

# HELIUM GAS TANK MODIFICATION

-Rudy Alforque, June 25, 2003

**Objective:** To determine the required reinforcement for a larger nozzle in both ends of the helium gas tank that is located near the compressor building at Bldg. 1005.

**Background Info:** The tank is an ASME U-stamped vessel, 10 ft in diameter with a hemispherical head at both ends. At present, there is a 6-inch nozzle welded to the head at each end and located exactly along the axis of the tank; it reduces into a 4-in. pipe for the remainder of the run.

For reasons beyond the scope of this report, a decision was made to replace the current piping with 10-in. sch. 40 pipes. Thus the penetration into the tank head would have to be increased to accommodate a new 10-in. nominal-size nozzle.

The basic data on the boilerplate is as follow:

- Shell Thickness: 0.8125 in.
- Head Thickness: 0.466 in. ( $t_1$  in Fig. 1, below)
- Max. External Pressure: 15 psi @ 125°F
- Hydrostatic test pressure: 375 psi
- Material: SA-612

From Table 1A of the 1992 Boiler and Pressure Vessel Code, Part D, the max allowable stress,  $S_y$ , of SA-612 is 20.2Ksi

In addition, since the standard hydrostatic pressure test in accordance with UG-99 of the BPV Code is usually at 1.5 times the max. allowable working pressure, we can assume that our vessel has been qualified to a max. allowable working pressure of  $P_a = 375/1.5 = 250$  psi.

**Required Reinforcement:** The basic Code requirement regarding a vessel opening per UG-36 and UG-37, is that around the opening (with specified *limits*), the vessel must be reinforced with an equal amount of metal that has been removed for the opening. Not necessarily the *actual* amount of metal removed, however, but only the amount that is *required to resist* internal pressure; vessels are usually fabricated with plate and nozzle thickness a little more than what is required to resist internal pressure.

## Case A: Back-of-the-envelope calculation

Since our vessel has been fabricated already, and the head thickness,  $t_1 = 0.466$  in, has been established, we need only to reinforce the proposed opening such that  $A_3 \geq A_1$  in Fig. 1. For the sake of simplicity, if we ignore the weld metal, and the inside extension of the nozzle, the result would be towards the conservative side.

The proposed opening is for a standard 10-inch, schedule 40 pipe with the following dimensions:

- OD = 10.75 in.
- ID = 10.02 in. (In Fig. 1,  $R = 10.02/2 = 5.01$  in)
- Wall = 0.365 in. ( $t_2$  in Fig. 1)

Thus, we need to determine the dimensions of  $A_3$  such that  $A_3 \geq A_1$ . The limit of the dimensions, however, is governed by UG-40 of the Code. Neglecting corrosion allowance since it is not so significant in our case, from UG-40b, the pertinent limit would be the greater of the following (refer to Fig. 1):

1.  $X = (L + t_2 + R) \leq 2R$ , or  $L \leq R - t_2 \leq 4.645$  in.
2.  $X = (L + t_2 + R) \leq (R + t_1 + t_2)$ , or  $L \leq t_1 \leq 0.466$  in.

Hence, the L-dimension of the reinforcement should be within 4.645 in. If we choose  $L = 3.75$  in, and

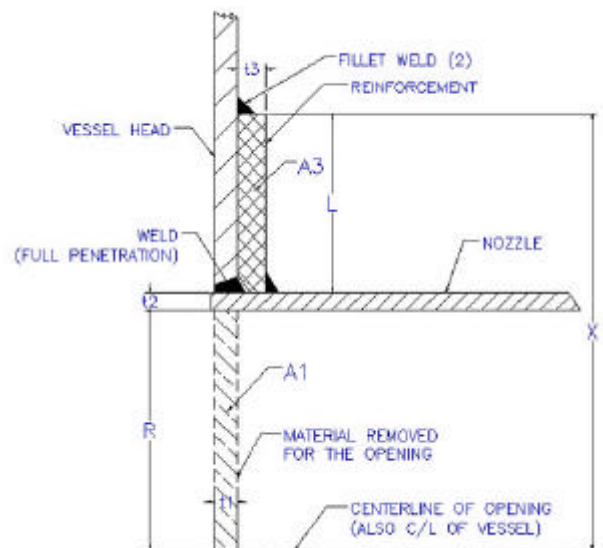


Fig. 1

$t_3 = 0.625$  in, then  $A_3 = (L \times t_3) = 2.344 \text{ in}^2$ ; in comparison,  $A_1 = (R \times t_1) = 2.335 \text{ in}^2$ . Therefore, the reinforcement would be satisfactory. (Note that the limit for  $t_3$  per UG-40c is quite broad in our case that we have a lot of freedom in choosing its value).

The reinforcement determined in this quick back-of-the-envelope approach, would be on the conservative side as long as the material properties of the head, nozzle, and reinforcing plates are the same.

### Case B: Reinforcement as specified by the Code

In this approach, we will use the nomenclature and formulas as shown in Fig. UG-37.1 (see attached) taken from the 1992 Boiler and Pressure Vessel Code, Section VIII, Div. 1. Possible differences in material properties will be accounted for.

First, we calculate the required head thickness to resist an internal pressure of  $P_a = 250$  psi:

For a hemispherical head with pressure on the concave side, the required head thickness per UG-32, Eq. 3:

$$t_r = P(Rh)/(2SE - 0.2P),$$

where  $Rh$  = radius of hemispherical head =  $(10 \text{ ft})/2 = 60$  in,  $S = S_v = 20.2$  Ksi (see above),  $E$  = lowest efficiency on any joint in the head. From Table UW-12 of the Code, we chose  $E = 0.85$  to add some conservatism.

Substituting values,  $t_r$  equals 0.437 in, which is slightly smaller than the actual head thickness,  $t = t_1 = 0.466$  in.

For the nozzle, readily available standard seamless carbon steel piping, either SA-53 or SA-106, would have a max. allowable stress of  $S_n = 12$ Ksi. Using Eq. 1, UG-37, the required nozzle thickness is:

$$t_{rn} = PR/(SE - 0.6P), \text{ where } S = S_n = 12000 \text{ psi.}$$

Substituting values,  $t_{rn}$  equals 0.125 in; the actual thickness of a schedule 40 nozzle is  $t_n = t_2 = 0.365$  in.

Now, let us assume that the nozzle is abutting the inside surface of the head wall. In other words, we will not give credit as part of the reinforcement the inside extension of the nozzle. This will make our calculations simpler without sacrificing the validity of the results. In addition, we will neglect corrosion allowance as it is not so significant in this case. The fillet welds will be 1/4-in which conform to Fig. UW-16.1, sketch (d).

From UG-37, other relevant parameters are,  $f_{r1} = 1$ , for nozzle wall abutting the vessel wall;  $f_{r2} = S_n/S_v = 12/20.2 = 0.594$ ;  $E_1 = 1$ , for an opening through a solid plate; and correction factor,  $F = 1$

### Area of reinforcement required, A:

$$A = dt_r F + 2t_n t_r F(1 - f_{r1}) = (10.02) \times 0.437 \times 1 + 0 = \mathbf{4.383 \text{ sq. in.}}$$

### Available Area of Reinforcement:

Available in shell,  $A_1$  = larger of the following

$$= d(E_1 t - Ft_r) - 2t_n (E_1 t - Ft_r)(1 - f_{r1}) = 10.02 \times (1 \times 0.466 - 1 \times 0.437) - 0 = \mathbf{0.286 \text{ sq. in.}}$$

$$= 2(t + t_n)(E_1 t - Ft_r) - 2t_n (E_1 t - Ft_r)(1 - f_{r1}) = 2 \times (0.466 + .365) \times (1 \times .466 - 1 \times 0.437) - 0 = 0.047$$

Available in nozzle,  $A_2$  = smaller of the following

$$= 5(t_n - t_{rn}) f_{r2} t = 5 \times (0.365 - 0.125) \times 0.594 \times 0.466 = 0.333, \text{ or}$$

$$= 5(t_n - t_{rn}) f_{r2} t_n = 5 \times (0.365 - 0.125) \times 0.594 \times 0.365 = \mathbf{0.261 \text{ sq. in.}}$$

Available in welds,  $A_{41} = (\text{leg})^2 f_{r2} = (0.25)^2 \times 0.594 = \mathbf{0.037 \text{ sq. in.}}$

Total area available,  $A_1 + A_2 + A_{41} = \mathbf{0.584 \text{ sq. in.}}$

Since  $A_1 + A_2 + A_{41} < A$ , a reinforcing element will be necessary. The required area of the reinforcing element would be:

$$A_5 \geq (4.383 - 0.584) = \mathbf{3.8 \text{ sq. in.}}$$

If we use plate carbon steel, SA-516, the max. allowable stress value is  $S = 15$  Ksi. Hence,  $f_{r4} = S_p/S_v = 15/20.2 = 0.743$ .

Assuming that the reinforcing element extends outward from the OD of the nozzle by **3.75 in**, then

$$D_p = OD + 2 \times 3.75 = 18.25 \text{ in.}; \text{ assume the thickness of the element, } t_e = \mathbf{0.7 \text{ in.}}$$

$$A_5 = (D_p - d - 2t_n) t_e f_{t4} = (18.25 - 10.02 - 2 \times 0.365) \times 0.7 \times 0.743 = \mathbf{3.9 \text{ sq. in.}} > \mathbf{3.8 \text{ sq. in.}}, \text{ thus adequate.}$$

Note: If  $S_v = S_n = S_p = 20200 \text{ psi}$ , the required reinforcement element would be only 3.5 sq. in.; with a 3.75 by 0.5 in reinforcement,  $A_5$  would be 3.75 sq. in. and thus would have been adequate.

The following tables summarize other possible scenarios for quick reference:

**Table 1: Schedule 40 Nozzle**

Nozzle: Schedule 40			
Max. Pressure, Pa	250	120	psi
Required head thickness, tr	0.437	0.210	in.
Required nozzle thickness, trn	0.125	0.059	in.
Area Required, A	4.383	2.102	sq. in.
Area available in shell, A1	0.286	2.567	sq. in.
Area available in nozzle, A2	0.261	0.331	sq. in.
Area available in weld, A41	0.037	0.037	sq. in.
Total Area Available	0.584	2.935	sq. in.
Reinforcement needed:	3.799	0	sq. in.

**Table 2: Schedule 20 Nozzle**

Nozzle: Schedule 20			
Max. Pressure, Pa	250	120	psi
Required head thickness, tr	0.437	0.210	in.
Required nozzle thickness, trn	0.129	0.061	in.
Area Required, A	4.525	2.170	sq. in.
Area available in shell, A1	0.295	2.650	sq. in.
Area available in nozzle, A2	0.045	0.085	sq. in.
Area available in weld, A41	0.013	0.013	sq. in.
Total Area Available	0.354	2.749	sq. in.
Reinforcement needed:	4.171	0	sq. in.

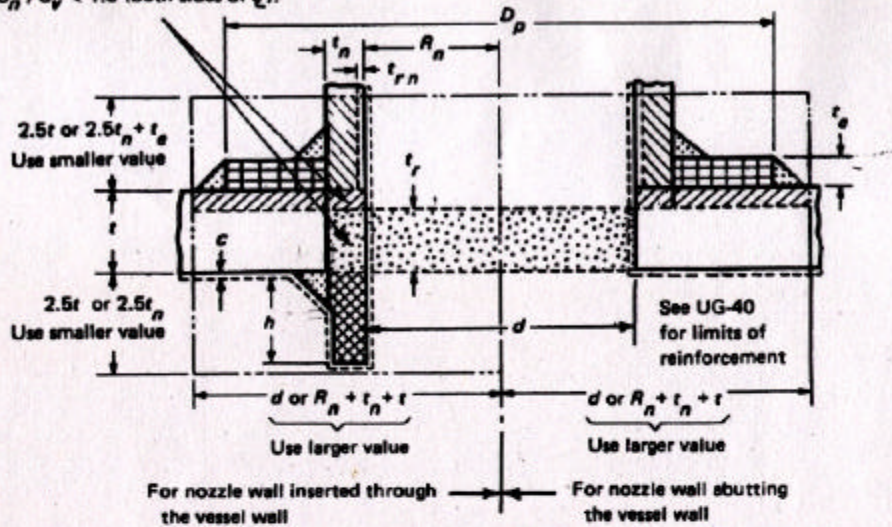
*Note: The weld size for schedule 20 nozzle was decreased to 0.15 in.*

**Further Comments:** It has been contemplated to de-rate the vessel to about 8 atmospheres, or 120 psi since the operating condition will perhaps never reach within the vicinity of the current rating. Thus I added some calculations here for such a scenario, and thus establish a design that attempts to follow the intent of the Code. Please note that under the column of 120 psi where no reinforcement is required, A41 should be 0 and the total area available should be reduced accordingly, but it is quite insignificant that I did not bother to do any re-calculation. If this scenario is adopted, however, further thorough analysis should be made regarding the load-carrying capacity of the shell-to-nozzle weld.







I would like to point out as a reminder to everyone concerned, however, that whatever in-house modification we do to the vessel, the current ASME U-stamp rating will be rendered invalid automatically and we are required to remove the current stamp. Only a company that is authorized to use the National Board R stamp and BNL is not one of them must perform repairs/modifications to stamped pressure vessels. Hence, the potential benefits of the modification must be clearly established with proper documentation to justify why we need to abandon the current U-stamp. Since this is a safety-related issue, the implementation plan and the resulting modified vessel should be qualified and approved by a BNL safety committee such as perhaps the BNL-mandated Cryogenics Safety Committee.

**GENERAL NOTE:**





Includes consideration of these areas if  $S_n / S_v < 1.0$  (both sides of  $\epsilon$ ).



**Without Reinforcing Element**

-  =  $A = d t_r F + 2 t_n t_r F (1 - f_{r1})$  Area required
  -  =  $A_1 \begin{cases} = d(E_1 t - F t_r) - 2 t_n (E_1 t - F t_r) (1 - f_{r1}) \\ = 2(t + t_n)(E_1 t - F t_r) - 2 t_n (E_1 t - F t_r) (1 - f_{r1}) \end{cases}$  Area available in shell; use larger value
  -  =  $A_2 \begin{cases} = 5(t_n - t_{rn}) f_{r2} t \\ = 5(t_n - t_{rn}) f_{r2} t_n \end{cases}$  Area available in nozzle projecting outward; use smaller value
  -  =  $A_3 = 2(t_n - c) f_{r2} h$  Area available in inward nozzle
  -  =  $A_{41} = \text{outward nozzle weld} = (\text{leg})^2 f_{r2}$  Area available in outward weld
  -  =  $A_{43} = \text{inward nozzle weld} = (\text{leg})^2 f_{r2}$  Area available in inward weld
- If  $A_1 + A_2 + A_3 + A_{41} + A_{43} > A$  Opening is adequately reinforced
- If  $A_1 + A_2 + A_3 + A_{41} + A_{43} < A$  Opening is not adequately reinforced so reinforcing elements must be added and/or thicknesses must be increased

**With Reinforcing Element Added**

- $A$  = same as  $A$ , above Area required
  - $A_1$  = same as  $A_1$ , above Area available
  - $A_2 \begin{cases} = 5(t_n - t_{rn}) f_{r2} t \\ = 2(t_n - t_{rn}) (2.5 t_n + t_w) f_{r2} \end{cases}$  Area available in nozzle projecting outward; use smaller area
  - $A_3$  = same as  $A_3$ , above Area available in inward nozzle
  -  =  $A_{41} = \text{outward nozzle weld} = (\text{leg})^2 f_{r3}$  Area available in outward weld
  -  =  $A_{42} = \text{outer element weld} = (\text{leg})^2 f_{r4}$  Area available in outer weld
  -  =  $A_{43} = \text{inward nozzle weld} = (\text{leg})^2 f_{r2}$  Area available in inward weld
  -  =  $A_5 = (D_p - d - 2 t_n) t_w f_{r4}$  [Note (1)] Area available in element
- If  $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5 > A$  Opening is adequately reinforced

**NOTE:**

(1) This formula is applicable for a rectangular cross-sectional element that falls within the limits of reinforcement.

**FIG. UG-37.1 NOMENCLATURE AND FORMULAS FOR REINFORCED OPENINGS**

(This Figure Illustrates a Common Nozzle Configuration and Is Not Intended to Prohibit Other Configurations Permitted by the Code.)