2022 API STORAGE TANK CONFERENCE & EXPO

October 10-13, 2022 | Marriott Marquis San Diego Marina, San Diego, California

AMMONIA STORAGE CONFIGURATIONS

Alex Cooperman, PhD, P.E., P.Eng.; Yogesh S. Meher, P.E.; Jeffrey C. Garrison, S.E., P.E.
CB&I Storage Solutions

American Petroleum Institute

DISCLAIMER

This paper and/or program may contain confidential or proprietary information. The information, observations, and data presented in this paper and/or program are intended for educational purposes only and do not identify, analyze, evaluate, or apply to actual, specific engineering or operating designs, applications, or processes. The comments and opinions are those of the author and not McDermott or CB&I Storage Solutions, are based on available information, and in all cases, reference shall be made to the actual wording and meaning of applicable codes and standards. The use of or reliance on any information, observations, or data provided is solely at your own risk.

Ammonia Production Resurgence

Major Drivers for resurgence of ammonia demand and Ammonia storage

- Green Energy Transition;
- Hydrogen demand as Ammonia is a good option to transport H2 molecules;
- Green Hydrogen production is environmentally friendly;
- Drives demand for Larger Ammonia Tanks (currently up to 70,000MT) but potentially up to 100,000MT.

Objectives

Examine Refrigerated Ammonia Storage Tank Configurations:

- Governing Codes And Standards
- Available Storage Concepts
- Typical Tank Configuration For Each Concept
- Pro And Cons For Each Concept

Ammonia Storage Concerns And Their Mitigations

- Stress Corrosion Cracking (SCC)
- In-tank Pumps

Governing Regulations

Ammonia Facilities:

USA: ANSI CGA G-2.1- 2014 - Requirements for the Storage and Handling of Anhydrous Ammonia.

Europe: None

Refrigerated Ammonia Storage Tanks (Typically Steel Tanks):

USA: API625, API620 Annex R

Europe: EN 14620: 2006 Parts 1, 2, 4, 5

EFMA Guidance for inspection of atmospheric, refrigerated ammonia storage tanks

General Environmental and Safety

29CRF1910.119 & OSHA 3132 – Process Safety Management

40CFR68 – Chemical Accident Prevention Provisions

Refrigerated Anhydrous Ammonia Storage

Typical Refrigerated Ammonia (NH_3) Storage Parameters

1. Specific Gravity: 0.68
2. Boiling Point at Atmospheric Pressure: -28°F
3. Design Pressure: 2 psi max

Material For Storage Tanks

Low-Temperature Carbon Steel

Issues And Concerns

1. Toxic Product
2. Issues with in-Tank Pumps – Compatibility with typical pump materials
3. Potential for Stress Corrosion Cracking (SCC)

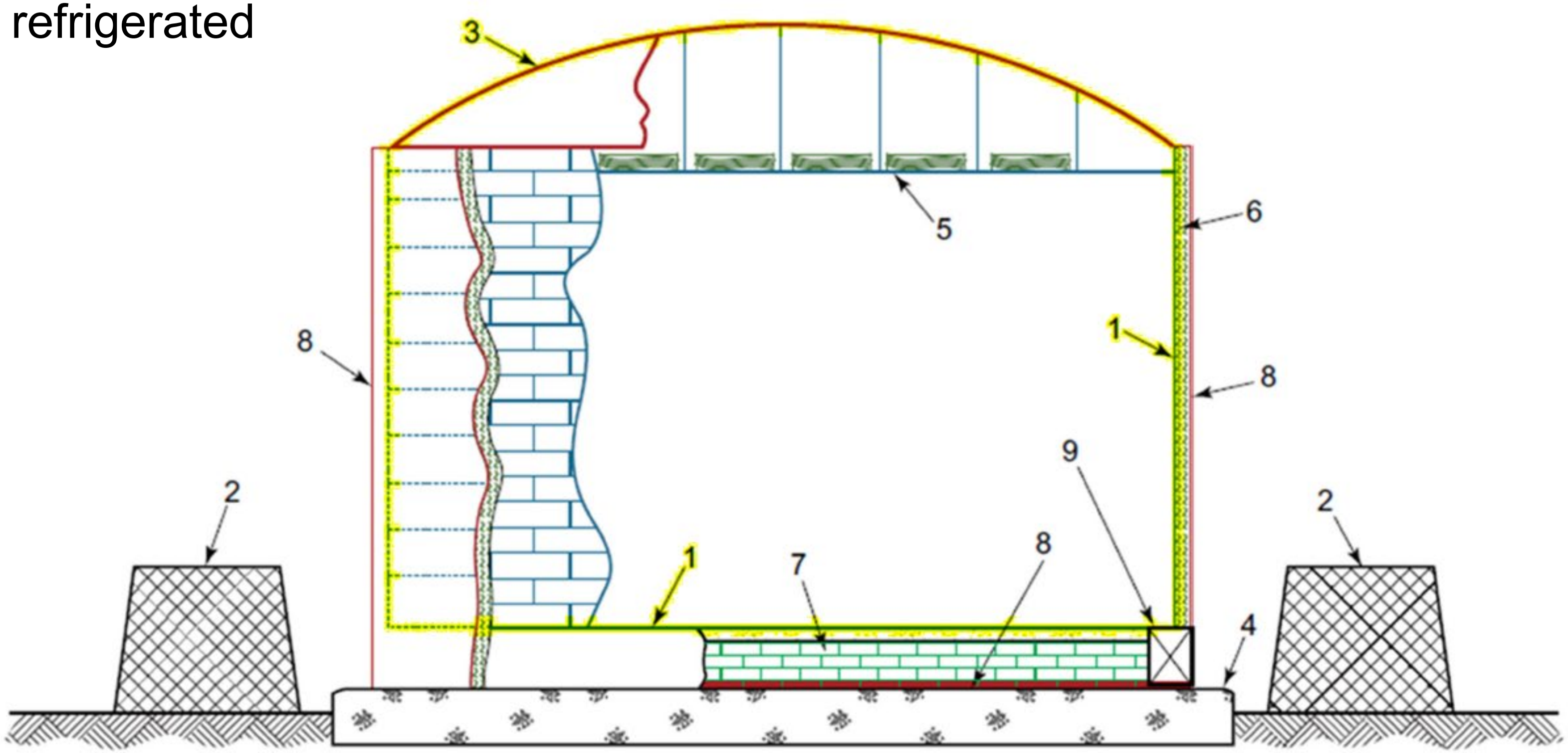
Ammonia Storage Tank Concepts

Refrigerated Ammonia Storage Tank Concepts Defined in API 625 and EN14620-1

- Single Containment Tank System (Single Wall or Double Wall)
- Double Containment Tank System
- Full Containment Tank System
- Double/Full Containment with Penetrations

Single Containment Tank System – Single Wall

- Single liquid and vapor tight container used to store refrigerated product.



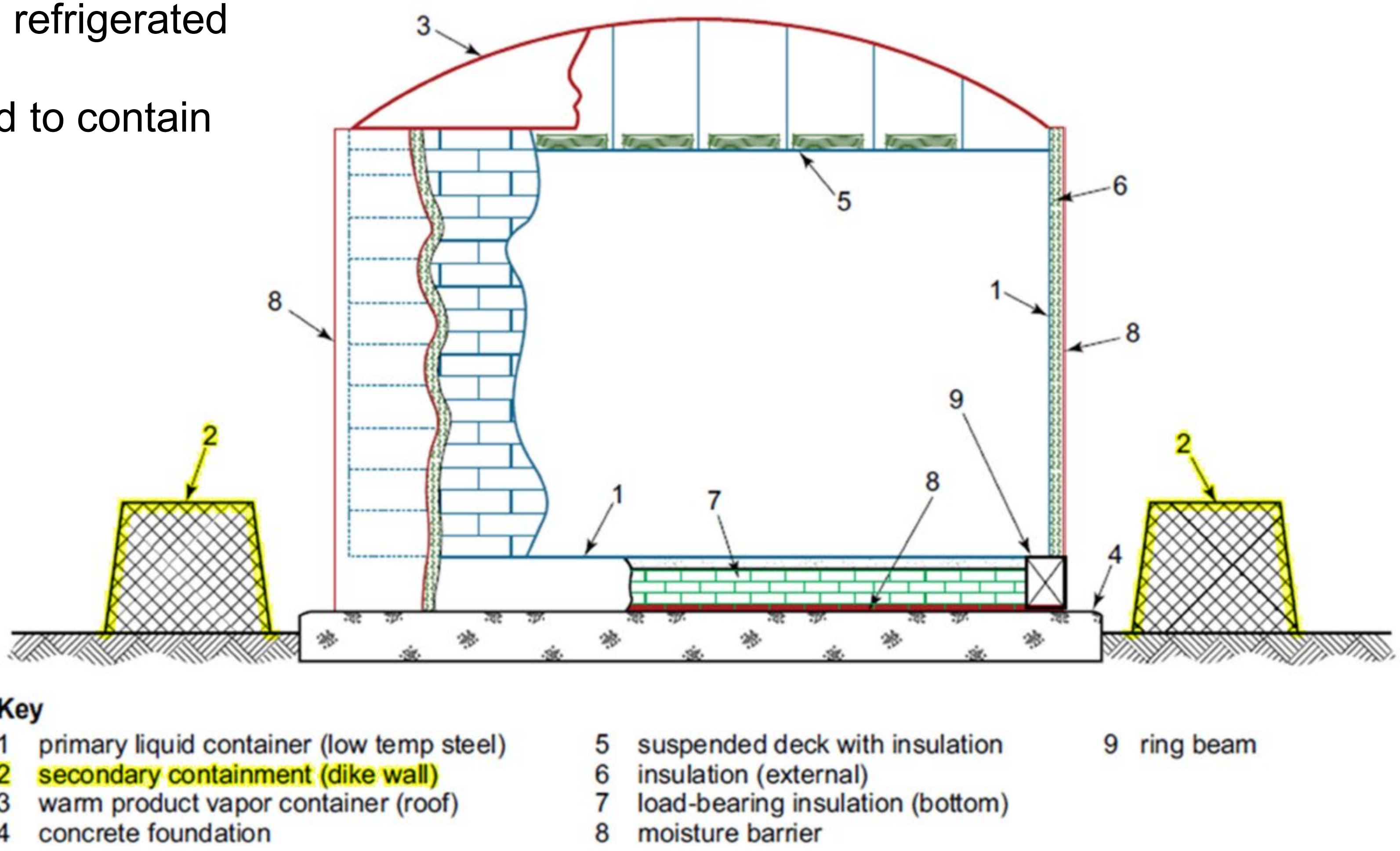
Key

1 primary liquid container (low temp steel)
2 secondary containment (dike wall)
3 warm product vapor container (roof)
4 concrete foundation
5 suspended deck with insulation
6 insulation (external)
7 load-bearing insulation (bottom)
8 moisture barrier
9 ring beam

Figures: courtesy to API625

Single Containment Tank System – Single Wall

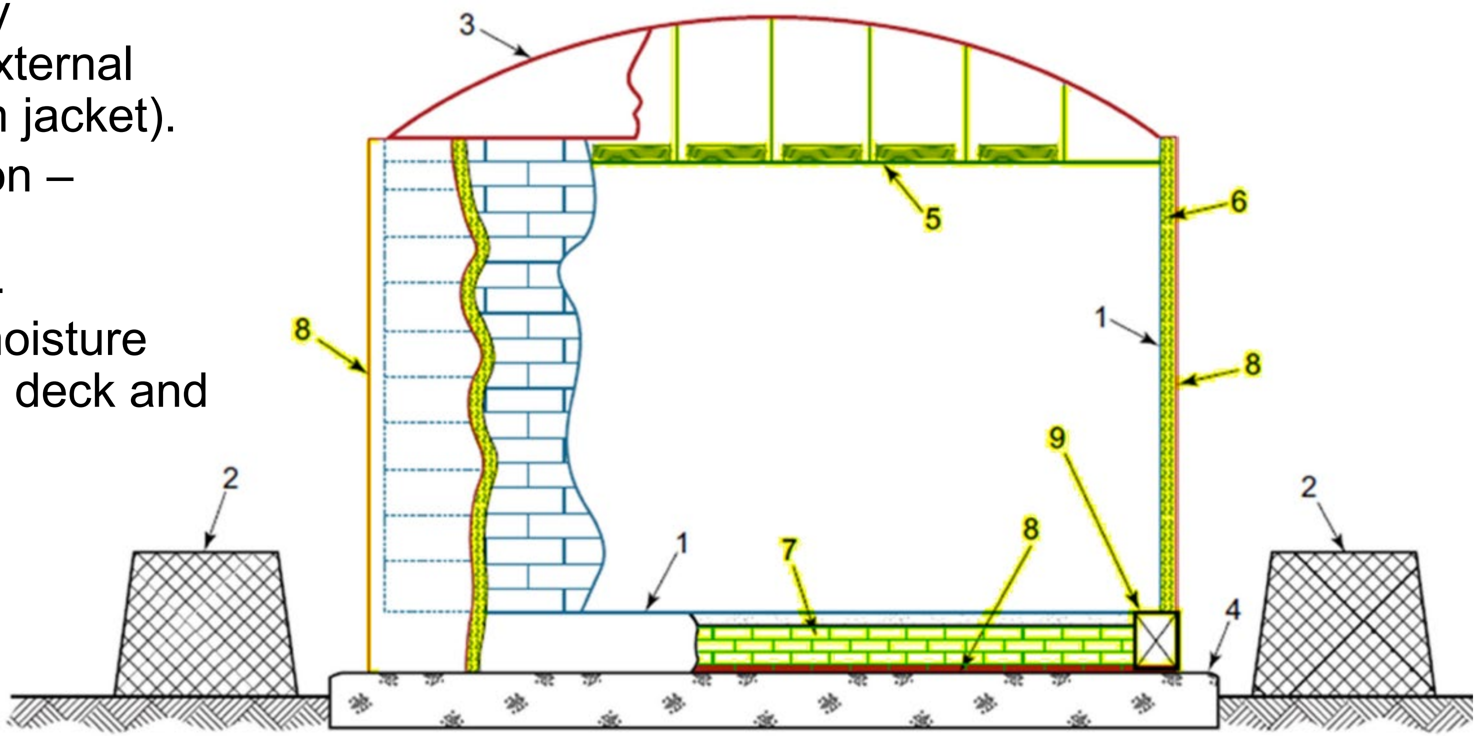
- Single liquid and vapor tight container used to store refrigerated product.
- Remote dike is required to contain leaks.



Figures: courtesy to API625

Single Containment Tank System – Single Wall (Insulation)

- Bottom Insulation – Cellular glass
- Shell Insulation – Typically Polyurethane foam with external weather barrier (aluminum jacket).
- Suspended Deck Insulation – Typically Fiberglass
- Alternate Roof Insulation - Polyurethane foam with moisture barrier without suspended deck and insulation (Not Typical).



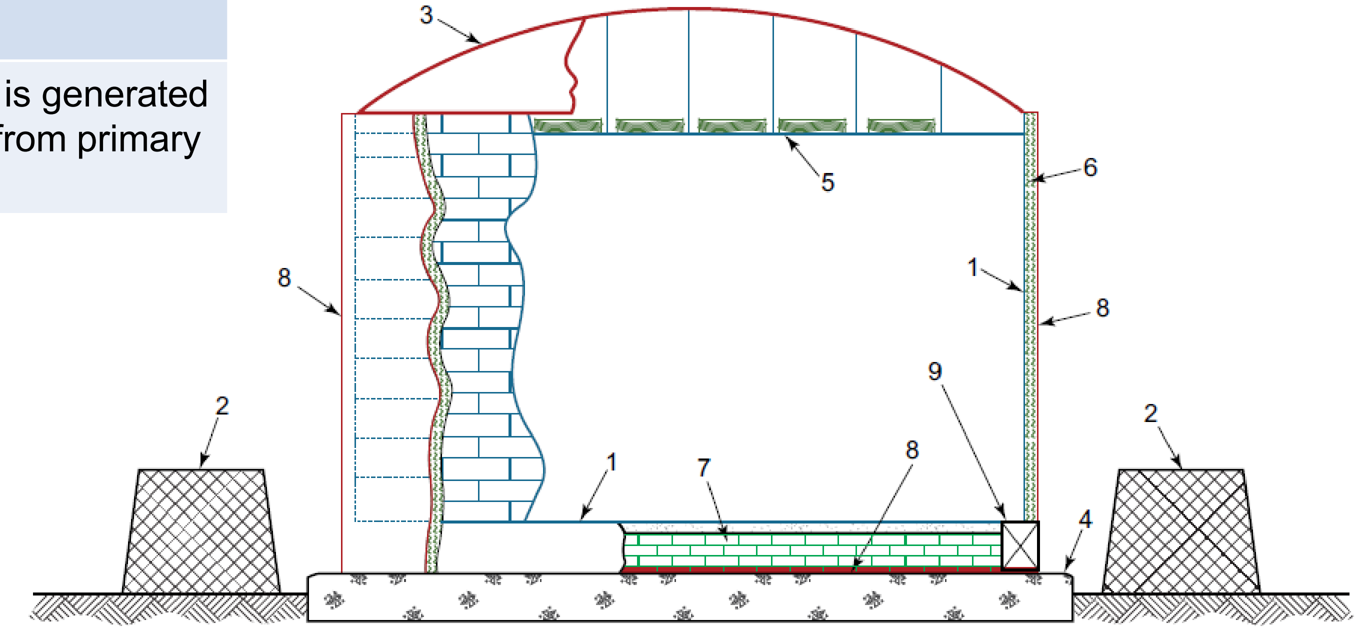
Key

1 primary liquid container (low temp steel)
2 secondary containment (dike wall)
3 warm product vapor container (roof)
4 concrete foundation
5 suspended deck with insulation
6 insulation (external)
7 load-bearing insulation (bottom)
8 moisture barrier
9 ring beam

Figures: courtesy to API625

Single Containment Tank System – Single Wall

PROS	CONS
Most Economical.	Requires availability of significant real estate.
Ease of Construction.	Large toxic vapor cloud is generated in case of product leak from primary container.



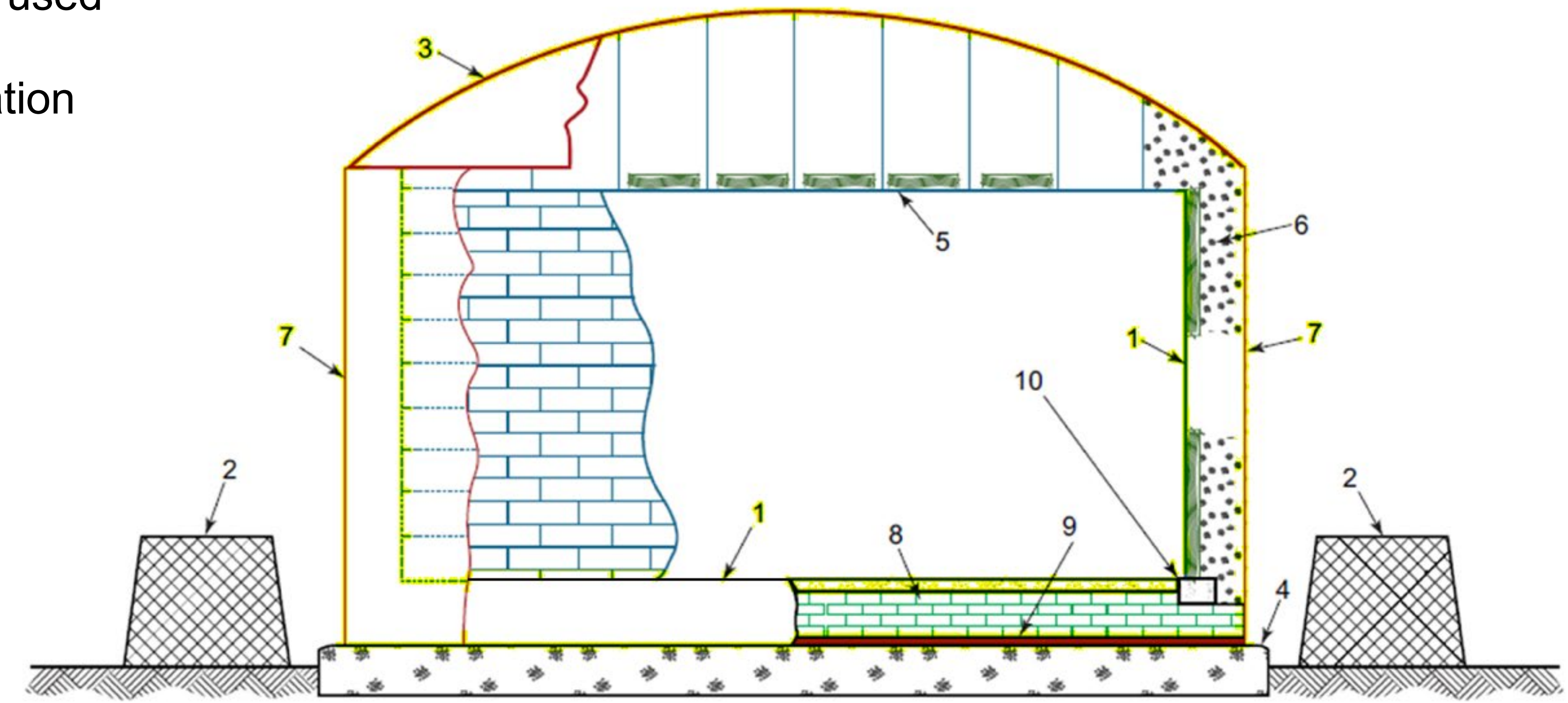
Key

1 primary liquid container (low temp steel)
2 secondary containment (dike wall)
3 warm product vapor container (roof)
4 concrete foundation
5 suspended deck with insulation
6 insulation (external)
7 load-bearing insulation (bottom)
8 moisture barrier
9 ring beam

Figures: courtesy to API625

Single Containment Tank System – Double Wall

- Primary liquid tight container used to store refrigerated product.
- Outer warm vapor and insulation container.



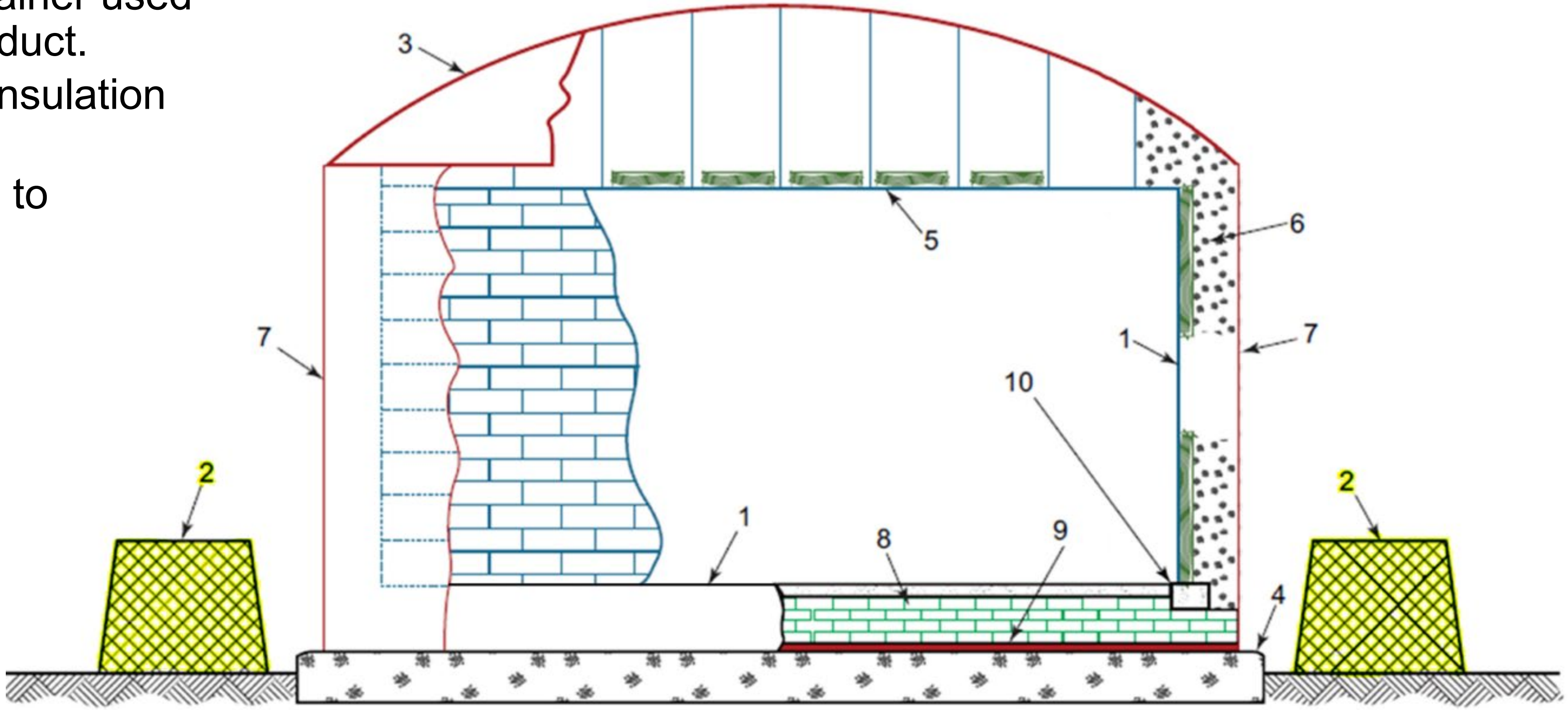
Key

1	primary liquid container (low temp steel)	5	suspended deck with insulation	8	load-bearing insulation (bottom)
2	secondary containment (dike wall)	6	insulation (annular)	9	warm product vapor container (bottom)
3	warm product vapor container (roof)	7	warm product vapor container (wall)	10	ring beam
4	concrete foundation				

Figures: courtesy to API625

Single Containment Tank System – Double Wall

- Primary liquid tight container used to store refrigerated product.
- Outer warm vapor and insulation container.
- Remote dike is required to contain leaks.



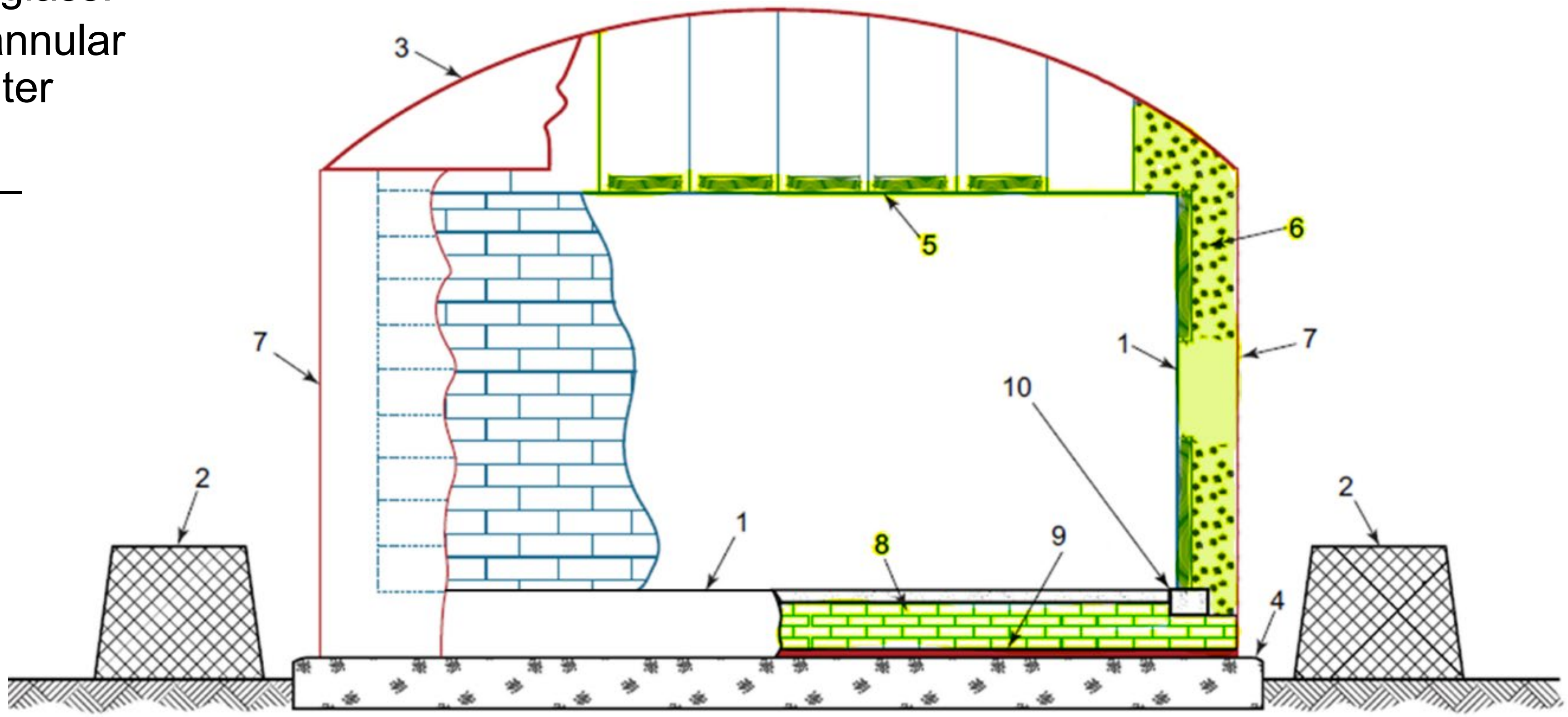
Key

1 primary liquid container (low temp steel)
2 secondary containment (dike wall)
3 warm product vapor container (roof)
4 concrete foundation
5 suspended deck with insulation
6 insulation (annular)
7 warm product vapor container (wall)
8 load-bearing insulation (bottom)
9 warm product vapor container (bottom)
10 ring beam

Figures: courtesy to API625

Single Containment Tank System – Double Wall (Insulation)

- Bottom Insulation – Cellular glass.
- Shell Insulation – Perlite in annular space between inner and outer tank shells.
- Suspended Deck Insulation – Typically Fiberglass



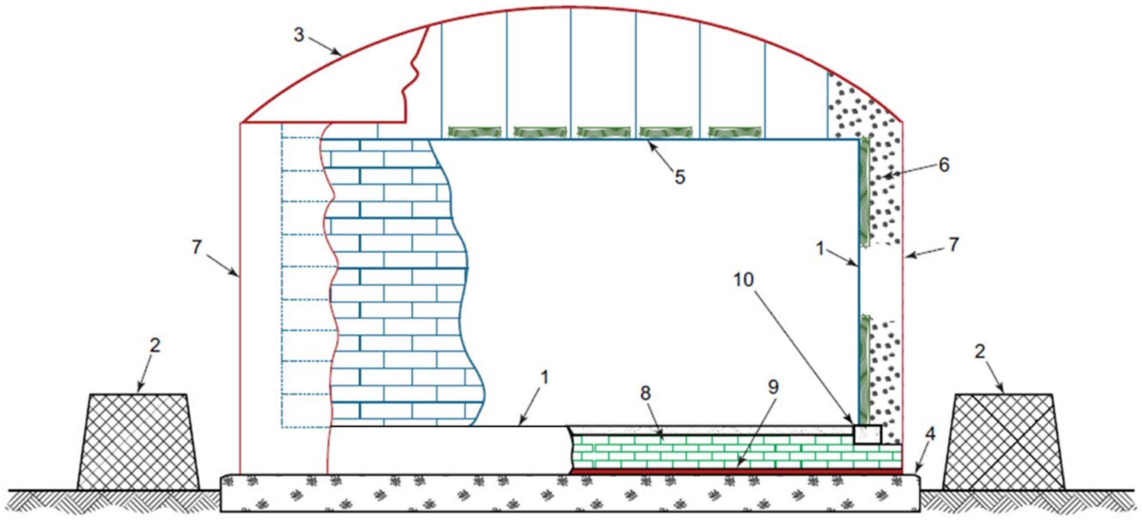
Key

1 primary liquid container (low temp steel)
2 secondary containment (dike wall)
3 warm product vapor container (roof)
4 concrete foundation
5 suspended deck with insulation
6 insulation (annular)
7 warm product vapor container (wall)
8 load-bearing insulation (bottom)
9 warm product vapor container (bottom)
10 ring beam

Figures: courtesy to API625

Single Containment Tank System – Double Wall

PROS	CONS
Relatively Economical.	Requires availability of significant real estate.
Insulation is protected from the environment.	Large toxic vapor cloud is generated in case of product leak from primary container.
Perlite Insulation provides excellent insulation value and reduced product boil-off.	
Outer tank protects Primary container from external hazards (wind, blast, radiation).	

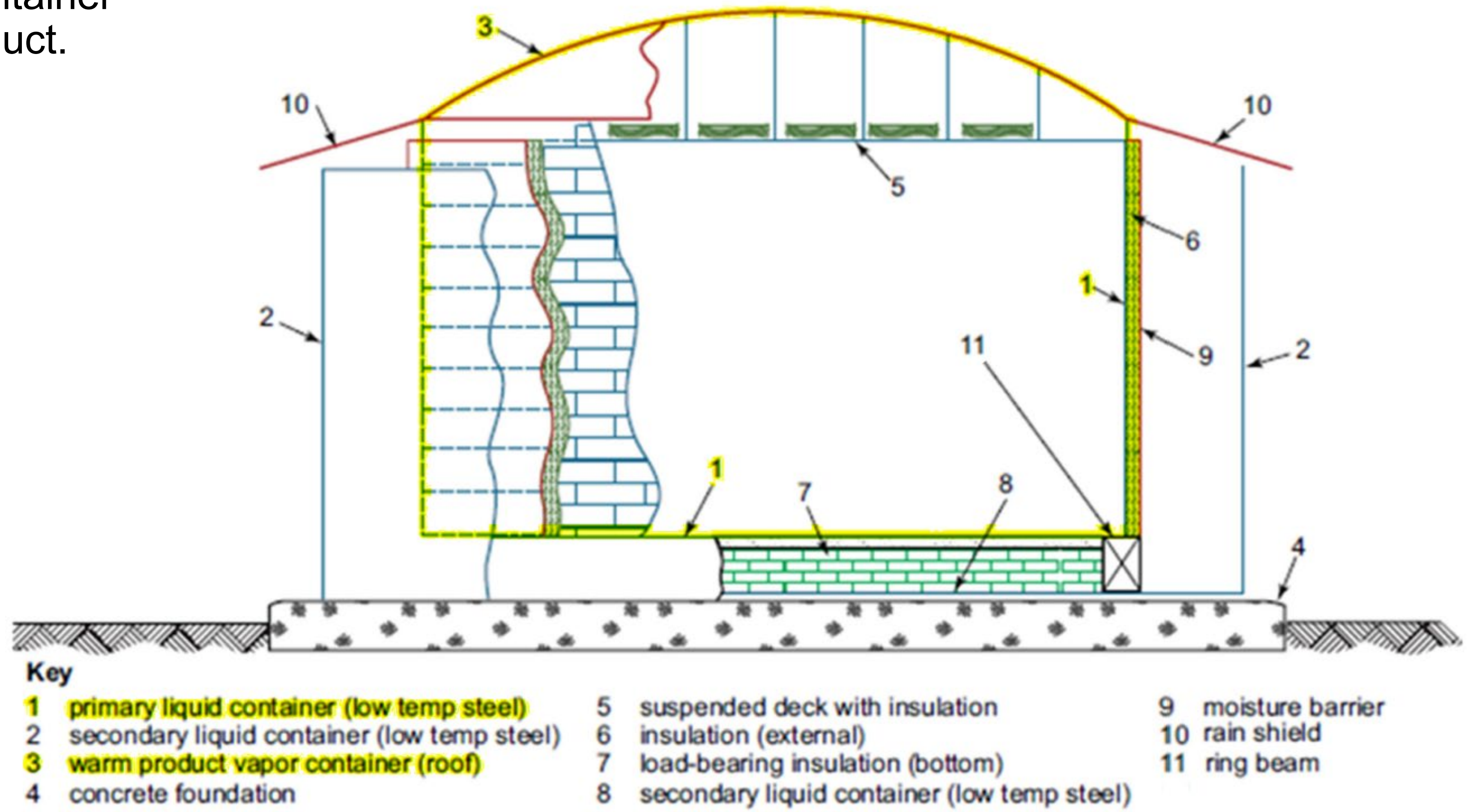


Key
1 primary liquid container (low temp steel)
2 secondary containment (dike wall)
3 warm product vapor container (roof)
4 concrete foundation
5 suspended deck with insulation
6 insulation (annular)
7 warm product vapor container (wall)
8 load-bearing insulation (bottom)
9 warm product vapor container (bottom)
10 ring beam

Figures: courtesy to API625

Double Containment Tank System

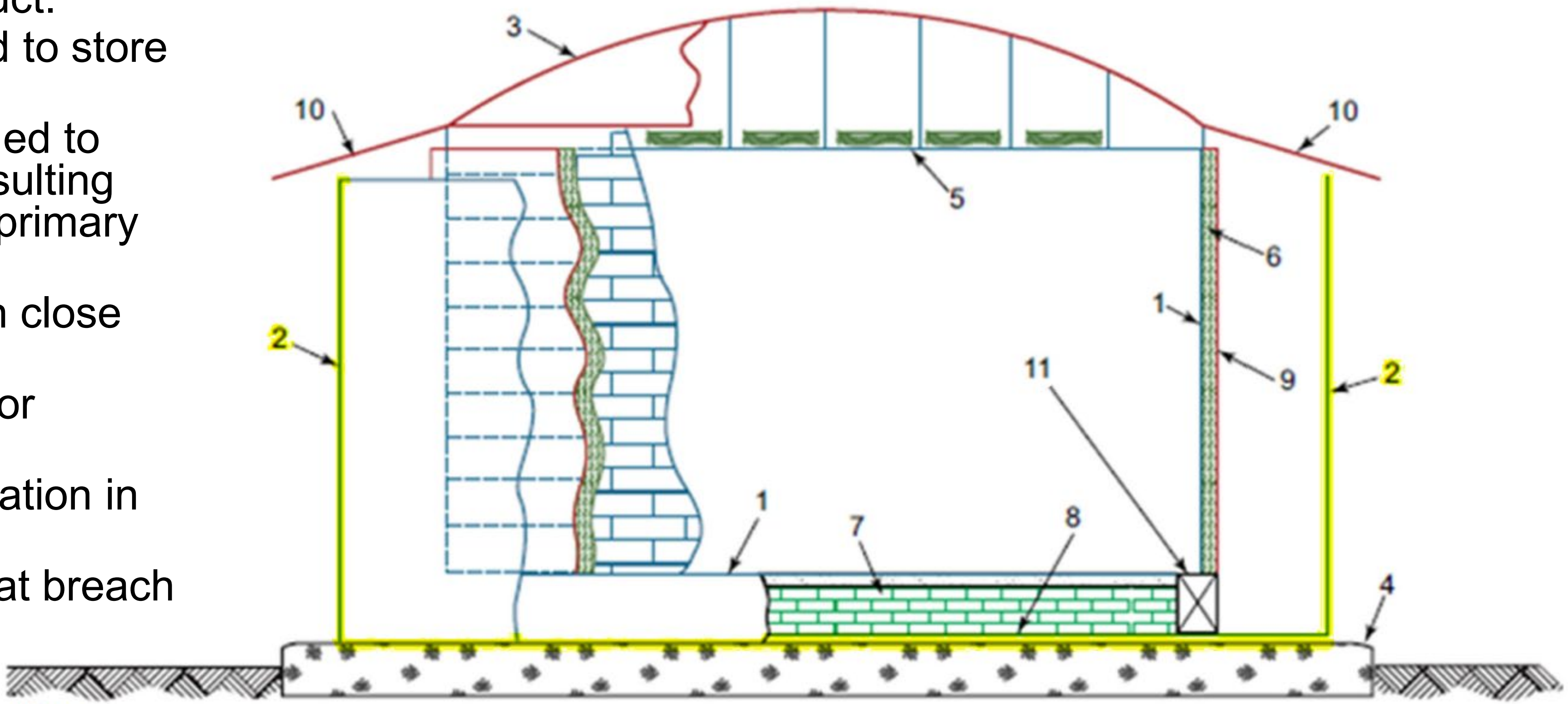
- Inner liquid and vapor tight container used to store refrigerated product.



Figures: courtesy to API625

Double Containment Tank System

- Inner liquid and vapor tight container used to store refrigerated product.
- Secondary containers designed to store refrigerated liquid.
- Secondary container not intended to contain or control any vapor resulting from product leakage from the primary container.
- Secondary container shall be in close proximity to primary container.
- Shed roof over annular space for weather protection.
- Atmospheric moisture condensation in annular space can be an issue.
- Shell or bottom penetrations that breach the primary or secondary liquid container are not allowed



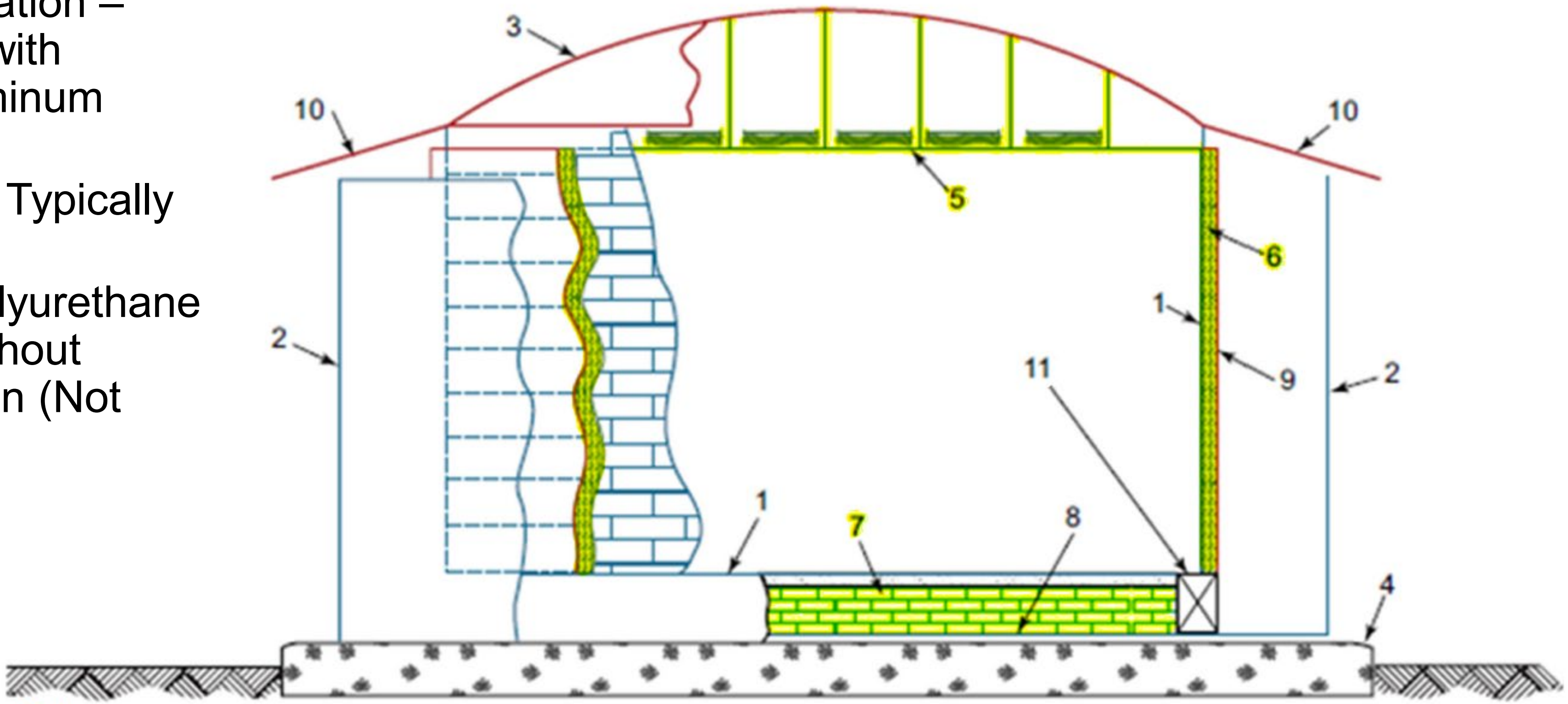
Key

1 primary liquid container (low temp steel)
2 secondary liquid container (low temp steel)
3 warm product vapor container (roof)
4 concrete foundation
5 suspended deck with insulation
6 insulation (external)
7 load-bearing insulation (bottom)
8 secondary liquid container (low temp steel)
9 moisture barrier
10 rain shield
11 ring beam

Figures: courtesy to API625

Double Containment Tank System - Insulation

- Bottom Insulation – Cellular glass.
- Primary Container Shell Insulation – Typically Polyurethane foam with external weather barrier (aluminum jacket).
- Suspended Deck Insulation – Typically Fiberglass
- Alternate Roof Insulation - Polyurethane foam with moisture barrier without suspended deck and insulation (Not Typical).



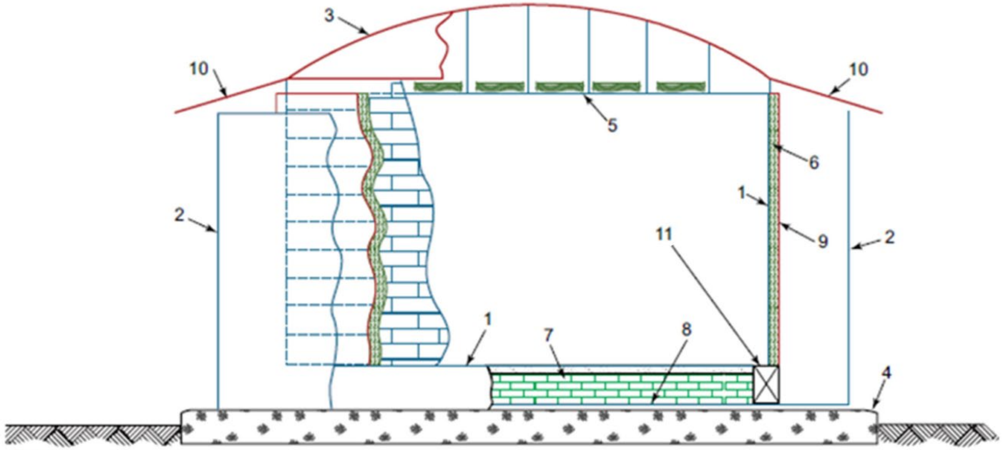
Key

1 primary liquid container (low temp steel)
2 secondary liquid container (low temp steel)
3 warm product vapor container (roof)
4 concrete foundation
5 suspended deck with insulation
6 insulation (external)
7 load-bearing insulation (bottom)
8 secondary liquid container (low temp steel)
9 moisture barrier
10 rain shield
11 ring beam

Figures: courtesy to API625

DOUBLE CONTAINMENT TANK SYSTEM

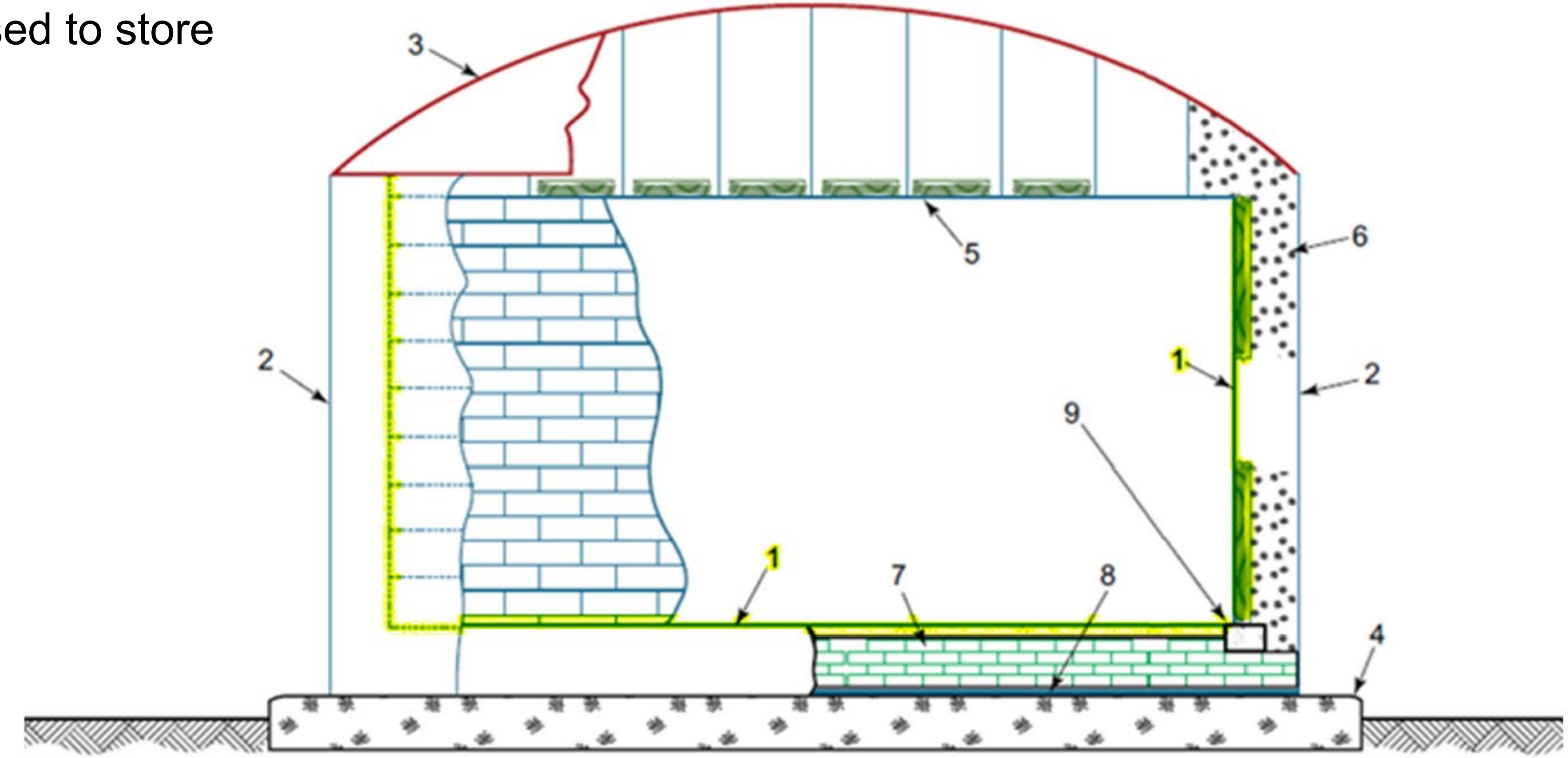
PROS	CONS
Reduced real estate demand when compared to single containment tank system.	Does not contain or control any vapor resulting from product leakage from the primary container.
Reduced generation of vapor cloud in case of leak compared to single containment.	More expensive installation when compared to a single containment tank.
Secondary Container protects Primary from External Hazards (Wind, Blast, Radiation)	
Failure of secondary container does not affect normal operability of the primary container	



Figures: courtesy to API625

Full Containment Tank System

- Inner liquid tight container used to store refrigerated product.



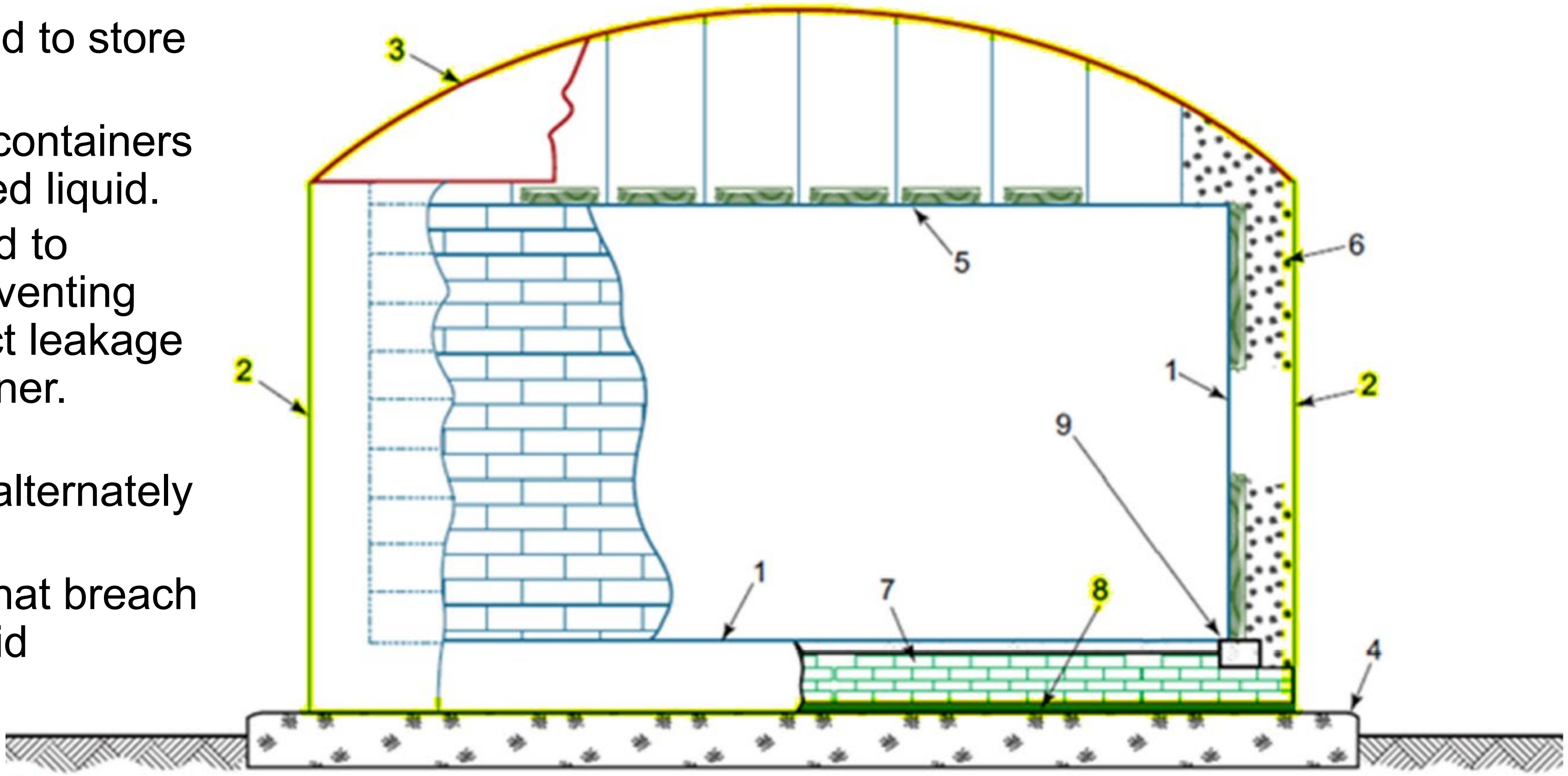
Key

1 primary liquid container (low temp steel)
2 secondary liquid container (low temp steel)
3 warm product vapor container (roof)
4 concrete foundation
5 suspended deck with insulation
6 insulation (annular space)
7 load-bearing insulation (bottom)
8 secondary liquid container (low temp steel)
9 ring beam

Figures: courtesy to API625

Full Containment Tank System

- Inner liquid tight container used to store refrigerated product.
- Both Primary and Secondary containers designed to contain refrigerated liquid.
- Secondary Container designed to control the vapor release (via venting system) in the event of product leakage from the Primary liquid Container.
- Secondary Container is low-temperature steel material or alternately from prestressed concrete.
- Shell or bottom penetrations that breach the Primary or Secondary liquid Container are not allowed.



Key

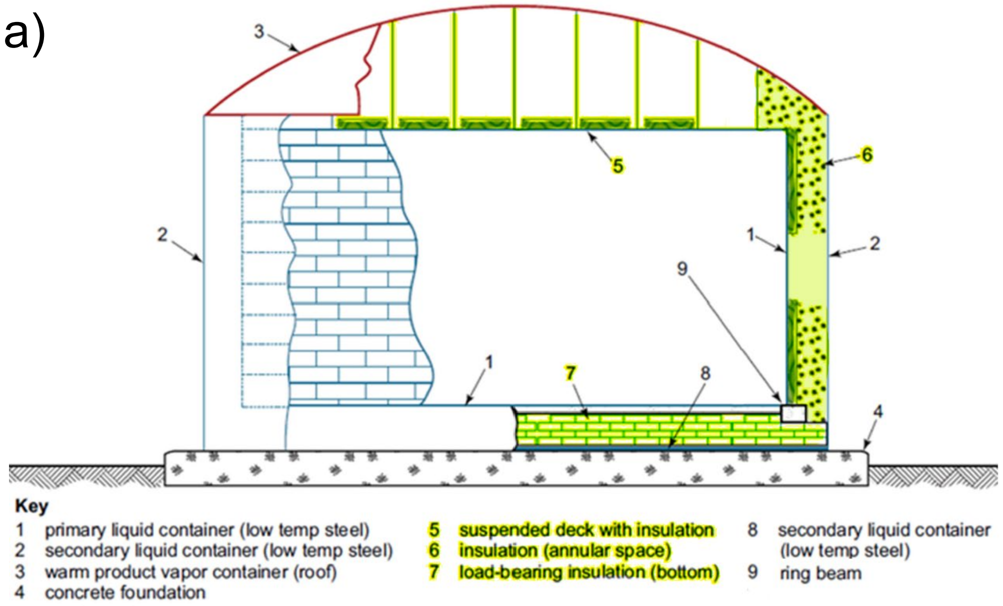
1 primary liquid container (low temp steel)
2 secondary liquid container (low temp steel)
3 warm product vapor container (roof)
4 concrete foundation
5 suspended deck with insulation
6 insulation (annular space)
7 load-bearing insulation (bottom)
8 secondary liquid container (low temp steel)
9 ring beam

Figures: courtesy to API625

Full Containment Tank System - Insulation

- Bottom Insulation – Cellular glass
- Suspended Deck Insulation – Typically Fiberglass
- Shell Insulation
  a) Perlite in annular space between inner and outer tank shells.
  b) External foam insulation with weather barrier on outside of the secondary container

a)



b)

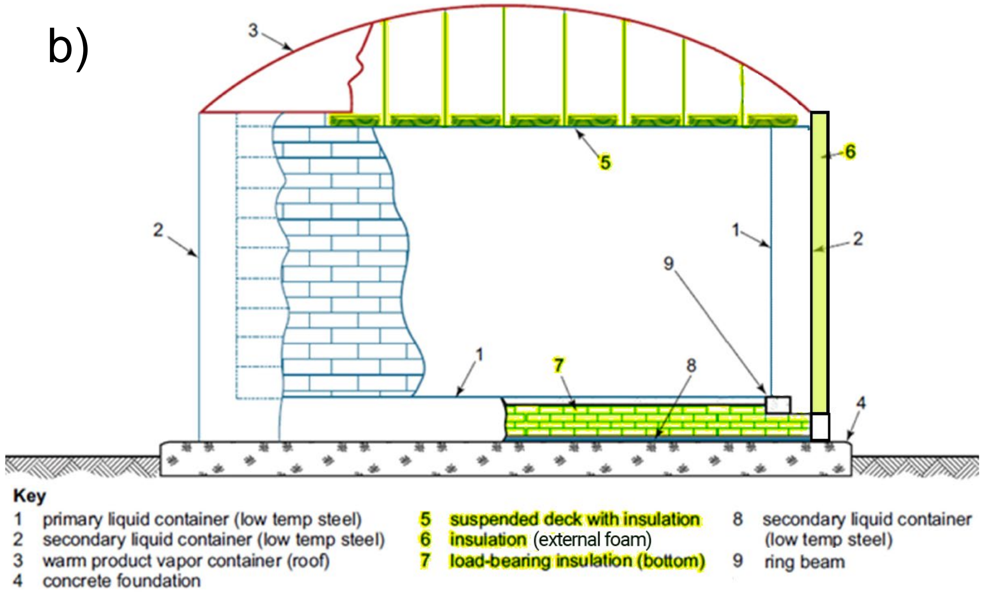


Figure: courtesy to API625

Perlite vs External Insulation (Full Containment Tanks)

Perlite

Advantages	Disadvantages
Low cost and excellent insulation value	Needs to be removed for the annular space access
Condensation in the annular space is unlikely as outer tank is at ambient temperature.	
Outer tank surface is accessible. Piping, stairs and accessories can be attached.	
All year-round installation. Not affected by weather. Can be done in parallel with other site work	
Not sensitive to external fire	

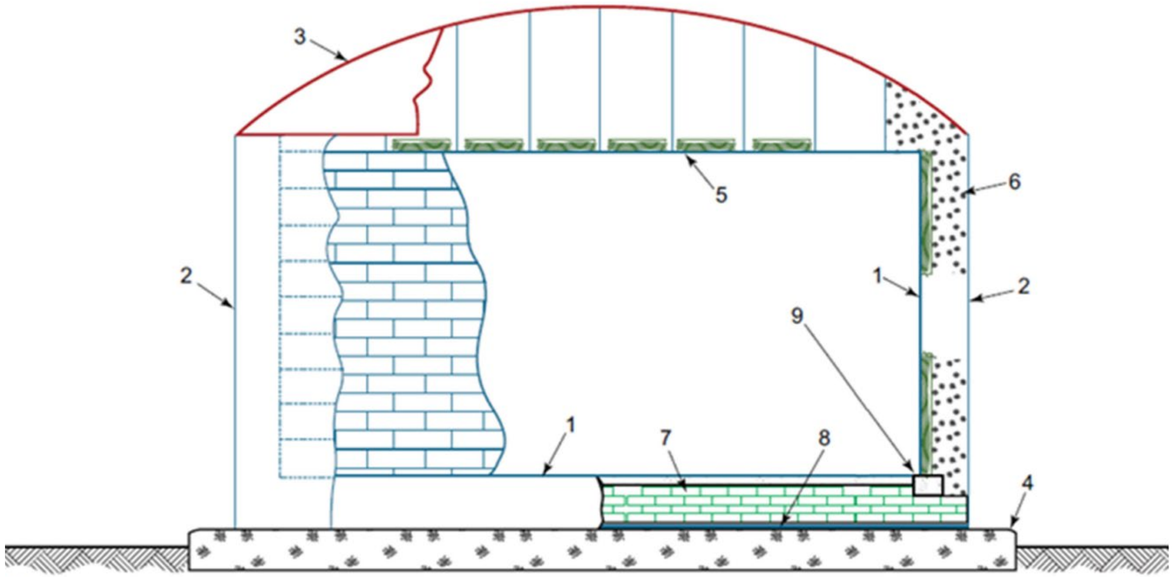
External Foam Insulation

Advantages	Disadvantages
Annular space can be accessed once tank is taken out of service.	Materials cost may be high with respect to insulation properties.
A well-maintained external insulation system will protect the outer shell surface from corrosion.	Higher potential for product condensation in cold annular space.
	Sensitive to external fire.
	Unable to view/monitor external tank wall.
	Shell attachments not allowed. Free standing stair towers and piping support towers are required.

Figures: courtesy to API625

Full Containment Tank System

PROS	CONS
Reduced real estate demand when compared to single containment tank system.	More expensive installation when compared to a single containment tank.
Controlled vapor release in case of the primary container leak.	
Secondary Container protects Primary from External Hazards (Wind, Blast, Radiation).	



Key

1 primary liquid container (low temp steel)
2 secondary liquid container (low temp steel)
3 warm product vapor container (roof)
4 concrete foundation
5 suspended deck with insulation
6 insulation (annular space)
7 load-bearing insulation (bottom)
8 secondary liquid container (low temp steel)
9 ring beam

Figures: courtesy to API625

Double and Full Containment Tanks – With Side Penetrations

Double and Full Containment Tanks – With Side Penetrations concept meets the requirements of double or full containment tank systems defined in API 620, except that shell or bottom **penetrations and manways that breach the primary or secondary containment are allowed.**

The Double and Full Containment Tanks – With Side Penetrations concept is allowed with the following conditions:

- The penetrations are specified by the purchaser;
- No prohibition exists in applicable regulations;
- The penetrations are accounted for in the assessment of risk;
- In-tank valves are provided for all penetrations except the following:
    - dead end lines (such as drain lines) in secondary liquid container that do not exceed 4-inch NPS, nor exceed 18-inch projection;
    - instrumentation cable glands through the secondary liquid container;
    - manways
- A remote dike wall is provided in addition to the secondary containment that is part of the tank system. The volume contained by the dike shall be equal to 110 % of the flow from a full line break prior to closure of the largest in-tank valve.
- Side Penetrations will allow the use of external tank pumps.

Figures: courtesy to API625

In-Tank Pumps Vs Ex-Tank Pumps

Ammonia Issues with In-Tank Pump:

- Ammonia reacts rapidly with copper, brass, bronze and many alloys, especially those containing copper.
- Nitrogen purged motor and power conduit required to protect copper cable and motor windings from contact with ammonia
- Motor needs to be cooled by combination of product cooling and by the nitrogen purge
- Magnetic coupled motor to pump/impeller shaft, which limits torque transfer and can result in larger pump tube diameters.
- Pump bearing can only be Ceramic and not bronze due to ammonia incompatibility.

Ex-tank Ammonia Pumps:

- External Tank Pump configuration is the most common in Ammonia Service.
- Motor is not directly exposed to ammonia fluid, so there is no reactivity with ammonia.
- Pumps are generally installed in a pump pit.
- Easier access for maintenance since pumps, associated piping and instrumentation are at grade
- Product sendout piping does not need to be routed from the top of the tank, most piping, instrumentation, and valving can be located at grade providing easier operation and maintenance access.

Other LESS COMMON Configurations

Single Containment Tank:	Double Wall-Double Roof with insulation in the annular space
	Double Wall with foam insulation external to inner tank
Double Containment Tank:	Secondary containment wall open to atmosphere encloses Double Wall Single Containment Tank
	Single Wall Tank with External Shell Insulation inside a secondary liquid containment wall with nitrogen purged annular space
Full Containment Tank:	Double Wall- Double Roof with perlite insulation
	Double Wall- Double Roof with external insulation
	Double Wall, Suspended deck, Foam insulation on Inner tank

Reasons for these configuration being less common:

- More expensive, more complex
- Foam insulation may absorb ammonia vapors.

General Concern For All Ammonia Tanks

Stress Corrosion Cracking (SCC) – Ammonia Liquid Attacking Stressed Steel.

- Known Cases of Leaks and Failure for ambient temperature Pressure Vessels.
- Recent studies indicate SCC possibility for refrigerated ammonia storage.
- No Known SCC failures/leaks for refrigerated tanks. Even after 50+ years of Service.

SCC Driving Factors:

- High stresses including Residual Stresses in Welds/HAZ (Heat Affected Zone).
- High Hardness in weld and HAZ.
- Oxygen promotes SCC on tank wetted surfaces.

SCC Mitigation And Monitoring

SCC Mitigation:

- Minimize residual oxygen (purge to low O_2 when tank is placed in service)
- Balancing the Material Properties –
  - Minimizing yield strength of the base and weld metal.
  - Minimizing the weld metal and heat affected zone hardness
  - Maximizing the plate, weld metal, and heat affected zone toughness for low temperature
  - Use special weld technique to reduce residual stresses & weld hardness
- Water is effective SCC inhibitor. Add 0.2% of water to ammonia
- Minimize number of times tank is taken out of service to prevent O_2 ingress

Controlling Tank Condition - Regulations Often Require Periodic Inspections

Full Inspection with taking out of service

- Potential issue: Oxygen Introduced every time – Promotes SCC

Acoustic Emission (AE) - Crack Growth Monitoring Technique

- Potential of producing false positive impression
- AE vendor must be highly qualified and specialized

Driving Factors For Tank Concept Selection

- Risk Assessment
- Economics
- Real Estate Availability
- Regulations

Tank Configuration Selection

Most Economical:

- Single Containment
- Single Wall
- External Foam insulation
- Suspended Deck

Why Is This Configuration Not Always Used?

- Risk Assessment May Require Closely Spaced Secondary Container
- Real Estate Availability

Tank Configuration Selection

Full or Double Containment?

- Similar from external hazard protection standpoint. Double has some advantages
- Both offer liquid containment in case of leak from primary.
- Full Containment Benefit: Controlled vapor release in case of leak from primary.
- Full containment tank cost a bit higher.

Most Commonly Selected Configuration for Ammonia Service - Full Or Double Containment With Penetrations

- **Reason:** Complications with reliable in-tank pumps.
- **Penetrations:** Process piping in either shell or bottom.
- **Code Compliance Requirements:**
  - Installation of In-tank valve for all process lines.
  - A dike to contain 110% of leak for closure time of the largest in-tank valve.

Summary

Five Tank Concepts Are Available:

- Single Containment
- Double Containment
- Double Containment with Penetrations
- Full Containment
- Full Containment with Penetrations

Concept Selection Is Based On Risk Assessment And Economics

Each Concept Includes Various Configurations Depending On:

- Liquid Containment Requirement
- Vapor Control Requirement
- Insulation Concept And Type
- Available Real Estate

Summary (Continued)

Most Economical – Single wall tank, but sometimes does not pass risk assessment.

Commonly Selected - Double or Full containment tanks with wall or bottom penetrations, in-tank valves, and external pumps.

Tank Material Of Choice - Low-temperature Carbon Steel

SCC Concern Addressed by:

- Select steel grade and welding technique to minimize residual stresses and weld hardness
- Minimizing oxygen ingress
- Monitoring crack growth

QUESTIONS

Alex Cooperman, Ph.D., P.E., P.Eng. – Senior Principal Engineer, LT&C Storage
(Alex.Cooperman@mcdermott.com)
Yogesh S. Meher, P.E. – Director of Engineering, LT&C Storage
(Yogesh.Meher@mcdermott.com)
Jeffrey C. Garrison, S.E., P.E. – Design Manager, LT&C Storage
(Jeff.Garrison@mcdermott.com)
CB&I
www.cbi.com