the foundations, dimensions and location of base plates and holding-down bolts.
2. Refer to DEP 34.00.01.30-Gen. for loading data and load combinations.

3.2.5.3 Structural steel

1. Refer to DEP 34.28.00.31-Gen. and standard drawing S 28.022 for design of stair, stair treads, railings, and platforms.

3.2.5.4 Fire proofing

1. Refer to DEP 34.19.20.11-Gen. and DEP 80.47.10.30-Gen. for the requirements for fireproofing of structures and vessel supports.

3.2.6 Identification

1. Storage vessels should be identified with a tag number, painted prominently on the shell.
2. Product identification marking shall be prominently located next to receipt and discharge connections.

3.3 INSTRUMENTATION

3.3.1 General

1. All instrument components in contact with LPG (liquid or vapour) shall be suitable for all of the following conditions:
 - a. LPG service;
 - b. for operation over the range of liquids level;
 - c. design temperatures and design pressures of the vessel.
2. Instrument components in contact with LPG (liquid or vapour) should be suitable for the vessel test pressure.
3. Refer to DEP 32.31.00.32-Gen. for instrumentation requirements.

3.3.2 Level measurement

1. One failure-revealing level gauge (i.e., main gauge) for continuous indication shall be employed.
2. A second gauge should be incorporated if the expected mean-time-between-failure of the main gauge would result in operationally unacceptable availability figures, as determined either by existing procedures for Brownfield projects or by the Principal for Greenfield projects.
 - a. The second gauge, if used, should work on a different measurement principle than that of the main gauge.
3. If a local indication of level is required independently of the main gauge, a third, less accurate, level instrument may be provided.
 - a. This instrument shall not be used for safeguarding functions.
4. Refer to DEP 32.80.10.10-Gen. for the requirements for instrumentation for safeguarding functions.
5. Glass level gauges SHALL [PS] not be used.
6. Magnetic float gauges, capacitance gauges or rotary gauges may be used.

3.3.3 Level protective functions and alarms

3.3.3.1 General

1. In order to protect against overfilling due to product receipt or liquid expansion, all LPG storage vessels shall be equipped with a liquid level safeguarding and alarm system, see (3.3.3.3).
2. Level alarms shall have both visual and audible output.

3. From a safeguarding point of view, high level alarm/alert and high-high level alarm/trip shall be independent; refer to DEP 32.80.10.10-Gen.

Figure 6 and Figure 7 show alarm settings (liquid expansion/ullage tube length) to be determined for various vessel sizes.

4. Low-level alarm/alert and low-low level (emergency) alarm/trip shall be incorporated, where loss of liquid level could lead to equipment failure or gas blow into liquid full system.
5. Because all connections have to be made from the top of the vessel, dependable and serviceable low level switches are difficult to install. Hence, for pump protection, the derived switching functions from the analogue instrument may be used.

A liquid sensor mounted in the suction line is an alternative solution for pump protection. For pump protection, pressure differential or electrical phase shift detection are options.

3.3.3.2 Maximum safe filling level based upon maximum product temperature rise

1. The maximum safe filling level based upon maximum product temperature rise (see Figure 7) shall be set so that the vessel will never become more than 99 % liquid full when the Bulk mean temperature of the liquid reaches the maximum operating temperature. See (3.2.3.1).
2. The maximum safe filling level shall be based on the maximum rise in product temperature that may occur in practice. This rise will be the difference between the lowest in-vessel product temperature and the maximum operating temperature. The maximum safe filling level is determined as per Equation 1.

$$V_f = 0.99V \frac{g_i}{g_m} \quad \text{Equation 1}$$

Where: V_f = Maximum safe filling volume in litres (gal)
 V = Vessel capacity in litres (gal)
 g_i = Density of liquid at maximum operating temperature
 g_m = Density of liquid at lowest storage temperature

The % ullage volume required for Figure 7 will be:

$$\% \text{ Ullage Volume} = (V - V_f) * 100/V$$

3. Where a reliable minimum temperature is not available, a rise of at least 30 °C (54 °F) should be allowed for. Refer to Figure 5 when calculating the extent of product expansion, using the temperature section of the curve most appropriate to the product temperatures experienced at the location.

3.3.3.3 Filling operations

3.3.3.3.1 Vessel with a capacity less than or equal to 50 m³

1. Vessels with a capacity of less than 50 m³ (1765 ft³) and are closely supervised during filling should be equipped at least with fixed ullage gauges as a means of overfill protection.

"Close supervision" involves having a dedicated operator for the filling operation.

2. A dedicated risk assessment shall be carried out in order to determine the valid barriers required to manage the risks associated with these operations to ALARP.