Agenda Item: 620-2042

Title: Annex Y – Membrane Component of Membrane Containment Tank Systems

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Purpose: Rama Challa presentation to SCAST leadership Fall 2016 Meeting

Source: API 625 Multiple Sections and Annexures C, D

Revision: Std 620 Annex Y MTWG update Rev-1

Impact: The business impact of this item is neutral.

Rationale: Membrane Tanks are an Option for Refrigerated and Cryogenic Storage. Various regulatory standards such as NFPA59A have incorporated the concept in regulation since 2016. NFPA59A-2016 Requires Compliance with API Standards such as API 625 and API 620. Current API Standards do not include Membrane Tanks. The rationale to fill the gap that currently exists.

The metallic membrane for the membrane tank is governed by the rules of API 620. A new Annex Y was created to address the requirements for the membrane and its components.

Proposal: See attached

Notes
1. Std 620 Annex Y MTWG update Rev-1 (12/04/2018) includes editorial corrections such as duplicated words etc.
**Annex Y**

(Normative)

**Membrane Component of Membrane Containment Tank System**

### Y.1 Scope

#### Y.1.1 General

This annex, together with portions of the basic sections of API 620 and annexes Q & R, provides requirements for the materials, design, and fabrication of the metallic membrane of a membrane containment tank system. The requirements of other sections and annexes of this standard apply to membranes only where such other sections are explicitly referenced. The complete tank system, of which the metallic components are a part, shall be in accordance with API 625.

#### Y.1.2 Definitions

The definitions of the following specialized terms used in this annex are found in API 625.
- membrane
- membrane containment tank system
- membrane tank outer container

#### Y.1.3 Membrane

Membrane is the main component of a membrane containment tank system. It is a thin metallic sheet that forms a liquid and vapor tight barrier during normal operation. Membrane shall be provided with a double network of corrugations, allowing free movement under all loading conditions.

The membrane shall be anchored to the insulation system or to the membrane tank outer container (concrete or metallic) so that its position is maintained throughout its lifetime. When anchored, the membrane shall be arranged such that a vapor and liquid tight container is obtained.

All the membrane components shall be designed in such a way that they can withstand all design loads throughout the tank lifetime. Membrane shall keep its form through smooth deformation or displacement.

### Y.2 Materials

#### Y.2.1 Selection and Ordering

- **Y.2.1.1** The materials shall be in accordance with Table Y-1 and
- **Y.2.1.2** The thickness of the membrane shall not be less than 1.0 mm (0.04 in).
- **Y.2.1.3** Material requirements for other metallic accessories shall be per Table Q-1.
### Table Y-1—Materials for Membrane

<table>
<thead>
<tr>
<th>Component</th>
<th>Materials</th>
</tr>
</thead>
</table>
| Membrane  | ASTM A240 Type 304  
            | ASTM A240 Type 304L  
            | EN 10028-7 X5CrNi18-10(1.4301)  
            | EN 10028-7 X2CrNi18-9(1.4307)  
            | EN 10028-7 X2CrNiN19-11(1.4306)  
            | JIS G4305 SUS304  
            | JIS G4305 SUS304L |

Note: Material produced to specifications other than those listed may be used if the material is certified to meet all the requirements of a material specification listed in this section and that its use is approved by the Purchaser.

### Y.3 Design

#### Y.3.1 General

Design considerations shall be as specified in API 625, Section 6, “Design and Performance Criteria” together with the following additional provisions describing the membrane design in detail. The design of each component of the metallic membrane shall be performed by either numerical analysis or by realistic model testing.

The following are the main requirements for the membrane design:

1. The membrane shall remain stable under all design loads and load combinations. It shall be demonstrated by numerical analysis or model testing that buckling/collapse of the corrugations does not occur.

2. The membrane shall maintain smooth deformation or displacement when loads are applied in any direction. It shall be demonstrated by numerical analysis or model testing that no progressive deformation of the membrane under cyclic loading can take place.

3. The membrane shall have sufficient fatigue strength for the number of cyclic loads considered. The design of the membrane shall be carried out either though model tests and/or numerical analysis.

The anchorage system utilized for anchoring of the membrane into the insulation or concrete shall be able to withstand all design loads and load combinations, including seismic loads. Design of the anchoring system shall be such that any damage to the anchorage system during upset events does induce damage to the membrane and cause it to leak.

#### Y.3.2 Numerical analysis

**Y.3.2.1** For the numerical analysis, either elastic or elasto-plastic or elasto-plastic with large deflection calculation using finite element method (FEM) shall be required. The following shall be considered for the analysis:

1. Tank System Contractor shall demonstrate that the methodology of the calculation produces result that correlate with the physical test.
(2) Residual stresses induced by forming operations shall be accounted for.

(3) Equivalent stresses shall be evaluated using the von-Mises’s theory for both static and fatigue design.

(4) Where appropriate the deformation produced by the thermal load shall be applied as a boundary condition.

(5) Calculation of the maximum stress or strain shall always be based on the principal axes.

(6) The membrane shall be designed for seismic loading. The finite element model shall include the tank structure and liquid, including liquid/structure interaction.

(7) Maximum permitted deviations in the membrane and its supporting surfaces shall be modeled as basis for the installation tolerances applied in Y.5.2.6.

**Y.3.2.2 Stress/strain curve**

The stress/strain curve for the material used for the membrane shall be established taking into account the following considerations.

(1) It shall be established for the selected material.

(2) Usage of the part of the stress-strain curve that corresponds to reduction of section (i.e. necking down range) shall not be permitted in the numerical analysis.

(3) Poisson’s ratio is different for the elastic and plastic regions of the stress-strain curve. The numerical model shall consider the variation of the Poisson’s ratio.

**Y.3.2.3 Stability under static loadings**

It shall be demonstrated that the membrane maintains its shape through smooth deformation under the specified static loads. Buckling analysis shall then be conducted to demonstrate that the membrane corrugations do not buckle or collapse under the total internal pressure loading. A factor of safety of 4.0 shall be used to determine the lowest buckling eigenvalue if the model used in the analysis is based on the theoretical shape. This may be reduced to 2.0 if the model used in the analysis reflects the initial imperfections that are present in the membrane due to the manufacturing process.

Thermal deformation shall be considered to be a stable state and the safety factor shall only be applied on the pressure load.

Stresses in anchors shall be within design allowable stresses per Section Q.3.3.

**Y.3.2.4 Progressive deformation (ratcheting)**

It shall be demonstrated that no progressive deformation can occur in any part of the membrane under both thermal and liquid pressure loads after ten operating loading and unloading cycles. For this combination, a loading cycle shall consist of that load combination that induces maximum and minimum stresses in the membrane.

**Y.3.2.5 Fatigue behavior**

**Y.3.2.5.1 General**

The biaxial stress condition shall be determined by means of an equivalent stress or strain, computed using the principal values of stress or strain respectively through von Mises criteria.

**Y.3.2.5.2 Strain range**

The equivalent strain ranges for fatigue life assessment shall be assessed for all cyclic loads including the load combinations. The equivalent strain range for cyclic loads shall be computed by the method specified in either EN 14620-2 or JGA RP-107-02.
Y.3.2.5.3 Fatigue curve (SN-Curve)

The choice of the design fatigue curve shall take into account the fact that the membrane is subjected to low cycle fatigue at low temperature, and that it locally undergoes plastic deformations.

A representative fatigue curve for the selected material shall be used for the design taken from JGA RP-107-02 and ASME Sec VIII div.2.

Miner's law shall be used as the basis for cumulative damage summation to determine the fatigue life. The Miners sum shall be less than 1.

Y.3.2.5.4 Fatigue strength for welded joints

Fatigue strength for welded joints shall be evaluated by the same procedure as Y.3.2.5.3. The equivalent elastic strain range for the welded joints shall be multiplier of the one for the base metal unless the fatigue curves of the specific welded joints are used. The multiplier or the fatigue strength reduction factor (FSRF) shall be per ASME Sec VIII div.2 Tables 5.11 and 5.12. For a fillet weld, the multiplier shall be 4.0 times for the root assessment and shall be 2.5 times for the toe assessment. The multiplier for toe assessment may be reduced to 1.7 if 100% PT (Y.5.3.2) is done. As an alternate to the ASME Sec VIII div.2, the FSRF shall be based on BS 7608.

NOTE: Alternate FSRF values shall not be used, unless the Tank System Contractor demonstrate and justify their adequacy. If used, they shall be proven to be based on the stress concentration factor (SCF) and the notch sensitivity, taking into account the effects of joint configuration, welding process, cyclic plasticity, residual stress, post-weld heat treatment, the nondestructive inspection performed and metallurgical factors.

Y.3.3 Physical Model testing

Y.3.3.1 General

When physical model testing is used, the tests shall be carried out on the components of the system and shall include welds, if any, at the critical location. The model shall be in full scale and the extent shall be such that the boundary effects are insignificant on the results. The number of test specimens shall be such that reliability is ensured. As a minimum, each component shall be tested at least three times. The test may be carried out at ambient temperature.

NOTE: The limited amount of data indicates that the steels used for membrane as specified at Y.2.2.1 have a better behavior, both in static and in fatigue, in cryogenic conditions than in ambient condition.

The locations of measuring devices shall be determined using numerical analysis, “reflection photo-elasticity” or “Brittle coating” methods.

The strain gauges that are used shall be shown to be reliable for use on the material surface and configuration considered. Furthermore, they shall permit the computation of the stresses and strains through the principal directions.

Y.3.3.2 Stability under static loading

It shall be demonstrated that the membrane maintains its shape though smooth deformation under the specified static loads.

It shall be demonstrated that no unstable collapse/buckling can occur on the corrugations under the total pressure for all pressure loads including seismic pressure loads. A minimum factor of safety of 1.25 shall be applied to each individual test if model used for testing incorporates the maximum initial imperfections that are permitted by the manufacturing and installation tolerances. Otherwise, a minimum factor of safety of 2.0 shall be applied to each individual test.

NOTE: In the case of tests carried out at ambient temperature, the thermal loads may be represented by subjecting
the specimens to an elongation prior to application of the pressure to simulate the operating pressure loading and the seismic loading.

**Y.3.3.3 Progressive deformation (ratcheting)**

It shall be demonstrated that progressive deformation stops in all parts of the membrane under both thermal and liquid pressure loads within ten cycles of maximum/minimum loads. The first measured reversal of deformation indicates stabilization. See Figure Y-1 below.

![Progressive Deformation](image)

**Y.3.3.4 Fatigue behavior**

**Y.3.3.4.1** The equivalent range of strains shall be obtained by either static test using actual size model or fatigue test using actual size model. The model shall include welds, if any, that may affect the fatigue performance of the membrane.

**Y.3.3.4.2** The determination of fatigue curve from cyclic testing of actual size model shall be performed in accordance with either:

a) JGA RP-107-02 7.4.3(3) (a) (ii)c or

b) EN14620-2 5.2.2.3.4

**Y.3.3.4.3** Miner's law shall be used as the basis for cumulative damage summation to determine the fatigue life. The Miners sum shall be less than 1.

**Y.3.4 Design Loads**

**Y.3.4.1 Individual loads**

The membrane shall be designed for both static load and cyclic load.

(1) Static (non-cyclic) loads include the following.

i. Internal pressure load (P$_i$) – Design liquid pressure and design gas pressures on each part of membrane for normal operation and accidental conditions.

ii. External pressure load (P$_e$) – Design gas pressure of the insulation space

**NOTE:** Typically this is established by the membrane technology provider.
iii. Seismic loads (E₀, Eₛ) – Loads caused by the earthquake. OLE (or OBE) and CLE (or SSE) seismic shall be applied as required in API 625 section 6.6.1

iv. Thermal loads (T) – Loads caused by temperature difference between atmospheric temperature and liquid product temperature

v. Mechanical loads (Mₛ) – Loads caused by forces external to the membrane such as self-weight, outer container/insulation deformation, attachments and other apparatus.

(2) Cyclic loads include the following:

i. Liquid pressure (ΔPₗ) – Maximum operating range of liquid pressure fluctuations caused on each part of membrane.

ii. Gas pressure (ΔPₒ) – Maximum operating range of gas pressure fluctuations caused on each part of membrane.

iii. Thermal load 1 (ΔT₁) – Amplitude of thermal loads caused by temperature difference between liquid product temperature and gas product temperature of membrane surface at normal operating stage. (variation of temperature during filling and emptying)

iv. Thermal load 2 (ΔT₂) – Loads caused by temperature difference between atmospheric temperature and liquid product temperature. (variation of temperature between commissioning and decommissioning)

v. Mechanical loads (ΔMₑ) – Cyclic loads by the deformation of membrane tank outer container/insulation

Number of cycles for establishing the design life of the membrane containment tank system are based on the normal operating conditions of the storage tank. The purchaser shall provide information on the operating conditions of the tank. (Refer to API 625 4.2.1)

\[ n_1: \text{ Operating cycles} \]
\[ n_2: \text{ Decommissioning/commissioning cycles for the life of the tank.} \]

When this information is not available, then the design should be based on the following assumptions:

\[ n_1 = 1000 \text{ cycles} \]
\[ n_2 = 2 \text{ complete cycles} \]

Y.3.4.2 Load Combinations

(1) Stability under static loading

The following load combinations shall be used for the demonstration of stability under static loading.

a) \( P_i + T + M_s \)

b) \( P_e + T + M_s \)

c) \( P_i + T + M_s + E_o \)

d) \( P_i + T + M_s + E_s \)

NOTE: Refer to Y.3.5 for stability under seismic load.

(2) Progressive deformation (ratcheting)
The following load combinations shall be used for the demonstration of progressive deformation.

a) \( \Delta P_L \) (maximum 10 cycles)
b) \( \Delta T_2 \) (maximum 10 cycles)
c) \( \Delta P_L + \Delta T_2 \) (maximum 10 cycles)

(3) Fatigue behavior

As a minimum, the following load combination and corresponding number of cycles shall be used to evaluate the fatigue behavior of each part of the membrane. When the membrane tank outer container deformations are significant, \( \Delta Mc \) shall be added to each load combination indicated below.

NOTE: In evaluating the significance of the \( \Delta Mc \) load, note that steel outer membrane tank containers have greater movements than those made from concrete. These movements are both from internal liquid/pressure loads as well as for outside ambient temperature swings.

**Bottom membrane**

a) \( \Delta P_L + \Delta P_G \) (\( n_1 \) operating cycles)
b) \( \Delta T_2 \) (\( n_2 \) cycles)
c) \( \Delta P_L + \Delta P_G + \Delta T_2 \) (\( n_2 \) cycles)

**Wall membrane below maximum operating liquid level**

a) \( \Delta P_L + \Delta P_G \) (\( n_1 \) operating cycles)
b) \( \Delta T_1 \) (\( n_1 \) operating cycles)
c) \( \Delta T_2 \) (\( n_2 \) cycles)
d) \( \Delta P_L + \Delta P_G + \Delta T_1 \) (\( n_1 \) operating cycles)
e) \( \Delta P_L + \Delta P_G + \Delta T_2 \) (\( n_2 \) cycles)

**Wall membrane above maximum operating liquid level and roof membrane**

a) \( \Delta P_G \) (\( n_1 \) operating cycles)
b) \( \Delta T_1 \) (\( n_1 \) operating cycles)
c) \( \Delta T_2 \) (\( n_2 \) cycles)
d) \( \Delta P_G + \Delta T_1 \) (\( n_1 \) operating cycles)
e) \( \Delta P_G + \Delta T_2 \) (\( n_2 \) cycles)

**Y.3.5 Stability under seismic load**

The membrane and the membrane tank outer container shall be able to withstand following seismic loads in operating conditions. The rules in API 625, Section 6.6.1 shall be applied for computing seismic loads.

**Y.3.5.1 For an OBE event**, it shall be demonstrated that:

i. Membrane adequacy is demonstrated by using either Y.3.2 or Y.3.3, with no decrease in the factor of safety.
ii. Stresses in anchors shall be within design allowable stresses per API 620, Section Q.3.3, increased by 33% for seismic loading;

Y.3.5.2 For an SSE event, the membrane shall retain liquid tightness.

NOTE: The membrane may have permanent deformation.

Y.3.5.3 For an ALE event, the membrane may fail. The membrane tank outer container Type M-CC shall be capable of containing the liquid.

Y.3.6 Penetrations

Penetrations through the membrane of a membrane containment-with-penetrations tank system shall be designed to the same performance requirements as the membrane. Loads from penetrations shall not be supported by the membrane.

NOTE: For the design requirements for penetrations through the membrane tank outer container of a membrane containment-with-penetrations tank system, refer to basic sections of API 620, Annex Q and Annex R.

Y.4 Welding Procedures

Y.4.1 General

The rules in this section shall apply to the membrane. Any other components for the membrane tank shall be in accordance with the basic sections, annex R and annex Q of this standard.

Y.4.1.1 Welding for membrane

Gas Tungsten Arc Welding (GTAW) or Plasma Arc Welding (PAW) processes with filler metal or autogenously (without filler metal) shall be used. Gas Metal Arc Welding (GMAW) utilizing either short-circuiting arc or pulsed spray arc mode of transfers may also be used.

NOTE: Membrane materials are thin and therefore the welding process selected for use shall be suitable for the application.

Y.4.1.2 Welding Procedure Qualification

Welding Procedure Qualification shall be in accordance with 6.7.

Y.4.1.3 Impact Test for Membrane Material

Impact tests for austenitic stainless steel welds shall conform to Q.4.4.

Y.4.1.4 Qualification of Welders

Y.4.1.4.1 Welders and welding operators qualification tests shall be performed on actual membrane sheet assemblies. Qualification tests shall be performed in all positions and the vertical progression to be welded. Each test coupon shall be macrographically examined and acceptable welds shall meet the acceptance criteria in Y.5.4.1.

Y.4.1.4.2 During production, each welder and welding operator shall be evaluated periodically. As a minimum, each welder and welding operator shall be tested once per month and each welding machine once a week.

Y.4.1.4.3 The Manufacturer shall maintain a record of the welders employed, showing the date and result of tests and the identification mark assigned to each. These records shall be certified by the Manufacturer and shall be accessible to the inspector.
Y.5 Requirements for Fabrication, Examination, and Testing

Y.5.1 General

The rules in this section shall only apply to the membrane. Any other components for the membrane tank shall be in accordance with the basic sections, annex R and annex Q of this standard.

Y.5.2 Miscellaneous Requirements

Y.5.2.1 The corrugations shall be cold formed by pure folding or deep draw process using compression molding machine.

Y.5.2.2 The reduction by cold forming from the as rolled thickness of the membrane shall not exceed 20%.

Y.5.2.3 Prior to the forming and after shearing or laser cutting, all burrs shall be carefully removed and if necessary, the curvature at the sheet ends due to shearing shall be removed.

Y.5.2.4 The membrane joints shall be lap or butt welds.

Y.5.2.5 The lap weld joints may be welded with filler metal or autogenously (without filler metal).

Y.5.2.6 The membrane and insulation systems shall be installed within tolerances that have been verified by numerical analysis or physical model testing to ensure compliance with the design requirements of this annex.

Y.5.2.7 The Tank System Contractor shall specify the tolerances of the membrane tank outer container so that the membrane with insulation can accommodate the tolerances.

Y.5.3 Extent of Non-Destructive Examination

Y.5.3.1 All the membrane welds shall be visually examined.

Y.5.3.2 As a minimum, 5% of all type of welds performed in a work shift shall be examined by Liquid Penetrant Method unless 100% of the completed membrane welds are examined by Liquid Penetrant Method after completion. The selection factors of these 5% of each weld type shall include orientation, welding direction, and the complexity of the welding being performed.

NOTE: Refer to Y.3.2.5.4. The multiplier factor to obtain the equivalent range of strain for the welded joints are different depending on the percentage of examination by Liquid Penetrant Method.

Y.5.3.4 100% of the repair welds shall be examined by Liquid Penetrant Method and vacuum box testing.

Y.5.3.5 100% of the membrane welds of in the closing of temporary opening shall be examined by liquid penetrant method and vacuum box testing.

NOTE 1: If a hydrostatic test of the tank is performed after completion of the membrane, Liquid Penetrant examination shall be performed prior to the hydrostatic test.
NOTE 2: by "repair welds" it means weld repaired after the tracer gas tightness tests.

Y.5.4 Examination Method and Acceptance Criteria

Y.5.4.1 Visual Examination

The personnel performing the visual inspection shall be qualified. Refer to Section 7.15.5 for visual examination requirements and requirements for personnel performing visual examination. However,
acceptable welds shall meet size requirements and be free of visible; undercut, nonfusion, cracks, unfilled craters, and other surface defects.

Y.5.4.2 Liquid Penetrant Method

The personnel performing the liquid penetrant method shall be qualified. Refer to Section 7.15.4 for liquid penetrant requirements and requirements for personnel performing liquid penetrant examinations. However, acceptable examinations shall have no visible indications.

Y.5.4.3 Vacuum Box Testing

Vacuum box testing shall be performed in accordance with 7.15.7.

Y.5.5 Repairs to Membrane

Y.5.5.1 Surface Scratches

Surface scratches on membrane made during manufacturing or installation shall be repaired in accordance with Table Y-2.

<table>
<thead>
<tr>
<th>Location</th>
<th>Depth of surface scratch / Nominal thickness</th>
<th>Repair Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat Part</td>
<td>≤ 5%</td>
<td>Acceptable as is</td>
</tr>
<tr>
<td></td>
<td>&gt; 5% and ≤ 25%</td>
<td>Smooth grind and buff</td>
</tr>
<tr>
<td></td>
<td>&gt; 25% and ≤ 50%</td>
<td>Repair weld, patch, or replace</td>
</tr>
<tr>
<td></td>
<td>&gt; 50%</td>
<td>Patch, or replace</td>
</tr>
<tr>
<td>Corrugation</td>
<td>≤ 5%</td>
<td>Acceptable as is</td>
</tr>
<tr>
<td></td>
<td>&gt; 5% and ≤ 10%</td>
<td>Smooth grind and buff</td>
</tr>
<tr>
<td></td>
<td>&gt; 10% and ≤ 50%</td>
<td>Repair weld, patch, or replace</td>
</tr>
<tr>
<td></td>
<td>&gt; 50%</td>
<td>Patch, or replace</td>
</tr>
<tr>
<td>Knot</td>
<td>≤ 2.5%</td>
<td>Smooth grind and buff</td>
</tr>
<tr>
<td></td>
<td>&gt; 2.5%</td>
<td>Replace</td>
</tr>
</tbody>
</table>

Y.5.5.2 Local Dents

Smooth local dents on membrane made during manufacturing or installation shall be repaired in accordance with Table Y-3. Sharp dents at any part of the membrane shall be removed and replaced.

<table>
<thead>
<tr>
<th>Location</th>
<th>Depth of dent / Nominal thickness</th>
<th>Repair Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat Part and Corrugation</td>
<td>≤ 50%</td>
<td>Acceptable as is</td>
</tr>
<tr>
<td></td>
<td>&gt; 50% and ≤ 150%, and depth/length less than 1/10</td>
<td>Acceptable as is</td>
</tr>
<tr>
<td>Knot</td>
<td>Other than above</td>
<td>Patch or replace</td>
</tr>
<tr>
<td>--------------</td>
<td>------------------</td>
<td>------------------</td>
</tr>
</tbody>
</table>

Y.5.5.3 The patch plate, if used, shall have a minimum size of 50mm (2 in.) in diameter. When a square shape is used, the corner shall be rounded with a minimum radius of 6mm (1/4 in.).

Y.5.5.4 All patch plates shall meet the design requirements of the membrane. (See Y.3.)

Y.5.5.5 Any repair made on the membrane shall be recorded.

Y.5.6 Temporary Attachments

Y.5.6.1 Materials for pads, lifting lugs, and other non-pressure parts, as well as temporary lugs for alignment and scaffolding attached to membranes shall confirm to requirements of Table Y-1.

Y.5.6.2 Welds for pads, lifting lugs, and other non-pressure parts, as well as temporary lugs for alignment and scaffolding attached to membrane shall be welded in accordance with Y.4.

Y.5.6.3 Temporary attachments shall be removed and any significant projections of weld metal shall be ground to a smooth contour followed by liquid penetrant examination and vacuum box testing.

Y.5.6.4 Membrane that is gouged or torn from removal of temporary attachments shall be repaired using a qualified procedure. The membrane plate shall be repaired by a lap patched or replaced. Any welds shall be ground to a smooth contour.

Y.5.7 Repairs to Welded Joints

When repairs are made to welded joints, the repair welding shall be in accordance with Y.4.

Y.5.8 Marking of Materials

Y.5.8.1 Material for membrane shall be marked so that the individual components are traceable to the mill test reports.

Y.5.8.2 All mill markings shall be in accordance with the requirements of ASTM A20 and ASTM A480 as applicable. All material markings performed by the Tank System Contractor shall be in accordance with the requirements of 7.7 and Y.5.8.1.

Y.5.8.3 Marking materials to be used on austenitic membranes shall contain less than 200 ppm of halogens.

Y.5.9 Construction Practices

Fabricated membrane pieces should have a joggle built into the fabricated piece to avoid excessive hammering for fitting during construction. Joggling shall consist of shifting, by shaping, a width of sheet parallel to the edge so as to permit it to overlap the corresponding edge of the adjacent sheet. (See Figure Y-2) Only non-metallic hammer shall be used. Any objectionable local damage caused by hammering shall be repaired in accordance with Y.5.5. The extent of permissive rework for any repair must be agreed to between the Purchaser and the Tank System Contractor. If the rework is determined to have been excessive, the reworked area shall be cut out and replaced.
Y.5.10 Protection of Membrane during Shipping and Storage

Y.5.10.1 Membrane components shall be adequately protected during shipping and storage to avoid damage to membrane component surfaces and edges from handling (scratches, gouge marks, etc.) and from environmental conditions (corrosion, pitting, etc.).

Y.5.10.2 Membrane components shall be protected from moisture or stored in inclined position to prevent water from collecting and standing on surface at all stages of fabrication and construction.

Y.6 Testing of Membrane Tank

Y.6.1 General

The rules in this section shall only apply to the membrane. Any other components for the membrane tank shall be in accordance with the basic sections, Annex R and Annex Q of this standard.

Y.6.2 General Procedure

Y.6.2.1 Vapor tightness check is essential for ensuring the integrity of the membrane. The Tracer gas tightness test for the membrane shall be conducted after the entire membrane is completed, except for temporary construction opening area, if any. If temporary construction opening is utilized, the tracer gas test shall be done before closing this area. A temporary closing of the temporary construction opening shall be made prior to performing the tracer gas test.

Y.6.2.2 If a temporary construction opening is utilized, after the completion of the work and the removal of installation equipment, the temporary construction opening shall be closed. 100% of the membrane welds of this area shall be examined by liquid penetrant method and vacuum box testing.

Y.6.3 Test Preliminaries

Y.6.3.1 Adequate piping under the membrane shall be installed permanently to introduce tracer gas in the insulation layer.

Y.6.3.2 Liquid penetrant examination shall be completed prior to the tracer gas test.

Y.6.4 Detailed Procedure of the vapor tightness test using tracer gas

One (1) of the following tests shall be performed to check the vapor tightness of the membrane. The test shall be performed in accordance with a written procedure which has been reviewed and approved by the Purchaser.

Y.6.4.1 Ammonia test

Y.6.4.1.1 After cleaning of welds a reaction paint shall be applied on the surface of all welding joints including repaired welds prior to the start of ammonia leak test.

Y.6.4.1.2 The ammonia test shall be conducted per the requirements of ASTM E1066 or EN ISO 20485.
Y.6.4.1.3 Vacuum shall be applied to the insulation space prior to tracer gas injection to extract the air and air humidity in order to avoid ammonia absorption by residual moisture. Air and moisture removal may be performed using nitrogen gas.

Y.6.4.1.4 Ammonia nitrogen gas mixture shall be introduced into the piping under the membrane. The ammonia gas concentration shall be below maximum allowable limit for materials used in the insulation layer. Typical values of ammonia concentration range between 3% and 30% by volume so as to not to affect materials under the membrane.

Y.6.4.1.5 Tell-tale holes or slots shall be provided on the membrane for sampling the ammonia nitrogen gas mixture. Tell-tale holes shall have a minimum diameter of 8 mm (5/16 in.) or slots providing unwelded length of 20 mm (3/4 in.) to 30 mm (1¼ in.) long. The tell-tale holes or slots shall be located such that a uniform distribution of ammonia nitrogen gas mixture behind the membrane on the entire surface of the tank is assured.

Y.6.4.1.6 After completion of the ammonia test the tell-tale holes or slots shall be repaired by welding. The repair areas shall be examined by liquid penetrant method and vacuum box testing.

Y.6.4.1.7 Ammonia concentration shall be monitored and controlled regularly and reinjection of ammonia shall be performed if the concentration is below the acceptable level.

Y.6.4.1.8 Tell-tale holes or slots shall be carefully marked prior to the test process. At the end of the ammonia test a final check shall be performed to ensure that no tell-tale hole or slot has been missed. The marking method shall be compatible with the membrane and defined by company in charge of the test.

Y.6.4.1.9 The test pressure shall be above atmospheric pressure or lower than the maximum allowable pressure of the insulation layer.

Y.6.4.1.10 Ammonia holding time is dependent on the test pressure and concentration of the ammonia. ASTM E1066 provides guidelines for calculation of holding time for the test.

Y.6.4.1.11 If any defects are observed, they shall be repaired. The repair areas shall be examined by liquid penetrant method and vacuum box testing.

Y.6.4.1.12 After the completion of the ammonia test, the insulation layer shall be purged so that residual ammonia content is less than 1.5% by volume.

Y.6.4.2 Helium test

Y.6.4.2.1 This test consists in filling the insulation space with a dry air and helium mixture (or nitrogen and helium mixture). The technique shall be capable of detecting leakage of $1 \times 10^{-4}$ Pa m$^3$/s ($1 \times 10^{-3}$ std cm$^3$/s) or smaller.

NOTE: The insulation space may be evacuated of air prior to the tracer gas injection to assist achieving the required helium concentration.

Y.6.4.2.2 The helium test shall be conducted per the requirements of ASTM E499 or EN ISO 20485.

Y.6.4.2.3 The insulation space shall be pressurized over atmospheric pressure but less than the maximum allowable pressure of the insulation layer enabling the helium tracer gas to pass from insulation space to the tank through any leak on membrane welded joints.

Y.6.4.2.4 100% membrane welded joints shall be checked for leaks using dedicated leak detection detectors and sniffing the joints for potential helium leak. The leak test shall be performed from the interior portion of the tank.

Y.6.4.2.5 Helium nitrogen or helium dry air gas mixtures shall be introduced into the piping under the membrane. The helium gas concentration shall be above minimum allowable limit of 10%vol.
Y.6.4.2.6 Tell-tale holes or slots shall be provided on the membrane for controlling the helium concentration. Tell-tale holes shall have a minimum diameter of 8 mm (5/16 in.) or slots providing unwelded length of 20 mm (3/4 in.) to 30 mm (1¼ in.) long. The tell-tale holes or slots shall be located such that a uniform distribution of helium concentration behind the membrane on the entire surface of the tank is assured. After completion of the test the tell-tale holes or slots shall be repaired by welding. The repair areas shall be examined by liquid penetrant method and vacuum box testing.

Y.6.4.2.7 The control of helium concentration shall be performed regularly and reinjection of helium shall be performed if the concentration is below the acceptable level.

Y.6.4.2.8 Tell-tale holes or slots shall be carefully marked prior to the test process. A marking of the controlled welds shall be done during the test process. At the end of the helium test a final check shall be performed to ensure that no tell-tale hole or slot or no weld has been missed. The marking method shall be compatible with the membrane and defined by company in charge of the test.

Y.6.4.2.9 If any defect is observed, repair shall be carried out. The repaired weld shall be verified by liquid penetrant method and the vacuum box testing.

Y.6.5 Global Test of membrane

Y.6.5.1 The global test shall be required if the nominal thickness of the membrane is less than 2mm.

NOTE: The global test is a specialized non-destructive test designed specially to confirm the integrity of the membrane for the human errors made in the tank after the gas tracer tightness test and before its closing.

NOTE: The principle of the test is to establish a pressure difference between the interior of the tank and the insulation space to allow gas flow through the membrane if there are potential leaks through the membrane which may occur after the gas tracer tightness test.

Y.6.5.2 The tank is pressurized with air and regulated to be above the atmospheric pressure but less than the design pressure and the insulation space filled with nitrogen gas. The oxygen content in the insulation space shall be monitored hourly. The Oxygen meter shall be capable of measuring in 0.1% accuracy.

Y.6.5.3 For membrane containment tank system with concrete outer tank, the acceptance criteria shall be calculated according to oxygen content increase rate in the insulation space.

Y.6.5.4 For membrane containment tank system with metallic outer tank, the acceptance criteria shall be calculated according to differential pressure decay rate between the interior tank and the insulation space.

Y.6.5.5 Increase of oxygen content in the insulation space or decrease in the differential pressure beyond the acceptance criteria indicates a potential leak through the membrane. Investigations shall be carried out and the membrane shall be visually inspected to locate the potential leak through the membrane. If not detected, additional testing shall be performed to locate the potential leak. If the leak is through the membrane, it shall be repaired and a global test shall be repeated.

Y.6.5.6 Just after the completion of tracer gas test, a first global test shall be performed and a record reference curve shall be established for controlling the tightness of the membrane up to the commissioning operation.

Y.6.5.7 Daily monitoring of the membrane tightness shall be performed after completion of construction and during the dismantling and removing of the construction scaffolding. The pressure curve shall be compared with the reference curve made during the first global test to detect any possible damage on the membrane during dismantling.

Y.6.5.8 A final global test of membrane shall be performed after completion of the tank system including removal of all the equipment and completion of internals.

NOTE: Limited works inside tank may be permitted provided that protective measures to ensure membrane integrity are in place.
Y.6.5.9 The final global test, if performed, shall be used as reference for the control of membrane integrity during tank life for subsequent checks in case of maintenance operation or repair.

Y.6.5.10 Testing sequence

Y.6.5.10.1 Figure Y-3 provides the testing method for membrane containment tank system with concrete outer tank.

i. Oxygen shall be removed from insulation space;

ii. Oxygen content increase rate in the insulation space shall be accurately monitored with tank at atmospheric pressure (minimum 72 hours) just after completion of tracer gas test Y.6.5.5;

iii. Oxygen content increase rate in the insulation space shall be accurately monitored with tank pressurized (to 150 mbarg in maximum 24 hours with minimum 72 hours recording) just before commissioning Y.6.5.7;

iv. Comparison with acceptance criterion shall be performed.

![Diagram of Global Test Cycles for Membrane Containment Tank System with Concrete Outer Tank]

**Figure Y-3 – Global Test Cycles for Membrane Containment Tank System with Concrete Outer Tank**

Y.6.5.10.2 Figure Y-4 provides the testing method for membrane containment tank system with metallic outer tank.

i. Pull vacuum in the insulation space to minus 800 mbarg shall be carried out in 4 hours and stabilized one hour;

ii. The vacuum decay rate curve in the insulation space shall be accurately monitored with tank at atmospheric pressure (minimum 24 hours) just after completion of tracer gas test Y.6.5.5;
iii. The vacuum decay rate curve in the insulation space shall be accurately monitored with tank at atmospheric pressure (minimum 24 hours) just before commissioning Y.6.5.7;

iv. Comparison in between ii and iii shall be performed. Influences due to atmospheric changes shall be considered.

Figure Y-4 – Global Test Cycles for Membrane Containment Tank System with Metallic Outer Tank

Y.6.5.11 Acceptance criteria

Y.6.5.11.1 Membrane containment tank system with concrete outer tank

i. The criteria depends on the free volume of the insulation space;

ii. The oxygen content increase value from 72 hours to 144 hours shall be below (see Figure Y-3)

\[
\text{ppmv} = \frac{360,000}{\text{insulation space free volume (m}^3\text{)}}
\]

Y.6.5.11.2 Membrane containment tank system with metallic outer tank (see Figure Y-4)

i. During the reference test, the vacuum pressure shall indicate that the pressure will converge below atmospheric pressure. Upper limit of the curve is defined as the pressure below the atmospheric pressure registered by the gage where subsequent readings indicate less than 1% change in one hour. Typically this value will be below atmospheric and above -800 mbarg.

ii. The profile of the curve at the final test shall remain similar to the reference test and shall indicate that the pressure will saturate below atmospheric pressure. The rise of the pressure shall follow the same profile and reach the similar upper limit pressure as the reference curve. The pressure curve rise and upper limit pressure shall be within 10% of the reference curve.
Y.6.6 Hydrostatic and Pneumatic Test

If performed after membrane installation, hydrostatic and pneumatic test shall be per section 10.3 of API Standard 625.

Y.7 Quality Assurance

A quality management system shall be utilized to ensure that the work performed meets the quality requirements of this standard. Refer to API 625 Sec.8.1.

Y.8 Reference

<table>
<thead>
<tr>
<th>Standard/Reference</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTM E499</td>
<td>Standard Practice for Leaks Using the Mass Spectrometer Leak Detector in the Detector Probe Mode</td>
</tr>
<tr>
<td>ASTM E1066</td>
<td>Standard Practice for Ammonia Colorimetric Leak Testing</td>
</tr>
<tr>
<td>BS 7608</td>
<td>Guide to fatigue design and assessment of steel products</td>
</tr>
<tr>
<td>EN14620</td>
<td>Design and Manufacture of Site Built, vertical, Cylindrical, Flat-Bottomed Steel Tanks for the Storage of Refrigerated, Liquefied Gases with Operating Temperatures between 0°C and -165°C.</td>
</tr>
<tr>
<td>EN ISO 20485</td>
<td>Non-destructive testing - Leak testing - Tracer gas method</td>
</tr>
<tr>
<td>JGA RP-107-02</td>
<td>Recommended Practice for LNG Inground Tanks</td>
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</tbody>
</table>

Revision History

<table>
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<tr>
<th>Rev</th>
<th>Description</th>
</tr>
</thead>
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<td>1</td>
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