

## Notes for the Effective Design of Custom Built, Stainless Steel Tanks. ©

Tradition is one of the strongest influences in the design of many stainless steel tanks and vessels. Stainless is generally used where there are concerns regarding hygiene or corrosion. Both occur at a microscopic level and may not be fully understood. Most who require such vessels to hold or process their valuable products, may therefore favour proven designs and construction techniques, and that is a compellingly reasonable approach. Unfortunately however, carbon steel tradition remains unnecessarily residual in many cases.

Carbon steel is probably the most successful material of construction ever developed. If, when carrying out design, any doubts arise about the long-term adequacy of any particular size or thickness, using a heavier gauge, just in case, is a reasonably cost effective approach. Carbon steel's major drawback however is corrosion, and standard codes that must ensure adequate long-term integrity, include allowances for corrosion in their thickness formulae.

When designing in stainless steel however, this is not appropriate. If significant corrosion risk persists, either [another grade must be used](#) or stainless steel is not appropriate. It would be better to use carbon steel so that the corrosion rate will be obvious, and in some at-risk cases (such as pitting corrosion) it could even last longer. An example where observable deterioration is an advantage is the rigging wire of cruising class yachts. Stainless steel may look more desirable but evidential rusting will encourage replacement of the much cheaper, galvanised steel counterpart, in time to avoid a potentially disastrous failure.

The base cost of stainless is several times that of carbon steel. The materials in stainless steel tanks contribute between 30 and 60% to the ex-works price. Therefore, if a design procedure derives say 3.1mm thickness, the next commercially available size of 4mm is nearly 30% inefficient. Available standard thicknesses impose a commercial reality. This is particularly important if an 'exotic' grade of stainless is envisaged since an entry level duplex grade for instance, costs nearly ten times as much as mild steel.

### Robust design:

Tanks, as opposed to pressure vessels, should be considered of 'thin wall' construction where buckling is the predominant design constraint. Like carbon steel, stainless is relatively strong in tension but when 'thin' is vulnerable to buckling. Therefore any tank not designed to withstand vacuum, is likely to be at its most vulnerable during construction, transportation and/or installation. Only experience of the expected conditions can foretell adequacy to resist the rigours of that! Once in service and filled, the contents actually contribute to its stability.

An excellent example of this is spacecraft fuel cells. If left empty and unsupported, they are so thin-walled that they would buckle under their own weight. Consequently, during construction and making ready for lift-off, they are filled with inert liquid, which is only pumped off at the last moment, during charging. Isn't it great that stainless steel tanks aren't rocket science. Imagine needing to be an astronaut to be able to afford a beer...or a glass of milk if you prefer.

If a tank is designed according to common codes with seismic acceleration of zero, its ability resist damage before service tends to be marginal. If on the other hand it is designed to a minimum acceleration of 0.2 it is in my experience more up to it.

### Tank Architecture:

Once the required volume is set, the shape of the tank depends on any restrictions to its diameter or height, the type of ends (dome, cone or flat) and the efficient use of material.

When specifying the volume, consider how much *extra volume* needs to be included. This is sometimes referred to as ullage or

head space, and may include allowance for possible future needs, process events such as thermal expansion or foaming and also filling control, particularly when high speed pumping will be used. Not only is it embarrassing to have precious product spraying out through a vent or overflow but the hammer effect when the contents suddenly hit the vent could cause severe damage to the tank or filling system. It is worthwhile mentioning that the actual volume should include the bottom, seldom the top, and be measured only up to the lowest point of any overflow.

Restrictions to height or diameter are obvious. Suffice to say that you should check to ensure that any internal agitator components and the like can be withdrawn for maintenance when the tank is in service.

Whether dome, cone or flat ends are used requires a little thought and is also integrated into the cost factor. This with regard to their cost relative to each other and their cost relative to the barrel wall. Appearance is also surprisingly inherent in the choice. Dome ends are probably favoured when it comes to appearance, *but may not be appropriate*. When custom built, they are usually more expensive due to their labour content, particularly if of "[duplex](#)" grade which is prone to work hardening. Perhaps surprisingly, they may not be the best structurally either. They are the strongest option when subject to uniform internal pressure but their shape makes them less able to withstand external point loading at the centre, such as when a relatively heavy agitator is mounted there or even when an also relatively heavy maintenance engineer alights. Therefore, they will be better suited to a suspended bottom than a top. Yet how often do we see a dome top, resplendent with agitator and a cone bottom together? The cone bottom will probably have been correctly chosen for its superior draining quality, but why the dome top? Likely it looks better.

Flat ends should be constrained to bottoms so they can be supported by a sand or insulation blanket, on a plinth, of sufficient height to facilitate outlet fittings and drainage. They are neither aesthetic nor cost effective as tops except on very small tanks, because they need thickness to attain even reasonable rigidity in service. This extra thickness and their usual need of a supporting bridge often makes them more costly than domes. If height restriction forces you to opt for a flat top, I would suggest a minimum thickness in millimetres equal to the tank diameter in meters, plus a bridge if the diameter exceeds about 1.5 meters. If you also plan a heavy agitator, the bridge will need to be quite substantial and should perhaps be rigorously analysed.

With a good (minimum 35mm radius) knuckled edge, cone tops remain my personal preference. They are relatively easy to fabricate, structurally sound and of acceptable appearance. Depending on the relative material to labour price ratio, you can expect them to cost about a third less than domes. Do not however be tempted to make them with less than 15 degrees of slope angle. There is a rapid loss of inherent strength, in fact the API code does not allow it.

Since we are aiming to contain volume efficiently, we might normally expect a shape of least surface area to be the best. That of course would be a sphere but for most containment applications [spheres](#) are not as yet, cost effective. The next best choice would be a cylinder with an aspect ratio of 1, where height = diameter. However, even cones are, at best, about 25% more costly per unit area than the barrel wall. Taking required and practical thicknesses for each into account, the most cost effective aspect ratio is around 2:1 for a cone topped tank on a flat base and around 3:1 for a dome topped one.

If you are involved in the design, specification or procurement of stainless steel tanks to any significant degree, you will benefit by looking into the [features of TankGenii](#) which performs both the fundamental design and facilitates analysing their cost, from the basic information. It allows the options to be compared, almost instantaneously.

Finally, for designing any significant tank, some experience of stainless steel and its construction techniques is a recommended qualification, but needn't cost the best part of a rocket science budget.

## Probably the most common, in-service, failures occur through:

**1. Over pressurizing**, caused by rapid filling against a restricted vent condition. Sometimes an otherwise perfectly adequate vent can be restricted by a later, in-service event. Even the odd bird's nest has caused problems, so a grating should be fitted to any ventilation duct. Typically, compressive buckling failure will occur at the barrel to roof joint. The best solution is a knuckled or rolled joint, and depending on the tank size, this should never be less than 25mm or 1-inch radius, more on larger tanks.

**2. Barrel wall buckling** due to inappropriate design, particularly if hot-cold, clean-in-place, occurs against inadequate ventilation. Since steam condensation under cold spray is almost instantaneous, it is virtually impossible to design an adequate vent. A common safeguard is the inclusion of a fail stop device that requires a full sized manway to be open, before CIP can proceed. Another cause is to underestimate the effects of applied heavy roof loads, such as when a heavy agitator is fitted and inadvertently started when the tank is empty. Also consider the possibility of a plastic bag being sucked onto the vent outlet during discharge. The barrel wall must always be checked for buckling and since fabrication techniques will never produce a perfect cylinder, the application of the classic Euler formula should produce stresses not more than 60% of allowable.

**3. Leg attachment failure.** On tanks of any size, legs should always be designed so that their neutral axis meets the material of the barrel wall, as in the sketch above. The upper end of each leg thus needs to be profiled to match the bottom joint. Some designers insist on doubler plates to help spread the load. If they are fitted, they should include a small 'weep' hole. It is probably more economic, at least for the common austenitic grades say less than 6mm thick, to use extra thicknesses in the bottom and barrel wall.

It is worthwhile, for both structural and in-service hygiene reasons to **avoid any 'hard' corner joints** such as at tank wall to end joints. In the case of square tanks (rarely economic) a simple folded edge and a butt weld is better. For cylindrical tanks, the ends are best knuckled, even if 'knocked up' by hand.

I plan to add more notes, as I find the time to write them. Any appropriate [email](#) contribution or questions would be acknowledged and appreciated.