Rama Challa, Matrix PDM Engineering, USA, offers an introduction to LNG storage tank systems with reference to API 625.

Standard practice

At a time when small and large scale LNG facilities are in great demand, it is especially important to recognise their complexity. Owners and contractors have a responsibility to understand the equipment and nuances involved in design, construction, commissioning and operation. Umbrella standards, such as API 625,[1] ensure that systems provide a uniform level of performance, safety, reliability and quality, and provide an overall framework. API 625 addresses all aspects of a tank system and differs from component standards, such as API 620[2] for metallic materials.

This article introduces components of LNG storage tank systems, and covers storage types, construction materials, accessories and appurtenances. Certain aspects, such as performance criteria, are also included. In addition to this, a few key construction and post-construction activities are highlighted. Appropriate sections of API Standard 625, 'Tank Systems for Refrigerated Liquefied Gas Storage' are referenced.

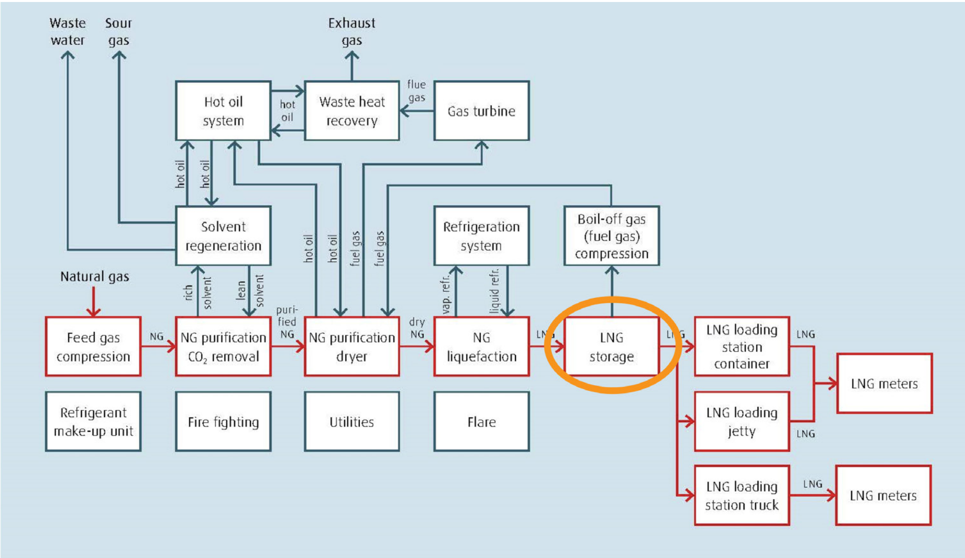

Figure 1. Storage: a component in the system (courtesy: Linde Engineering brochure on LNG plants[6]).

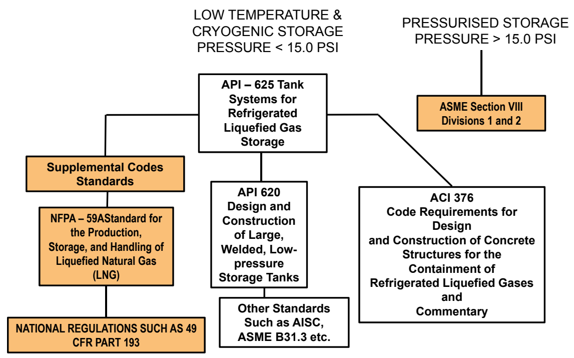

Figure 2. LNG tank US codes and standards structure.

Codes and standards

Storage, though critical, forms only a part of an LNG facility (Figure 1). Regulatory standards within the US, such as 49 CFR 193[3] and NFPA 59A[4], invoke API 625, which, in turn, defers to standards such as API 620 for metallic materials and ACI 376 for concrete parts (Figure 2).[5] Figure 3 indicates API 625's scope of coverage.

API 625 is handled by the Refrigerated Tank Task Group (RTTG) of the Subcommittee on Aboveground Storage Tanks (SCAST) within the Committee on Refining Equipment (CRE). API standards are consensus standards developed by industry experts drawn from owners and contractors. The RTTG was created in spring 2006 due to a perceived need for an umbrella standard. The first edition was published in August 2010. Some RTTG members participate in NFPA 59A, ACI 376, as well as other standards.

A typical LNG storage tank (Figure 4) can be considered as an inner tank with refrigerated liquid insulated from ambient conditions by a concrete or steel outer container. The 11 sections and five appendices of API 625 define the various components (Figure 5). The appendices address gas properties, foundation settlement, risk assessment and selection of storage, as well as inquiries.

Containment types

The three main storage concepts are covered in API 625 (Chapter 5 and Appendix C).

A single containment system consisting of an inner and outer container, designed and constructed so that only the inner container is required to contain liquid and be liquid-tight. The outer container, designed for product vapour pressure, retains and protects the insulation, but does not contain liquid if the inner container leaks. These systems require dikes that impact facility layout.

The double containment tank system consisting of a liquid and vapour-tight primary tank system built inside of a liquid-tight secondary liquid container. The secondary liquid container is liquid-tight, but not vapour-tight.

The full containment tank system consisting of a liquid-tight primary container and a liquid and vapour-tight secondary container. Both can independently contain the product. The secondary container controls vapour release in the event of a primary product leak. A key design feature is the thermal corner protection (TCP) at the outer tank base-to-wall joint. The TCP provides liquid tightness and thermally isolates this joint from the cold liquid in the event of a primary container leak.

Performance criteria

Once an owner has selected the tank and containment configuration, the design organisation establishes performance requirements. These requirements, in Section 6.4 of API 625, define the following:

- Conditions to calculate boil-off rate (625-6.4.4).
- Product rollover provisions by active temperature and density monitoring with in-service product mixing (625-6.4.5).
- Component design temperatures for material selection and allowable stresses (625-6.4.6).
- Details for the tank insulation system and attached piping for differential movement control during cooldown (625-6.4.7).
- Foundation settlement and effect on piping systems and insulation (625-6.4.8).
- Soil freezing mitigation by providing air gap or foundation heating (625-6.4.9).
- Seismic loading (625-6.4.10).

Of these items, boil-off and the seismic hazard study are typically owner activities.

Structural design

Structural design loads and load combinations follow API 625 Section 6.5 requirements. Design requires consideration of both normal and abnormal loads. Normal loads include dead load, liquid, seismic operating base earthquake (OBE), decommissioning and differential settlement effects. Abnormal loads include liquid spill, risk assessment loads (fire; external projectile; blast wave) and seismic safe shutdown earthquake (SSE) and aftershock level earthquake (ALE).

A seismic hazard study, per Section 6.5.2 of API 625, is required to define the ground motions associated with three earthquake levels. Performance requirements are as follows:

- OBE:
  - System operational during the event.
  - System to be operational with minor damage after multiple events.
- SSE:
  - Primary containment capability.
  - System isolation and maintainability during the event.
  - Survival of primary containment with minor leaks after singular event (with an expectation of extensive damage).
- ALE:
  - Secondary containment of the primary container volume at maximum normal operating level.
  - Secondary containment with minor damage and leaks after multiple events.

For certain locations, seismic loads may control the tank and foundation design. Seismic design, including sloshing effects, is covered in Section 6.6 of API 625.

Construction materials

The materials used are influenced by the design temperature of the tank, foundation and appurtenances. Materials must comply with the standards of construction, such as API 620, Appendix Q.

For single containment systems, the inner tank is usually constructed of 9% or 7% nickel carbon steel. Stainless steels or aluminiums that are rated for the -260°F design temperature are an option as well. The insulation deck is typically aluminium. The outer tank and roof are not rated for cryogenic temperatures and are made of carbon steel.

Full containment tank systems use the same inner tank materials. The outer tank and roof are typically made of

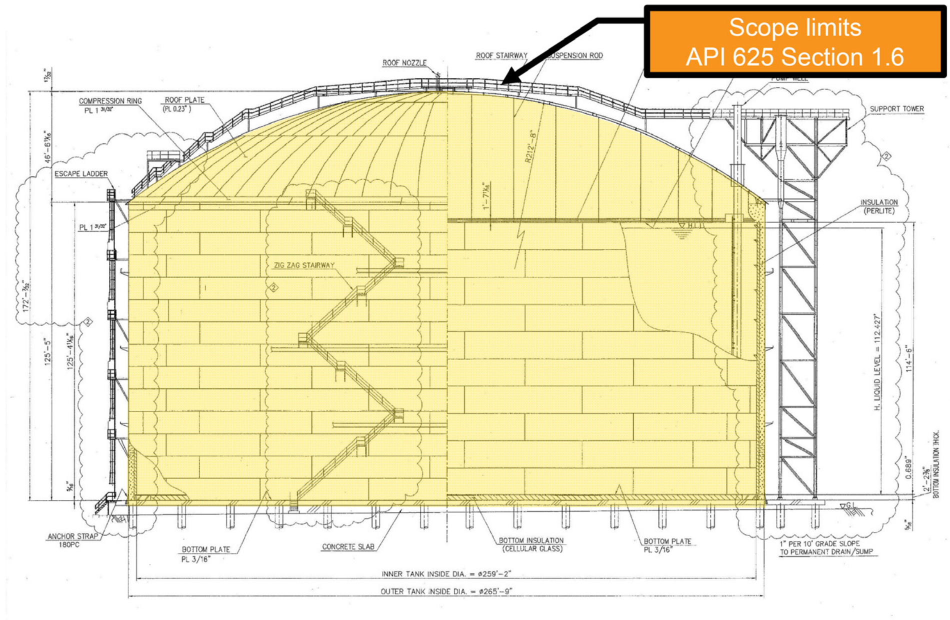

Figure 3. API 625 boundaries.

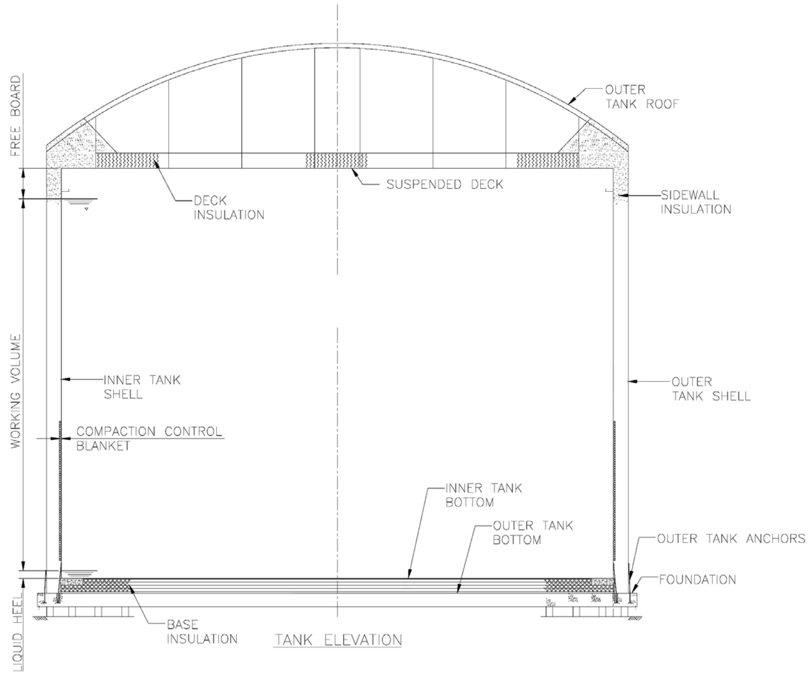

Figure 4. Nomenclature – basic LNG storage tank.

reinforced concrete. The outer tank liner is typically made of carbon steel with the TCP at the lower portion.

Insulation

The tank systems maintain the internal liquid below its boiling point to limit boil-off gas (BOG). The key to ensure this function is proper insulation (Section 9, API 625). Storage tank system design build contractors design insulation by coupling data from insulation manufacturers and in-house tests. Parameters considered include thermal conductivity, strength, density, etc. Figure 6 demonstrates some common types. A broad classification of the insulation system is as follows:

- Load bearing bottom and TCP insulation: cellular glass with open surface cells and interleaving material.
- External wall and roof insulation: rigid insulation covered by a weatherproofing and vapour barrier.
- Internal wall insulation: loose fill perlite, an expanded volcanic ore.
    - Loose fill perlite settles and compacts during repeated loading and unloading of the inner tank. As it settles, it will impose external pressure on the inner tank. A compaction control system in the form of a resilient blanket on inner tank is used to minimise the effect. A reservoir of extra perlite is maintained to cater for long-term settlement in the interstitial space.
        - If the resilient blanket is not installed, the inner tank is designed for the uncontrolled perlite pressure considering the designated fill/empty cycles of the inner tank.
- Suspended deck insulation: the system typically consists of normal fibreglass blankets.
- Penetration and internal piping insulation: cold vapour or liquid process piping is isolated from the roof by utilising thermal distance pieces with insulation.

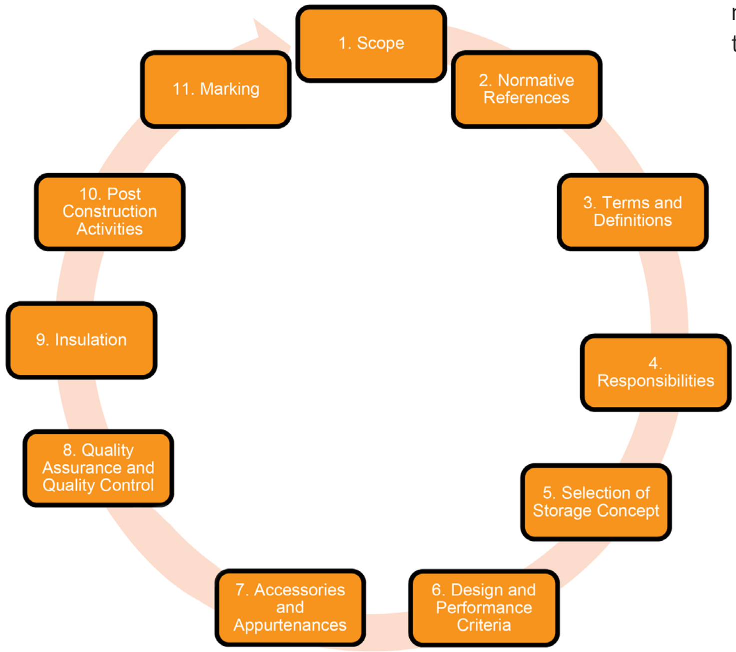

Figure 5. API 625 structure.

Accessories and appurtenances

The tank system accessories and appurtenances provide interfaces with the rest of the facility. These subsystems include the following (Section 7.0, API 625):

- External piping for tank purge, cooldown, fill and LNG send out (625-7.3).
- Tank pumping systems (625-7.3.3).
- Internal shut-off valves for single containment tanks with bottom or shell penetrations (625-7.3.1.4.2).
- External pressure relief and vacuum valves (625-7.4).
- Pressure, temperature and product density monitoring (625-7.5).
- External platforms and personnel access (625-7.2.3).

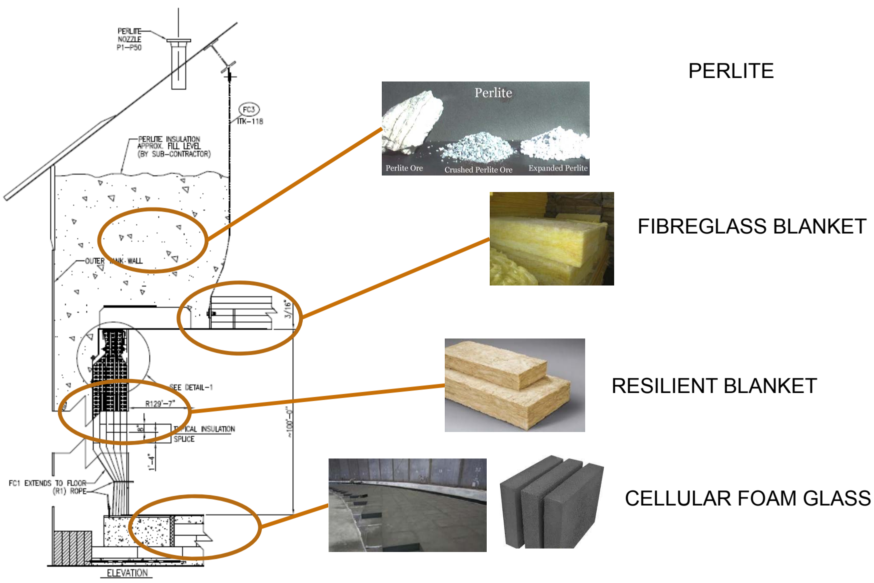

Figure 6. Insulation materials.

- Foundation heating, settlement monitoring and seismic motion monitoring (625-7.6).
- Hazard detection and mitigation (625-7.7).
- Lightning protection, tank grounding and aviation warning lights (625-7.8).

Additional requirements for these subsystems are addressed in API 620, ASME B31.3, NFPA-59A standards, as well as OSHA 29-CFR-1910.

Foundations

The type of foundation selected is affected by site soil properties, seismicity, climate, and owner-selected tank containment type. Good soil properties may lead to usage of a ring wall or slab on grade. For poor soils, piles and a pile cap are used. An elevated pile cap eliminates the foundation heating system due to the presence of an air gap preventing heat transfer to and from the soil.

Quality control and quality assurance

These systems require that design, procurement, shop fabrication, site construction and commissioning are performed by the tank system contractor under a quality management plan (QP) (Section 8, API 625) for compliance with design documents, codes and standards. Contractors employ a corporate level quality management system (QMS) that includes the concepts of quality planning (identification of standards), quality assurance (evaluation of overall project performance) and quality control (specific project result monitoring). A project specific quality plan (QP), derived from the QMS, includes project specific requirements. The QP has two components: quality assurance (QA) and quality control (QC).

QA is an offline activity that ensures that QC is completed per the plan. For example, it generally involves regular audit of the fabrication and construction QC for correctness and completeness. It also involves surveillance to ensure compliance with the project quality plan, drawings, specifications and procedures.

QC is an online activity that provides an operational means to fulfil quality requirements and produces results that comply with the QP. For example, the API 620 requirement that welds in the primary containers are examined using radiography (RT) or an ultrasonic method (UT) is a QC activity. Similarly, the dye penetrant examination (DPT) or vacuum box (VB) are QC activities as well. QC ensures that these types of activity are carried out.

Tank construction

Field construction of the LNG tank system depends upon the containment type selected. A general sequence for a single containment tank consists of the following:

- Steel fabrication.
- Foundation pour.
- Outer tank floor installation.
- Outer tank wall erection.
- Outer tank roof assembly and air raise.
- Inner tank floor insulation.
- Inner tank floor installation.
- Inner tank wall erection.
- Insulation deck installation.
- Hydrostatic and pneumatic testing.
- Sidewall and roof insulation installation.
- Installation of appurtenances and accessories.

Construction of double and full containment tanks are more complex and may include outer tank wall post-tensioning.

Post-construction activities

Activities after welding completion include hydrostatic and pneumatic testing, drying and tank purging (Section 10, API 625). Hydrostatic testing is carried out to ensure foundation adequacy and leak tightness of the completed inner tank. Pneumatic testing of the outer tank verifies leak tightness and anchor integrity.

Drying and purging prepares the completed tank system for cooldown and introduction of cryogenic LNG. This consists of the following:

- Removal of standing residual water.
- Purging with warm air followed by warm nitrogen.
- Purging with nitrogen to reduce oxygen followed by purging with methane to 80 – 90% concentration.

After the warm methane purge, the tank is gradually cooled down with LNG. During this process, the cooldown rate is carefully controlled to minimise the inner tank wall thermal gradients. Once cooled down, the tank system is ready to receive liquid and is placed into service.

Conclusions

LNG storage tank systems are complex entities with highly engineered components that, when combined together, constitute the storage system. The technology for these systems has evolved over the last 100 years with the first natural gas liquefaction plant in the US built in West Virginia in 1917, and the first LNG safety standards in the US coming into being in the late 1960s and early 1970s. Understanding is enhanced by advances in materials and operating history. Umbrella standards, such as API 625, reflect the collective experience of the contributors and ensure that the systems are built with safety and quality considerations. **LNG**

References

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