Title:	**External Pressure for API-620 Tanks**
Date:	Nov 10th 2023
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Purpose:	**Add Reference to API-650 Annex V for External Pressure Design for API-620 Tanks**
Source:	INQ-D009
Revision:	1
Impact:	Improved design for External Pressure.
Background/Rationale:	API-620 does not have any calculations for external pressure (vacuum). Instead, it has a singular statement saying any tank designed to API-620 should be good for 1-ounce vacuum. This Agenda Item adds a reference to API-650 Annex V and cleans up the use of “vacuum” or “partial vacuum” and uses “external pressure” instead.

Proposal: **Existing in black. Changes in red. ~~Removed sections are stricken out.~~ Notes/Comments in blue (Notes/Comments do not appear in the code)**

1.2 Coverage)

1.2.1 This standard covers the design and construction of large, welded, low-pressure carbon steel above ground storage tanks (including flat-bottom tanks) that have a single vertical axis of revolution. This standard does not cover design procedures for tanks that have walls shaped in such a way that the walls cannot be generated in their entirety by the rotation of a suitable contour around a single vertical axis of revolution.

1.2.2 The tanks described in this standard are designed for metal temperatures not greater than 250 °F and with pressures in their gas or vapor spaces not more than 15 lbf/in.^{2} ~~**gauge**~~ internal pressure or 1 lbf/in.^{2} external pressure.

3.1 Stress and Pressure Terms

3.1.1

design internal pressure (Pi)

The maximum positive ~~gauge~~ internal pressure permissible at the top of a tank when the tank is in operation. It is the basis for the pressure setting of the safety-relieving devices on the tank. The design internal pressure is synonymous with the nominal pressure rating for the tank as referred to in this standard (see 5.3.1).

3.1.2

design external pressure (Pe)

The design external pressure (Pe) shall not be less than 1 in. of water. Tanks that meet the requirements of this standard may be subjected to an external pressure of 1 in. of water without the need to provide any additional supporting calculations. API-650 Annex V may be used for the design of external pressure greater than 1 in. of water.

3.1.3

maximum allowable stress value

The maximum unit stress permitted to be used in the design formulas given or provided for in this standard for the specific kind of material, character of loading, and purpose for a tank member or element (see 5.5 and 5.6).

5.3 Pressures Used in **Design**

5.3.1 Above Maximum Liquid Level

5.3.1.1 Tank components, including those above the maximum liquid level, subjected principally to gas pressure shall be designed for the following.

a) A pressure not less than the relief valves' set pressure. The maximum positive gauge pressure shall be understood to be the nominal pressure rating for the tank (sometimes called the design pressure) and shall not exceed 15 lbf/in^2 gauge.

b) The maximum ~~partial vacuum (also called the design vacuum)~~ external pressure when the inflow of air (or another gas or vapor) through the vacuum relief valves is at the tank design maximum in-breathing flow rate.

5.3.1.4 The set pressure of the vacuum relief valve shall limit the ~~vacuum pressure~~ external pressure accumulation in the tank to the ~~design vacuum pressure~~ design external pressure.

5.4 Loads

5.4.1 Individual Loads

a) dead load (DL): the weight of the tank or tank component, including any insulation, lining, or corrosion allowance

unless otherwise noted.
b)hydrostatic and pneumatic tests (H,): the load due to conducting the tests specified in 7.18.
c) loads from connected piping (Lp)-
d) loads from platforms and stairways (Ls) (see Annex E).
e) minimum roof live load (L,): 20 lb/ft2 on the horizontal projected area of the roof.
f) internal pressure (~~Pg~~ Pi): the maximum positive gauge pressure given in 5.3.1.
g) external pressure (~~Pv~~ Pe): the maximum ~~partial vacuum~~ external pressure given in 5.3.1. The maximum ~~partial vacuum~~ external pressure shall be at least 1 in. water)

5.4.2 Load Combinations
The tank shall be designed for the following load combinations. If the absence of any load other than dead load results in a more severe condition, that load shall not be included in the combination.

a) DL + ~~Pg~~ Pi + Pl

b) DL + WL + 0.7 ~~Pg~~ Pi

c) DL + WL + 0.4~~Pv~~ Pe

d) DL + ~~Pv~~ Pe + 0.4(Lr or S)

e) DL + 0.4 ~~Pv~~ Pe + (Lr or S)

f) DL + 0.7 ~~Pg~~ Pi + Pl + E + 0.1S

g) DL + Ht

h) DL + Ls

i) DL + Lp + ~~Pg~~ Pi + Pl

5.5.4 Maximum Compressive Stresses
5.5.4.1 Except as provided in 5.12.4.3 for the compression-ring region, the maximum compressive stresses in the outside walls of a tank, as determined for any of the loadings listed in 5.4 or any concurrent combination of loadings expected to be encountered in the specified operation, shall not exceed the applicable stress values determined in accordance with the provisions described in 5.5.4.2 through 5.5.4.8. ~~These rules do not purport to apply when the circumferential stress on a cylindrical wall is compressive (as in a cylinder acted upon by external pressure)~~. However, values of S_{cs} computed as in 5.5.4.2, with R equal R1 when the compressive unit force is latitudinal or to R2 when the compressive unit force is meridional, in some degree form the basis for the rules given in 5.5.4.3, 5.5.4.4, and 5.5.4.5, which apply to walls of double curvature.

5.9.2 Levels of Analysis
Free-body analyses shall be made at successive levels from the top to the bottom of the tank for the purpose of determining the magnitude and character of the meridional and longitudinal unit forces that will exist in the walls of the tank at critical levels under all the various combinations of gas pressure (or ~~partial vacuum~~ external pressure) and liquid head to be encountered in service, which may have a controlling effect on the design. Several analyses may be necessary at a given level of the tank to establish the governing conditions of gas pressure (or external pressure) and liquid head for that level. The thicknesses required in the main walls of the tank shall then be computed by the applicable procedures given in 5.10.3.

5.10 Design of Sidewalls, Roofs, and Bottoms
5.10.1 Nomenclature
The variables used in the formulas of 5.10 are defined as follows.
P is the total pressure, in lbf/in.^{2} gauge, acting at a given level of the tank under a particular condition of loading,
Pl is the gauge pressure resulting from the liquid head at the level under consideration in the tank (see 5.4.1 b);
Pg see 5.4.1 g, *Pg* is positive except in computations used to investigate the ability of a tank to withstand

~~a partial vacuum~~ external pressure; in such computations, its value is negative;

5.10.2.2 Positive values of *T1* and *T2* indicate tensile forces; negative values indicate compressive forces.
5.10.2.3 Free-body analyses shall be made at the level of each horizontal joint in the sidewalls, roof, and bottom of the tank and at any intermediate levels at which the center of curvature changes significantly. The maximum total pressure (liquid head plus gas pressure) that can exist at a given level will not necessarily be the governing condition for that level. Sufficient analyses shall be made at each level to determine the combination of liquid head and gas pressure (or ~~partial vacuum~~ external pressure) that, in conjunction with the allowable tensile and compressive stresses, will control the design at that level. A tank may normally be operated at a fixed height of liquid contents, but the tank must be made safe for any conditions that might develop in filling or emptying the tank. This will necessitate a particularly careful investigation of sidewalls of double curvature.

5.10.2.7 Equation (2), Equation (5), and Equation (9) have been derived from a summation of the normal-to-surface components of the T1 and T2 forces acting on a unit area of the tank wall subjected only to pressure P. To be technically correct, the normal-to-surface components of other loads, such as metal, snow or insulation, should be added to or subtracted from P. For the usual internal design pressure, these added loads are small compared with P and can be mooted without significant error. Where the pressure P is relatively small, as in the case of a partial vacuum loading, the other load components can have a substantial effect on the calculated T2 force and resultant thickness.

Equation (3) and Equation (6) are correct only when P is the free-body pressure without the normal-to-surface components of other loads
5.10.2.7

The example in F.3 calculates the required roof thicknesses under a small ~~vacuum~~ external pressure by considering the metal, insulation and snow loads in Equation (1) through Equation (5). The designer should note that if these loads had been omitted, the calculated thicknesses would have been much less than the correct values.

In Equation (1), Equation (4), Equation (8), and Equation (10), W is intended to include loads of insignificant value, such as metal weight. At points away from the vertical centerline of the roof, the value of T2 is required for the thickness calculations of Equation (18), Equation (20), and Equation (22) and the value of P in Equation (2), Equation (5), and Equation (9) must be modified by the normal components of the added loads for the correction determination of *T2.*

5.10.3 Required Thickness
5.10.3.1 The thickness of the tank wall at any given level shall be not less than the largest value of *t* as determined for the level by the methods prescribed in 5.10.3.2 through 5.10.3.5. In addition, provision shall be made by means of additional metal, where needed, for the loadings other than internal pressure or possible ~~partial vacuum~~ external pressure enumerated in 5.4. If the tank walls have points of marked discontinuity in the direction of the meridional tangent, such as occur at the juncture between a conical or dished roof (or bottom) and a cylindrical sidewall, the portions of the tank near these points shall be designed in accordance with the provisions of 5.12.
5.10.3.2 If the unit forces T1 and T2 are both positive, indicating tension, for the governing combination of gas pressure (or ~~partial vacuum~~ external pressure) and liquid head at a given level of the tank, the larger of the two shall be used for computing the thickness required at that level, as shown in the following equations:

5.10.3.3 If the unit force T1 is positive, indicating tension, and T2 is negative, indicating compression, for the governing combination of gas pressure (or ~~partial vacuum~~ external pressure) and liquid head at a given level of the tank or if T2 is positive and T1 is negative, the thickness of tank wall required for this condition shall be determined by assuming different thicknesses until one is found for which the simultaneous values of the computed tension stress, S_{tc}, and the computed compressive stress, S_{cc}, satisfy the requirements of 5.5.3.3 and 5.5.4.5, respectively. The determination of this thickness will be facilitated by using a graphical solution such as the one illustrated in F-2.[17] Notwithstanding the foregoing provisions, if the unit force acting in compression in the case described does not exceed 5 % of the coexistent tensile unit force acting perpendicular to it, the designer has the option of determining the thickness required for this condition by using the method specified in 5.10. 3.2 instead of complying strictly with the provisions of this paragraph. The value of the joint efficiency factor, *E,* will not enter into this determination unless the magnitude of the allowable tensile stress, S_{ta}, is governed by the product ES_{ts} as provided in 5.5.3.3.

5.10.3.6 The procedure described in 5.10.3.5 is for the condition in which biaxial compression with unit forces of unequal magnitude is governing. In many cases, however, a tentative thickness will have been previously established by other design conditions and will need to be checked only for the external pressure ~~or partial vacuum~~ condition. In such cases, the designer has only to compute the values of S_{ec} for both T1 and T1 and then check to see that these satisfy the requirements of 5.5.4.4, as specified in Step 6. (See F.3 for examples illustrating the application of 5.10.3.5.)

5.10.5 External Pressure Limitations

5.10.5.1 The thicknesses computed using the formulas and procedures specified in 5.10, where *Pg* is a negative value equal to the ~~partial vacuum~~ external pressure for which the tank is to be designed, will ensure stability against collapse for tank surfaces of double curvature in which the meridional radius, *R1,* is equal to or less than *R2* or does not exceed *R2* by more than a very small amount. Data on the stability of sidewall surfaces of prolate spheroids are lacking; the formulas and procedures are not intended to be used for evaluating the stability of such surfaces or of cylindrical surfaces against external pressure. API-650 Annex V may be used for the design of external pressure greater than 1 in. of water.

5.10.5.2 This standard does not contain provisions for the design of cylindrical sidewalls that are subject to ~~partial internal vacuum~~ external pressure in tanks constructed for the storage of gases or vapors alone. However, cylindrical sidewalls of vertical tanks designed in accordance with these rules for storing liquids (with the thickness of upper courses not less than specified in 5.10.4 for the tank size involved and with increasing thickness from top to bottom as required for the combined gas and liquid loadings) may be safely subjected to ~~a partial vacuum~~ an external pressure in the gas or vapor space not exceeding **1 ounce per square in.** with the operating liquid level in the tank at any stage from full to empty. The vacuum relief valve or valves shall be set to open at a smaller ~~partial vacuum~~ external pressure so that the **1-ounce** ~~partial vacuum~~ external pressure will not be exceeded when the inflow of air (or gas) through the valves is at the maximum specified rate.

Should 1 ounce be change to 1 in. of water like API-650?

1oz/si = 1.73078 in h2o

5.10.6 Intermediate Wind Girders for Cylindrical Sidewalls

5.10.6.1 The maximum height of unstiffened sidewall, in ft, shall not exceed:

5.10.6.1 The maximum height of unstiffened sidewall, in ft, shall not exceed:

$$H_1 = 6(100t)\sqrt{\left(\frac{100t}{D}\right)^3}$$

where

H_1 is the vertical distance between the intermediate wind girder and the top of the sidewall or in the case of formed heads the vertical distance between the intermediate wind girder and the head-bend line plus one-third the depth of the formed head, in ft;

t is the thickness of the top sidewall course, as ordered condition unless otherwise specified, in inches;

D is the nominal tank diameter, in ft.

NOTE This formula is based on the following factors.

a) A 3-sec gust design wind velocity, *V,* of 120 mph which imposes **a** dynamic pressure of 25.6 lbf/ft2. The velocity is increased by 10 % for either a height above the ground or a gust factor. The pressure is thus increased to 31 lbf/ft2. An additional 5 lbf/ft2 is added for ~~internal vacuum~~ external pressure. This pressure is intended by these rules to be the result of a 120 miles per hour 3-sec wind gust at approximately 33 ft above the ground. *H1* may be modified for other wind velocities, as specified by the Purchaser, by multiplying the formula by $(120/V)^2$. When a design wind pressure, rather than a wind velocity, is stated by the Purchaser, the preceding increase factors should be added, unless they are contained within the design wind pressure.