

CHEMICAL PROCESSING

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Special Report



AVOID COMMON
MISTAKES
WITH
VESSELS



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Avoid Costly Materials Mistakes

Consider a variety of factors related to materials when specifying vessels

By Chip Eskridge, Aker Kvaerner Plant Services Group, Mike James, DuPont, and Steve Zoller, Enerfab.

GONE ARE the days when most companies retain their own materials engineers/metallurgists or fabrication savvy personnel on staff. With the swings in the process industries over the past two decades, a number of companies have elected to dispense with their materials/metallurgy group and instead rely on a process engineer or a consulting metallurgist to specify materials of construction. Process engineers are specifying welded equipment more and more, and often with a lack of fabrication/materials know-how. Their approach is to rely on a fabricator to guide them through the materials decisions and to point out any oversights. Furthermore, with the widespread use of sophisticated vessel design software, many small- to mid-sized fabricators no longer employ engineers. Instead they depend on technicians to design vessels, many of whom lack the technical insight or materials background often required. In today's market, fabricators often do not have the time to challenge material/fabrication datasheet abnormalities and merely add these additional costs to their bid or choose not to bid, putting the engineer in a less competitive position. As a result, if the engineer receives a quote from the fabricator, it's weeks later, higher than expected, and with exceptions, deviations and surprises, all of which must be reconciled before proceeding. In the end, the project will have incurred unnecessary schedule delays, higher equipment costs, and then finds itself over budget and behind schedule before it gets off the ground.

You can pre-empt such problems with a bit of guidance. So, in this first article in our three-part series, we'll look at a dozen important factors to consider in materials selection. We won't get deep into the technical weeds but will provide pointers gleaned from our first-hand experiences that can help you avoid costly mistakes and delays.

1. *Select the right material.* For non-corrosive service, use design temperature to choose a readily available, cost-effective material. Table 1 offers a general guide [1, 2]. For corrosive or hydrogen service, consult a materials engineer.

2. *Avoid specifying materials by trade name.* Many projects involve replacement-in-kind of existing or similar equipment. The original design may have specified a particular brand or trade name alloy such as Hastelloy C276, Carpenter 20-Cb3, Monel or Inconel 600, and so these words are used throughout project development. Citing brand or trade name materials was necessary in the 1970s because many were unique and protected by patents. Today however, most major metals manufacturers produce their own and competitors' alloys. So, unless sticking with an exact proprietary alloy is mandated, using generic names, such as Alloy C276, Alloy 20, Alloy 400, or specifying the trade name "or equal" on the data sheet is more appropriate.

3. *Take your bid expiration date seriously.* Prices for commodity metals change daily on world metal exchanges. There was a time when mills/suppliers only adjusted their prices once per month and you could hold onto a firm quote for



MATERIAL SELECTION GUIDE							
DESIGN TEMPERATURE, °F		MATERIAL	PLATE	PIPE	FORGINGS	FITTINGS	BOLTING
CRYOGENIC	-425 to -321	Stainless Steel	SA-240-304, 304L	SA-312-304, 304L	SA-182-304, 304L	SA-403-304, 304L	SA-320-B8 with SA-194-8
	-320 to -151	9 Nickel	SA-353	SA-333-8	SA-522-1	SA-420-WPL8	
LOW TEMPERATURE	-150 to -76	3 ½ Nickel	SA-203-D	SA-333-3	SA-350-LF3	SA-420-WPL3	SA-320-L7 with SA-194-4
	-75 to -51	2 ½ Nickel	SA-203-A				
	-50 to -21	Carbon Steel	SA-516-55, 60	SA-333-6	SA-350-LF2	SA-420-WPL6	SA-193-B7M with SA-194-2H
	-20 to 4		SA-516-All	SA-333-1 or -6			
	5 to 32		SA-516 All	SA-53B or SA-106B	SA-105	SA-234-WPB	
33 to 775	SA-516 All						
ELEVATED TEMPERATURE	776 to 875	C- ½ Mo	SA-204-B	SA-335-P1	SA-182-F1	SA-234-WP1	SA-193-B5 with SA-194-3
	876 to 1,000	1 Cr-1/2 Mo	SA-387-P12- CI1	SA-335-P12	SA-182-F12	SA-234-WP12	
		1 ¼ Cr-1/2 Mo	SA-387-P11- CI2	SA-335-P11	SA-182-F11	SA-234-WP11	
	1,001 to 1,100	2 ¼ Cr- 1 Mo	SA-387-P22- CI1	SA-335-P22	SA-182-F22	SA-234-WP22	SA-193-B8 with SA-194-8
	1,101 to 1,500	Stainless Steel	SA-240-347H	SA-312-347H	SA-182-347H	SA-403-347H	
		Alloy 800	SB-424	SB-423	SB-425	SB-366	
Above 1,500	Alloy 800HT Alloy X	SB-443	SB-444	SB-446	SB-366		

Table 1. Temperature provides a good basis to select materials for use in non-corrosive service. Sources: References 1 and 2.

two to four weeks while it was evaluated. However, in recent years, metal pricing has become more sensitive to world events and more frequent and dramatic pricing swings occur. A fabricator recently reported that its quote for several large heat exchangers had to be adjusted upward \$300,000 when

the order was placed two months later — solely because of increases in stainless-steel tube cost due to a surge in nickel and molybdenum prices. In today’s market, fabricators must contend with material pricing from suppliers that can expire at the end of day. So, take your bid expiration date seriously.



On the other hand, carbon-steel costs, while rising, tend to be less volatile than those of alloy steels; so it's safe to assume normal escalation during the project development/estimating phase.

4. *Specify dual-grade stainless steel.* There's much confusion about "L" grade, straight grade, and dual-grade 300-series austenitic stainless steels — in particular, Types 304 and 316. Engineers often specify lone "L" grade materials such as Type 304L or 316L on data sheets. The reason: during welding, such low-carbon stainless steels resist chromium carbide sensitization that can lead to preferential heat-affected zone corrosion in some corrosive processes [3]. However, L grade stainless steels have lower strength than straight (non-L) grade stainless steels and the ASME code penalizes the design 15% to 20% with additional shell thickness and lower flange rating [4, 5]. What's important to understand here is that a lot of the weldable forms of stainless steels (Types 304/316) produced today in the U.S. come dual certified as Type 304/304L or Type 316/316L. These steels have the higher strength of straight-grade stainless steels and have the superior resistance to sensitization during welding of the L grade stainless. This is because they're now made in a melt furnace process that substitutes nitrogen for carbon. Nitrogen strengthens the steel (like carbon) but won't promote sensitization during welding. Fabricators often will purchase dual certified materials but will use the lower strength values of the L grade material in their calculations if you specify L grade material on your data sheet. This results in unnecessarily adding extra wall thickness and possibly crossing into a higher flange rating.

5. *Properly use corrosion allowance.* This allowance adds extra thickness to account for uniform metal loss over the equipment's expected service life. The key word here is uniform. Mild carbon steel uniformly corrodes due to the galvanic cell potential of the interlaced ferrite-cementite grain structure, called pearlite (Figure 1). Specifically, there are millions of anodic (ferrite) and cathodic (cementite) sites that in the presence of moisture provide the four necessary elements for corrosion (anode, cathode, metallic bridge, and electrolyte). Alloyed materials in aggressive service will also uniformly corrode because their strong protective oxide layer is breached. Specifying a cor-

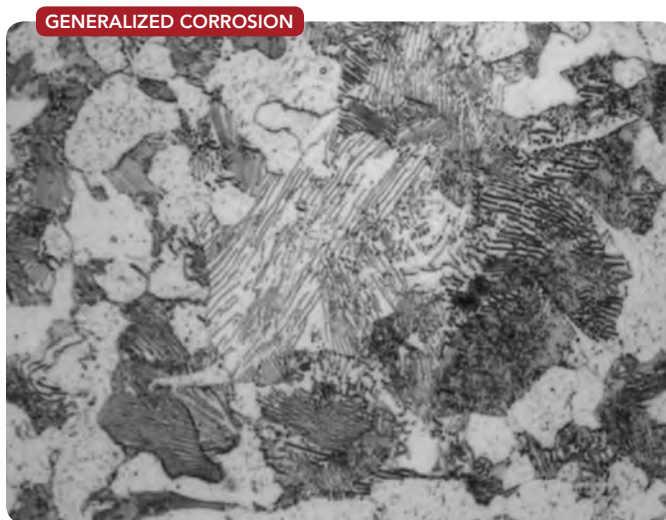


Figure 1. Carbon steel corrodes uniformly, so a corrosion allowance can be used. Photo courtesy of Matco Associates, Inc., Pittsburgh, Pa.

rosion allowance for these situations is appropriate. However, many alloys, such as austenitic stainless steels, duplex stainless steels, nickel alloys and titanium, are more resistant to uniform corrosion and tend to corrode locally — that is, pit or crack. So, it's less appropriate to specify a corrosion allowance for these materials in relatively benign processes. Furthermore, as the thickness of the stainless steel increases, the more likely it can become sensitized from repeated heat input during multi-pass welding. While a mere $\frac{1}{8}$ -in. corrosion allowance doesn't seem like much, it potentially can require a disproportional number of additional weld passes (and cost) depending on the weld procedure used.

A corrosion allowance isn't recommended for materials that are susceptible to stress corrosion cracking (Figure 2) in a given process. For example, for protection against chloride-induced stress corrosion cracking, it would be more appropriate to upgrade the material of construction to a duplex, lean duplex or super duplex stainless steel, rather than add a corrosion allowance to austenitic stainless steel. Specifying some duplex alloys actually can provide a cost savings because they have 20% to 35% higher allowable code stresses, resulting in a thinner wall vessel [4].



STRESS CORROSION CRACKING

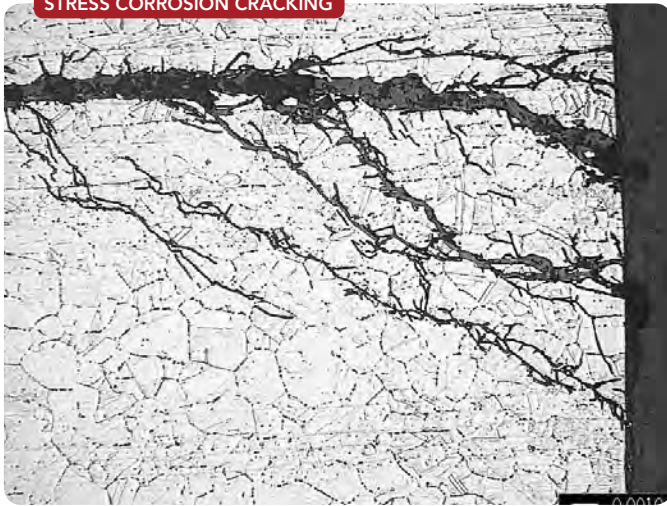


Figure 2. Many stainless steels and alloys resist uniform corrosion but are susceptible to localized attack. Photo courtesy of Matco Associates, Inc., Pittsburgh, Pa.

In summary, when uniform corrosion is expected, specify a corrosion allowance. When localized corrosion is expected, investigate other corrosion protection schemes.

6. *Know the relative cost of materials.* It's common knowledge that stainless steel is more expensive than carbon steel. However, the cost difference between a 300-series stainless steel and a lean duplex, duplex or super duplex stainless steel — or between stainless steel and high nickel alloys or zirconium — is less obvious. It's helpful to have a rough idea of the relative costs of materials so that meaningful discussions can take place during project development. Table 2 lists the relative costs (excluding fabrication costs) of commonly used materials. Note, though, the cost and delivery for any given alloy can vary greatly from vendor to vendor based on current stock and availability. It's always good practice to question the fabricator about how many material suppliers it got quotes from or to make independent inquiries into material costs, especially if you intend to sole source.

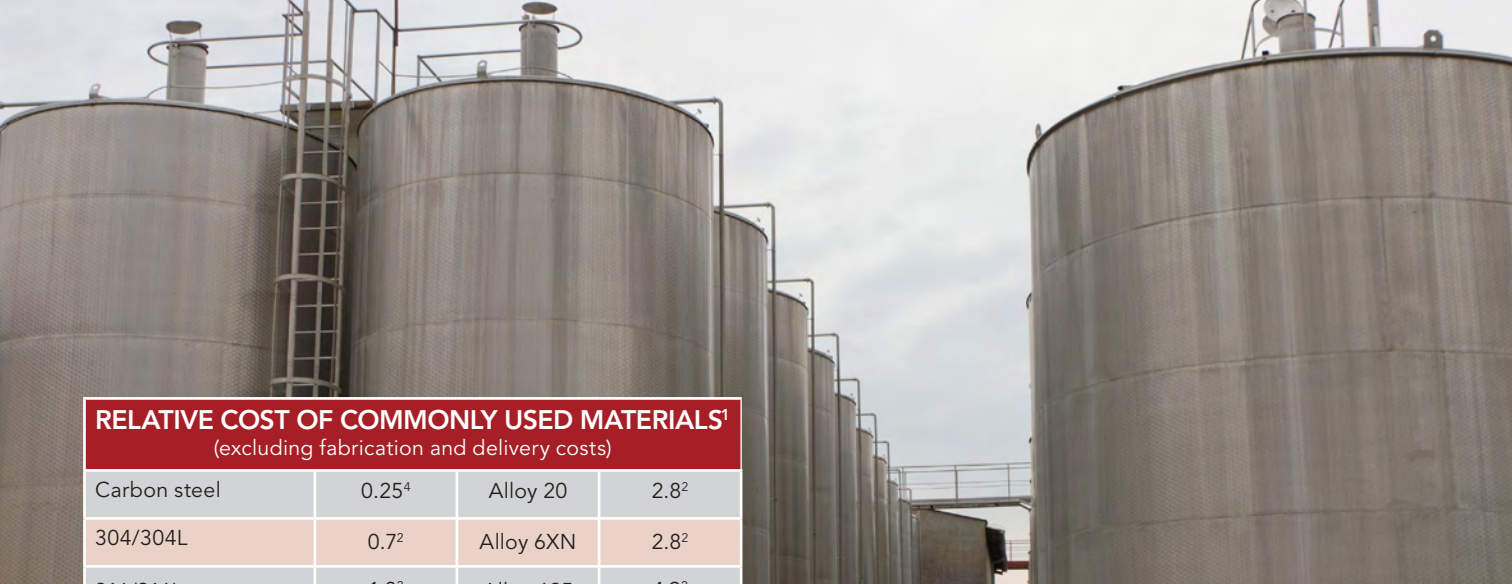
7. *Keep critical metal temperatures in mind.* We learn at an early age that water boils at 212°F (100°C) and freezes at 32°F (0°C) at atmospheric pressure. Engineers know that as water crosses these points, its physical and thermodynamic proper-

ties change and a new set of conditions apply. Many engineers, however, don't appreciate that solids also have temperature limits that, when crossed, create problems for the designer and thus can add additional steps (and cost) to the fabrication process. The most common material limit occurs at low temperature and is called the ductile-to-brittle transition temperature. It's an issue with carbon steels and other metals with a body centered cubic structure and manifests as a loss of ductility — i.e., the metal becomes brittle. Stainless steels, nickel-base alloys, aluminum, and copper (e.g., FCC and HCP) also have limits but at temperatures below -325°F. Carbon steels's ductility decreases with temperature and as carbon content increases. The ASME code protects against brittle failures by limiting carbon content to no more than 0.35% and by mandating the material either to be heat treated or impact tested when the ductile-to-brittle transition zone is approached. For thin-wall vessels, common carbon steel materials (SA-105, SA-106, SA-516-70) require heat treatment or impact testing at design temperatures below -20°F [6]. So, when possible, specify a warmer minimum design metal temperature to avoid these costs.

Below -55°F, all welders and weld procedures require a special qualification, which many fabricators may not have developed. For API-650 tanks, -40°F is the critical temperature where impact testing and welder re-qualification are required. For ASME B31.3 pipe, -50°F is the limit. Temperature limits are a function of weld thickness; the above values are for $\frac{3}{8}$ in. and thinner. As weld (wall) thickness increases, these temperatures rise, that is, get warmer. The key here is when specifying carbon steel at low design temperatures, crossing over a critical metal temperature by 1°F will add cost to an ASME code vessel, heat exchanger, piping system or API-650 storage tank.

8. *Consider coatings.* The practice of coating isn't new but remains under-utilized [7]. When quoting, fabricators often don't suggest coatings, though, because it's the owner's responsibility (per code) to specify materials of construction. Plus it means adding an additional manufacturing step (and thus one to four weeks) to an often already tight schedule. Furthermore, most fabricators really aren't expert in coating selection.

Proper selection of a coating that will resist the process



RELATIVE COST OF COMMONLY USED MATERIALS¹
(excluding fabrication and delivery costs)

Carbon steel	0.25 ⁴	Alloy 20	2.8 ²
304/304L	0.7 ²	Alloy 6XN	2.8 ²
316/316L	1.0 ²	Alloy 625	4.9 ²
2101 Lean Duplex	0.6 ²	Alloy 600	5.2 ²
2205 Duplex	1.0 ²	Alloy C276	5.0 ²
2507 Super Duplex	1.6 ²	Alloy 400	3.3 ²
Titanium – Grade 2	4.5 ³	Alloy 800	2.5 ³
Zirconium	8 ⁴	Alloy C22	5.1 ³

¹ Pricing based on 10,000-lb. order of plate material and does not include fabrication costs.

² Courtesy of Rolled Alloys. Note: ratios are subject to change and are for estimating purposes only.

³ Pricing obtained from major supplier which chose to remain anonymous.

⁴ Pricing based on survey of recent projects.

Table 2. Carbon steel can cost from about one-third to one-twentieth that of other metals.

is key. Coatings have limitations, primarily temperature. Many are restricted to 200°F to 300°F; they have a different coefficient of thermal expansion than the base metal they cover, which may make them more susceptible to separation over their service life. Like metallic vessels, coated equipment also requires periodic inspections. However, for moderate design temperatures, coating a carbon-steel vessel can be much more economical than purchasing a high alloy vessel or clad carbon-steel vessel. For instance, estimates for ethanol plants show savings of as much as 35% for coated carbon steel tanks compared to stainless ones.

9. *Check into non-metallics.* Many applications don't really require a metal tank. High density polyethylene (HDPE) tanks come in a wide range of sizes and configurations. From 200 to 12,000 gallons, these tanks cost a fraction of metal ones. The major disadvantages of HDPE tanks are pressure/temperature and anchoring limitations. They can't be rated for pressure/vacuum nor can they be designed with load-bearing attachments or platforms. Nozzles can be added to customize the tank but also with limitations. Tanks made of reinforced thermoplastic resin (RTR), also referred to as fiberglass-reinforced plastic (FRP), offer a more robust alternative. They overcome the limitations of HDPE tanks and can be designed/fabricated to either manufacturer's standards or to ASME RTP-1 — the later

requiring a bit more testing, inspections and documentation, which all come at a price. Above 15-psig design pressure (i.e., for pressure vessels), ASME Section X can be used. However, only a handful of manufacturers in the U.S. can provide a Section X Stamp.

10. *Use the extra metal to your benefit.* After design parameters are set, the fabricator will determine the required wall thickness. For instance, a 150-psig, 300°F, 4-ft.-diameter carbon-steel vessel, spot X-rayed with $\frac{1}{16}$ in. corrosion allowance, will have a required shell thickness of 0.326 in. The fabricator will purchase the next thicker commercially available plate, which would be $\frac{3}{8}$ in. (i.e., 0.049-inches thicker than required). This additional wall thickness can be used in one of three ways, and you have a control over its use.

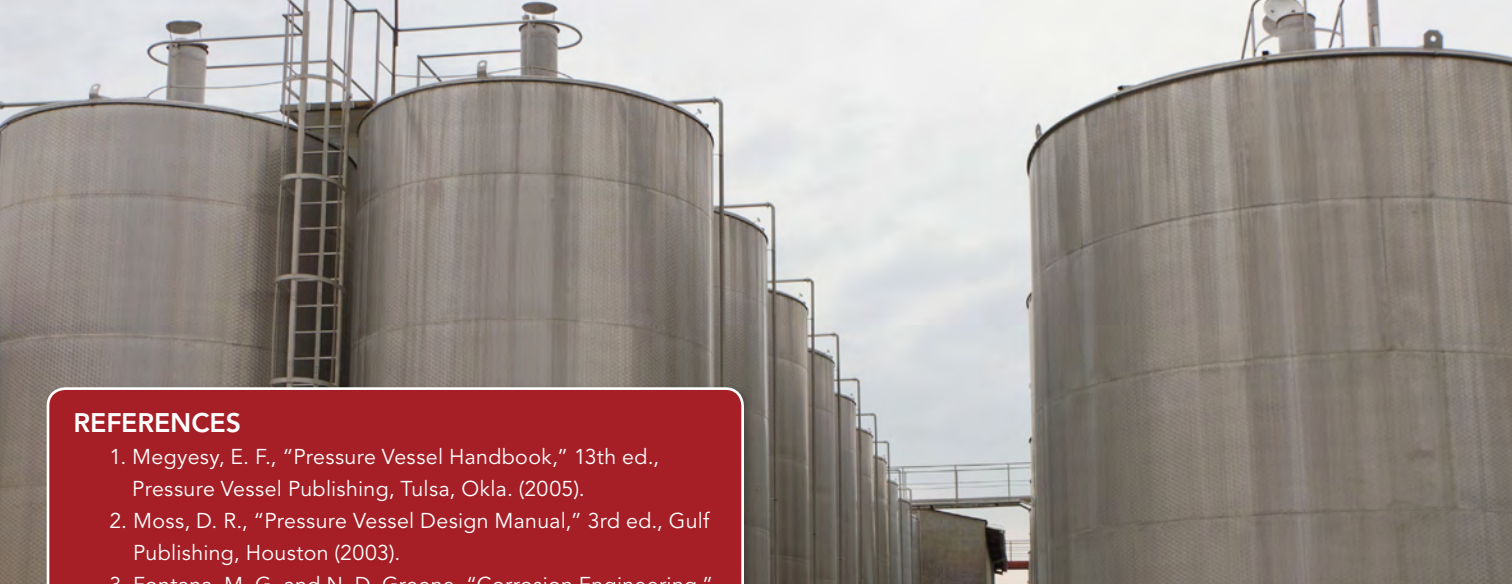
Option 1 is to use the extra metal to rate the vessel with a higher Maximum Allowable Working Pressure (MAWP) than the required design pressure, 178 psig instead of 150 psig here. This choice favors continuous processes, and gives production the option to operate the vessel harder (i.e., at higher pressure).

Option 2 is to set the MAWP equal to design (150 psig) and use the extra metal as additional corrosion allowance ($\frac{1}{16}$ in. plus 0.049 in.). This will give you a longer service life, which favors batch processes.

Option 3 is to set MAWP equal to design (150 psig) and use the extra metal to obtain a higher maximum design temperature. This option favors processes that have automatic temperature trips, such as exothermic reactors and fired heaters, and avoids possible fitness-for-service determinations if an excursion should occur.

The option selected can be changed later by performing a re-rate, although choosing Option 2 or 3 would require a new hydrostatic test. Also, when opting for Option 1 or 3, watch crossing into the next higher flange class.

11. *Understand the difference in surface treatments.* Pickling and passivating are surface treatments of carbon steel and corrosion resistant alloys that use acid or other solutions to remove surface oxides or improve corrosion resistance of the metal to a given process. Pickling is performed using a strong oxidizing acid, such as nitric or hydrofluoric acid, to remove



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the outer oxide layer. All stainless steels are pickled to various degrees after they're made. Approximately 25 mils to 50 mils (one mil equals 0.001 in.) of oxide is removed during pickling. Carbon steels typically aren't subject to pickling but are supplied in as-formed condition. On the other hand, passivation of stainless steel is performed using a weaker acid, such as weak nitric or citric acid, that preferentially removes the more easily extracted iron and nickel atoms from the oxide layer, leaving behind a chromium-oxide-rich surface. Usually less than 2 mils of metal are removed. Thus, after passivation, stainless steel has a bright finish. Pickling typically is performed at the mill or by a material supplier while passivation usually is done by the fabricator after the vessel is complete.

Fabricators that handle both carbon steel and stainless steel carry an inherent risk of contaminating their stainless steel by picking up free iron from tooling. Iron from carbon steel can be embedded in the stainless steel surface from the forming process (e.g., contaminated plate rolls), grinding wheels, machining operations and via airborne particles if not carefully controlled. It's good practice to passivate stainless steel vessels if a fabricator handles both carbon steel and stainless steel or if surface iron contamination and its deleterious effects on corrosion resistance can't be tolerated. Another way to avoid this problem is to only allow fabricators who specialize in stainless steel or higher-end alloys to perform the work. Often, a shop that specializes in alloy materials will turn down bid requests for carbon steel work

because of its low-end nature and the risk of contamination of alloy work.

12. Pay attention to surface finish. Polishing usually is specified for process reasons, although it can be very effective in improving equipment fatigue life in cycle service. Unless directed otherwise, fabricators usually will provide a mechanical polish that will leave very fine scratches, small burrs, and a less-than-uniform microscopic surface appearance. Often this is sufficient and cost effective for a surface finish no smoother than 10 Ra (average roughness or the measure of the peaks and valleys with respect to the mean surface). On the other hand, electro-polishing generally is more cost effective below 10 Ra. Electro-polishing essentially is controlled uniform corrosion. The surface is first mechanically polished (to a rougher finish than the specified final finish) and then placed in an electrolytic solution. Sacrificial cathodes are strategically placed in the solution, thereby causing the vessel to be anodic. A voltage is applied, resulting in a small amount (1 mil to 5 mils) of surface metal (and debris) being uniformly electro-chemically removed. Iron and nickel are more anodic than chromium and are removed more, leaving the surface chromium-rich and very shiny. This operation simultaneously performs a surface passivation. Electro-polishing is a superior finish but comes with a heftier price tag; it typically costs \$10,000 to \$20,000 more than mechanically polishing, depending on the size of the vessel.

Be precise when specifying the quality of finish. A U.S. supplier will interpret 10 Ra as micro-inches while a non-U.S. supplier may be thinking micro-meters. Of course, 10 Ra micro-inches is vastly different than 10 Ra micro-meters.

The next article in this series will address fabrication issues such as head, jacket and tubing choices, how to reduce fabrication costs using radiography and related topics. ●

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Avoid Costly Fabrication Mistakes

Keep in mind eleven points related to fabrication to ensure suitable vessels

By Chip Eskridge, Aker Kvaerner Plant Services Group, Mike James, DuPont, and Steve Zoller, Enerfab.

“TWENTY-TWO WEEKS after receipt of approved drawings.” How often do you see this in a quote and don’t understand why it takes so long to fabricate equipment. With the loss of in-house fabrication-savvy personnel over the last two decades, many owner/operators and engineering companies often write purchase specifications that can add unnecessary time and cost to a project.

So, in this second article in our series (see above for first article), we’ll provide pointers on how to avoid delays and achieve savings in the fabrication process. Moreover, we’ll cover techniques that, if schedules permit, can improve vessel reliability and thus forestall costly repairs down the road.

1. *Know your fabricator’s limitations.* Nearly all ASME-stamp-holder fabricators are qualified to weld carbon steel and stainless steel; some are qualified for high nickel. But when ordering vessels in an exotic alloy (e.g., titanium, tantalum or zirconium), another niche material (e.g., copper, aluminum or chrome-molys), or made via a specialized process (such as clad overlays), do your homework. Welding is a skill and all metals don’t weld in the same manner or require the same skill level to produce a quality weld. If a welder hasn’t used a specific welding process in the last six months, the ASME Code requires the welder to requalify. Therefore, strive to find fabricators that regularly weld the material you need. Call around before making your bidders’ list and request references or a rundown on recently fabricated equipment. This will eliminate “no bids” and less qualified fabricators.

Additionally, it’s a mistake to view a heat exchanger as just another vessel. Heat exchangers are “performance” vessels and “mechanical only” fabricators don’t have the necessary thermal performance software to appropriately analyze your process data to provide an optimum design. It may seem safe to award mechanical only fabricators “replace in kind” orders without performing a new thermal analysis but you may have missed an opportunity to improve your plant’s performance. Also, heat exchanger fabrication requires special processes such as tube-to-tubesheet welding and tube rolling, which depend upon acquired skills and knowledge. So, fabrication should be left to those companies well versed in manufacturing and analyzing heat exchangers.

2. *Be aware of wide loads.* A wide load is a generic term for over-the-road shipments whose width exceeds 8 ft. or height exceeds 13.5 ft. (Length and weight restrictions also apply.) Western U.S. states have a legal height limit of 14 ft. When exceeding these limits, state (and sometimes city) “wide load” permits must be obtained — requirements vary by state — and driving restrictions such as dawn-to-dusk curfews are imposed. It’s always easier to obtain permits for excess width; states usually require at least one escort vehicle. When height limits are exceeded, utility company involvement and police escort become the rule rather than the exception.

Shipping arrangements are handled by the fabricator but it’s useful to know where the break points are for per-



mits when developing your design. *In general, a vessel 12-ft. diameter (or less) can be shipped with minimal permitting and attendant costs.* This accounts for the deck height of a trailer and can mean the trailer must occasionally bypass an overpass. For larger diameters, the permit process gets more involved. A “stick trip” (travel of the entire route by a vehicle with a mounted stick to verify clearance prior to actual shipment) often is involved and the design of the equipment (i.e., location of nozzles and other external attachments)

will impact the permit. If possible, orient attachments to minimize the load height. Purchase vessels of this size and magnitude from fabricators knowledgeable about handling wide loads. Experienced personnel will recognize if a vessel can be shipped in large sections (Figure 1) and then welded together and tested in the field.

As the vessel’s diameter, weight or length increase, shipping costs can become an overriding factor on which fabricators you invite to bid. *Vessels more than 16-ft. diameter can only be trucked a short distance economically; hauling by either rail, barge, or shop fabricated in pieces and field assembled becomes the norm. Between 12-ft. and 16-ft. diameters, it becomes very situational, so chose your bidders wisely.* Moving a large vessel from the fabricator’s shop through a city to a major interstate or river can cost \$10,000/mile and usually the most direct route can’t be taken. Factor in geographic location. It’s easier to

THE IMPACT OF RADIOGRAPHY LEVEL

JOINT LOCATION	LINEAR FEET OF WELD	CASE A	CASE B	CASE C	CASE D
		RT-1 (Full)	RT-2 (Full)	RT-3 (Spot)	No RT
Long seam	16	16	16	1	0
Round seam	75	75	3	3	0
Large nozzles	5	4	0	0	0
Total number of shots		95	19	4	0
Cost @ \$75/shot		\$7,125	\$1,425	\$300	\$0
Resulting shell thickness		½-in.	½-in.	⅝-in.	¾-in.

Table 1. The level of X-raying directly affects the necessary thickness of material, as illustrated here for an 8-ft. diameter, 16-ft. long shell vessel with the same design pressure and temperature and with internal pressure governing the design. (Note: costs are approximate and can vary greatly depending on set-up costs, wall thickness (i.e. exposure source/time) and film type/length.)

ship wide loads in Western U.S. states than in the more congested Northeast.

3. *Move carefully with used and relocated vessels.* Several suppliers specialize in used equipment; check the classified ads in *Chemical Processing* and other magazines. Such vessels can be purchased at a discount and are available for your inspection if desired. Also, some operating companies often consolidate operations into a single location, which can lead to relocating vessels and other major equipment across state lines. When relocating a used ASME-code vessel to your state, first check with the office of the Chief Boiler Inspector in your state capital. Many state laws require pre-approval and inspection by that office before a vessel can enter the state. Failure to comply with state law carries monetary penalties.

4. *Pay attention to internal coils.* Internal coils can be included as part of an ASME vessel but aren’t required to



Figure 1. This wide load represents only one section of a large vessel that will require field assembly.

be code stamped. It's good practice to include internal coils in the pressure vessel scope so that strict quality control procedures are followed and third party inspections are performed. Internal coil failure can lead to forced shutdown, off-spec product quality and possibly safety concerns.

For internal coils, specify butt-type joints with 100% radiography and avoid internal flanges, threads, couplings and socket-type joints. Fillet welds, which are associated with socket joints, are more prone to fatigue failures and aren't easily radiographed. Return bends (180 deg.) and coils bent from pipe improve reliability by minimizing internal welds and fittings, which are the primary cause of coil failure. A heavy corrosion allowance is suggested. A coil will be buoyant if steam is used as a heating medium (because its specific gravity is less than

that of the product); so, design for both hold-down and thermal growth.

5. *Understand the role of code inspectors.* Vessel inspections are performed in the shop by Code Authorized Inspectors, commonly referred to as AIs. They aren't employed by the fabricator or vessel owner but by the fabricator's insurance company or, sometimes, by the local jurisdiction (i.e., state or city government). Their purpose is to confirm vessel safety — not absolute quality — by ensuring the fabricator has followed the rules and procedures of the ASME code. They check to ensure the materials, welding and testing meet the rules of the code for which the vessel was designed and major dimensions, such as vessel diameter and overall length.

It's up to the owner or designer to perform quality checks. AIs don't check for all nozzle locations or measure support lug location or many of the minor dimensional requirements (e.g., nozzle projection) needed for your project. They don't check for special surface finishes, internal or external coatings or contractual requirements written in requisitions and purchase orders. They will check for special testing and examination requirements if specified on the fabrication drawings. If dimensional accuracy or special coatings and finishes are essential for your project, it behooves you to schedule shop inspections.

6. *Address documentation and archiving.* How many times have you needed to replace a 20-plus-year-old vessel and worried about finding adequate documentation in the company files? Often only a drawing can be located; the code calculation, material certifications and testing records are long gone. The good news is that a vessel's drawing is enough for a fabricator to provide you with an adequate bid — keep in mind, though, many of the fabrication practices and materials of the past are now obsolete. If documentation



can't be found, there are alternatives you can explore in lieu of starting from scratch.

Perhaps the original fabricator still has the print. For ASME-stamped equipment, fabricators are required to retain what's called the "Manufacturer's Data Package" for five years, though many will hold on to this information much longer. However, over the last 20-plus years, substantial consolidation and attrition have reshaped the vessel industry. So, while it's worth trying, realistically you may find recovering information this way futile.

Your last chance for digging up old information is contacting the National Board in Columbus, Ohio. Besides training and accrediting code inspectors and auditing code stamp holders, it stores decades of manufacturers' data reports (U-1 forms). A data report is much like the birth certificate of the vessel; it provides a wealth of information, such as major dimensions, materials of construction, shell and head thicknesses, nozzle construction, radiography and hydrotest pressure. To find out if the U-1 form is available, first check the vessel's code nameplate in the field. If there's a NB number stamped on it (or on the drawing), simply call the National Board, provide this number and the manufacturer's name, and within days, for a nominal fee (i.e., \$20 to \$50), you'll have the data form faxed to you. (Same day service is available for a small additional fee.)

Such difficulties teach an important lesson. Be sure when purchasing vessels to include any special information (e.g., company purchase order, equipment number, special heat treatment or nondestructive evaluation) somewhere on the drawing because 20-plus years from now, a drawing may be all your successor is able to locate. Also, register and archive your vessel with the National Board — most states require registration [1],

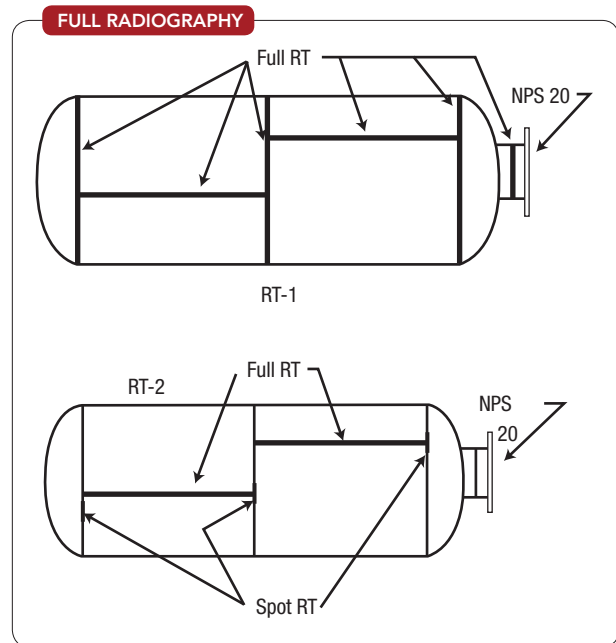


Figure 2. RT-2, which uses both full and spot X-raying, can enable savings in materials and fabrication.

but it's good practice even where not mandated. The cost is typically less than \$50 and your fabricator will handle the registration.

7. More (radiography) is less (metal). The continuing climb in alloy prices necessitates a paradigm shift in thinking. It's becoming more economical to specify more radiography (i.e., X-raying), not so much for joint quality but to reduce wall thicknesses.

Vessel data sheets require the engineer to specify the amount of radiography required for the service. Typically the choices are "full," "spot" or "none." This tells the fabricator how much X-raying it should estimate for the job



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but, more importantly, it affects the required shell and head thicknesses based on ASME code rules. The ASME Code recognizes two types of "full" radiography, RT-1 and RT-2. RT-2 *vessels provide the best balance in terms of risk and design economy* [2].

"Full radiography" indicates to the fabricator that "all" pressure-retaining butt joints in the main vessel (excluding small diameter and thin wall nozzles) are to be X-rayed. This can be costly but actually can provide substantial savings when fabricating vessels from expensive materials by avoiding any penalty in vessel shell/head thickness. In ASME Code terms, this amount of X-raying is referred to as "RT-1" (Figure 2) and is stamped as such on the code nameplate.

Full radiography often is confused with 100% radiography, with the later requiring X-raying of all butt welds, including small diameter and thin wall nozzles. Lethal services require 100% radiography. A savvy designer knows the difference and may specify 100% in non-lethal services where process reliability is crucial (e.g., continuous processes vs. batch) or where accessibility to certain joints will be restricted and hamper future repairs (e.g., jacketed designs).

"Spot radiography" is a common choice in the chemical industry for normal service fluids. It involves a 6-in. shot for every 50-ft. of weld seam at locations specified

in the code and incurs only a slight, 15%, wall thickness penalty. ASME designates this as "RT-3." On small and low hazard vessels, often no radiography or "none" is specified; this will increase the wall thickness another 15% (i.e., 30% thicker than for full X-ray).

RT-2, which is a hybrid between RT-1 and RT-3, seldom is specified by owners but offers economic advantages by permitting thinner wall vessels (Table 1). All long seams are fully X-rayed (similar to RT-1) and the longer circumferential seams are only spot X-rayed (similar to RT-3) with one extra quality shot at the T-junctions (Figure 2). Why RT-2? The long seam is stressed two times higher than circumferential seams for most vessels where wind load doesn't govern design (i.e., vessels under 50-ft. tall). So, have your fabricator quote an optional price for RT-2 on vessels constructed of alloy materials. A vessel engineer can work you through the rules.

In summary, full radiography was once considered only necessary for vessels containing highly hazardous processes or requiring maximum reliability. However, with the ever increasing cost of alloys, consider specifying RT-2 radiography for all welded equipment as a potential way to achieve material/fabrication cost savings.

8. *Release the head for fabrication ASAP.* Often, the first thing fabricators do when they get the go-ahead to begin fabrication is to order the heads. The design pressure, temperature, vessel diameter, material of construction, and amount of radiography are all that are needed to release the heads for forming. The fabricator usually will wait until the heads arrive (two-to-four weeks later) and check for dimensional accuracy before rolling the shell. So, to ensure the project remains on schedule, don't delay releasing the heads while you're finalizing nozzle sizes and locations. A few major fabricators have the equipment to form their own heads. Knowing this ahead



of time can be helpful if the project is schedule driven.

9. *Get anchor bolt templates.* Templates supplied by the fabricator, cut to match the equipment's actual anchor bolt pattern, can be very useful to your on-site construction contractor when project field schedules are tight. In these situations, concrete pads with anchor bolts often are poured and pre-set before the vessel arrives. If time allows, a contractor may wait for the vessel to accurately determine exact anchor bolt locations before pouring the pad. However, this has obvious time and cost consequences (e.g., crane rental). So, when warranted, have the fabricator provide (with the vessel or ahead of time) a 1/4-in.-thick metal or wood template of the vessel's actual anchor bolt circle pattern. As bolt circles get larger, base rings become thicker and the ability to correct out-of-tolerance bolt patterns becomes more difficult. Small diameter vessels with welded-on legs are just as susceptible to arriving with unacceptable tolerance deviations because they are mounted independent of each other.

10. *Opt for dual stamping.* The code allows vessels to be dual stamped (i.e., separate code nameplates for two sets of design pressure and temperature). Pilot plant vessels are good candidates because they potentially may handle an endless number of products/processes. The drawback to dual stamping is if both stamped pressures are over 15 psig, then the vessel would require over-pressure protection, i.e., two separate pressure-relieving devices — but this inconvenience can be minimized by installing a three-way full-port selector valve. It's possible to add a second nameplate after the equipment has been placed in service by "R-Stamping," but all the code requirements must be met for the alternative design conditions.

11. *Insist on a mechanical guarantee.* Fabricators aren't responsible for classifying a vessel for lethal service, select-

ing materials of construction or determining corrosion allowances. Nor are they required to provide you with a vessel free from imperfections. They merely need to follow the ASME Code rules and perform the necessary calculations, inspections and tests. The vessel you get won't be perfect. Therefore, add language in the purchase order requiring a limited mechanical guarantee. Fabricators won't agree to a lifetime guarantee but will accept one for a set period to repair failures due to mechanical workmanship not caused by neglect or mis-operation. A common term is 18 months after receiving the vessel or 12 months after placing it in service, whichever comes first. Insist that any repair performed resets the 12-month clock.

If the vessel maker completely overlooks a fabrication requirement listed in the specification that affects reliability, then push for a longer service guarantee, such as five years, for the missed item (e.g., rounded corners on pads that cause stress risers and can lead to premature fatigue cracking). You are in an excellent negotiating position once a vessel is fabricated with a design specification error and final payment is pending.

The last part of this series will delve into design issues, such as choosing the appropriate pressure and temperature, head and jacket choices, and how to design a rectangular tank. ●

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Avoid Costly Design Mistakes

Cutting the wrong corners can incur significant costs over a vessel's service life

By Chip Eskridge, Aker Kvaerner Plant Services Group, Mike James, DuPont, and Steve Zoller, Enerfab.

“JUST BUILD it to the Code.” That's the most common response you hear during a design review that involves purchasing a new pressure vessel. Yet, there're as many choices within the ASME code as there are when searching for your next vehicle. Smart choices can save you money during fabrication as well as over the lifecycle of the vessel. So, here, we'll attempt to condense the 5,000+ pages (50+ lbs) of the ASME Boiler and Pressure Vessel Code, or “the Code,” as it's affectionately known, into a simple guide when specifying vessels, heat exchangers and tanks. We'll focus on 10 key factors.

1. *Inside diameter versus outside diameter.* Process engineers often specify a vessel's diameter based on inside diameter (ID) to ease volumetric calculations. This also will simplify fabrication/installation of internal hardware (e.g., support rings, trays, distributors, etc.). However, sometimes specifying a vessel based on outside diameter (OD) is better. For instance, after a purchase order is issued, heads are the first things ordered — obtaining off-the-shelf heads is more likely if specified by nominal pipe sizes (NPS), which is OD from diameters 14 in. to 36 in. (For thin-wall heads, i.e., 2-in. thick or less, choosing ID or OD makes little difference, while most heads more than 36 in. are custom made.) As heads get thicker, hot forming is necessary and dies are based on ID. Thick, hot formed heads can be OD ordered but require an extra manufacturing step.

2. *Design pressure and temperature.* Required wall thickness is more sensitive to pressure than temperature. Therefore, specifying a design pressure 100 psig over the maximum

operating pressure is more costly than specifying a design temperature 100°F higher than what's needed. A design pressure of 25 psig–50 psig above that at the maximum operating/upset condition and not less than 90% of maximum allowable working pressure is industry practice. Keep design temperature to no more than 50°F–100°F above that at maximum operating/upset conditions. Also, watch your design pressure and temperature so as not to cross into the next higher flange class. Check ASME B16.5 for design temperature and limitations for flanges.

3. *Vacuum rating.* Although current project needs may not require a vessel to be vacuum rated, over its lifetime, changes in feedstock, products and technology will occur. A large number of re-rates now performed are on older vessels originally not documented for vacuum that now require it due to process changes. Many new vessels will rate for full vacuum and all for partial vacuum. So have the fabricator evaluate your proposed design for vacuum and apply it to the code stamp. With today's software, this calculation can be easily performed and at no cost. You may get full vacuum rating without any modifications — if not, consider spending a little extra now by welding on a stiffening ring and a couple of re-pads to avoid having to go through the cumbersome re-rate process and field hydro-test down the road. (See www.ChemicalProcessing.com/voices/plant_insites.html.)

4. *Head choices.* Functionality, not cost, should determine head choice; so understanding the functional differences is crucial. Dished heads for ASME vessels typically are available in three styles; elliptical (2:1), flanged and dished (F&D), and



hemispherical (hemi-heads). Under 600 psig, elliptical heads are the most common and least expensive in terms of wall thickness and forming costs. Above 600 psig, hemi-heads are economically attractive due to their inherent low-stress shape; below 600 psig, they are the most expensive choice because they are constructed of welded, segmental parts not a single piece. F&D (torispherical) heads have the lowest profile (height/diameter ratio) and compete well with elliptical heads under 100 psig, although they have half the volume. The low profile of the F&D head only is advantageous when top head accessibility is required for maintaining instruments, agitator, etc., or when space is limited below or, for horizontal vessels, to the sides. For vessels 24 in. or less, off-the-shelf pipe caps (elliptical) provide the most economical design.

Flat heads have very limited use for pressure vessels more than 24 in. in diameter. Because of their flat geometry, they offer far less resistance to pressure than elliptical and F&D heads of the same thickness. Engineers occasionally will specify a flat head, but this practice is uneconomical for pressures above 15 psig–25 psig. If a large diameter flat head is necessary for code equipment, then stiffening the head with structural I-beams is possible but requires sophisticated finite elemental analysis, a skill that not all fabricators possess.

5. *Jacket choices.* Consider functionality, not cost. Choosing the correct jacket is paramount to achieve process needs. The three common types — conventional, half-pipe and dimple — offer advantages and disadvantages with respect to process parameters, reliability and cost [1] (Table 1).

6. *Cones.* Conical sections (cones) are needed where there's a change in diameter or as a bottom head, e.g., for a bin or hopper. The rule here is keep the transition angle (referred to as the half apex angle) to 30° or less unless process conditions

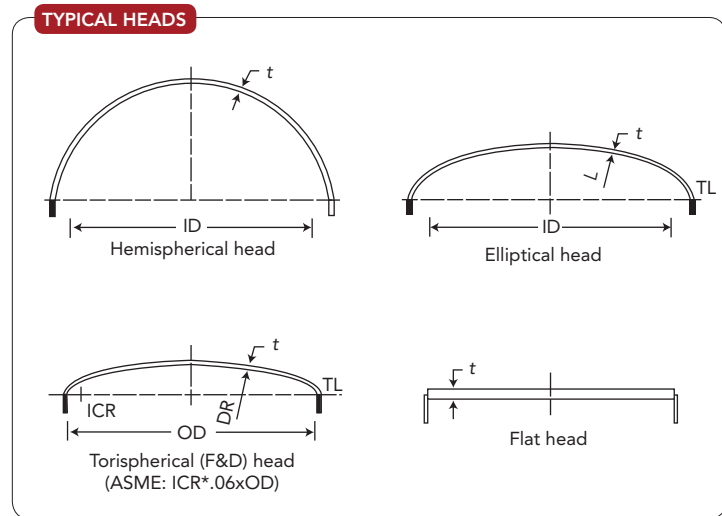


Figure 1. Curved heads predominate and avoid the pressure limitations of flat heads.

govern, as exceeding 30° adds costs. The ASME Code demands the piece have a rolled knuckle at both ends when the transition is greater than 30°; bending stresses complicate the calculation, putting it beyond the skill of many fabricators.

7. *Nozzles loads and projections.* The ASME Code [2] requires consideration of all loads. Designers routinely perform wind and seismic calculations but too often overlook nozzle loads due to thermal pipe stress — these can cause visible damage. If attached piping operates at more than 200°F we suggest providing the fabricator with the nozzle loads in Table 2 for a reasonable nozzle stiffening. By providing a reasonable nozzle load, the vessel fabrication and piping design can proceed in parallel and avoid pipe stress/nozzle loading issues months into fabrication.

Also, nozzle projections below the support ring or lugs shouldn't stick out further than the support bolt circle or



HOW TYPES OF JACKETING COMPARE		
TYPE OF JACKETING	ADVANTAGES	DISADVANTAGES
Conventional (full enclosure)	High flowrates Low pressure drop More coverage than other jackets	Poor heat transfer coefficients and heat transfer due to low velocities Thick wall required to withstand jacket pressure* Bypassing and dead zones — resulting in poor heat transfer Highest cost
Half-pipe	High flowrates Low pressure drop Suitable for dirty fluids and no bypassing High jacket pressure with no adverse effect on inner vesselwall thickness Good fatigue resistance (cyclic service) if applied with full penetration welds	Difficult to fabricate around nozzles Incomplete coverage More expensive than dimple jacket unless spacing is kept to 1 in. or less
Dimple	Least expensive Ability to withstand high pressures Easy to work around nozzle	Limited to steam and low flow liquids only performing maintenance heat transfer Least resistant to fatigue failures (cyclic service) Susceptible to plugging — requires clean fluid Difficult to estimate flow/pressure drop without vendor supplied empirical procedures Bypassing and dead zones — resulting in poor heat transfer

*Note: a spiral baffle in the jacket space, welded per Code as a stiffener to the inner wall, will reduce required inner wall thickness and improve heat transfer due to increased fluid velocity.

Table 1. Each type of jacketing has a particular combination of pluses and minuses.

structural steel will have to be removed when setting the vessel. This is ill-advised for heavy equipment.

8. *Rectangular tanks.* It's not cost effective to specify a rectangular vessel for pressure other than static head; therefore, only consider this configuration for atmospheric tanks. Flat surfaces are highly stressed under pressure (and vacuum) and the required thickness without adding stiffeners can be mind-boggling. An

engineer needing a rectangular tank often incorrectly specifies API 650 or ASME. Neither API 650 nor any other API standard exists for rectangular tanks. Appendix 13 of the ASME Pressure Vessel Code provides a methodology but will lead to an expensive over-design. Most fabricators will apply the stress/strain formulas in Roark [3] to design a safe and economical tank that can operate under 15 psig.



9. *Cyclic service.* If a vessel will experience an unusual number of thermal or pressure cycles over its design life, this could result in premature fatigue failure (usually at a weld) unless preemptive measures are taken. Fatigue is cumulative material damage that manifests as a small crack and progressively worsens (sometimes to failure) as the material is repeatedly cycled. A 1985 survey showed that fatigue was the second most prevalent cause of failure in industry (25%), closely behind corrosion (29%) [4].

It's up to the purchaser to instruct the fabricator what design/fabrication practices to follow to avoid fatigue. Cyclic service is usually associated with batch processes and ASME [5] provides the following rules:

Design for fatigue if $N_1 + N_2 + N_3 + N_4 \geq 400$ for non-integral (fillet weld) construction and $\geq 1,000$ for integral construction (i.e., no load-bearing fillet welds), or 60 and 350, respectively, in the knuckle region of formed heads, where N_1 is the number of full startup/shutdown cycles; N_2 is the number of cycles where pressure swings 15% (non-integral) or 20% (integral); N_3 is the number of thermal cycles with a temperature differential (ΔT) exceeding 50°F between two adjacent points no more than $2.5 (Rt)^{1/2}$ apart (where R is inside radius of vessel and t is thickness of the vessel being considered) — apply a two-times factor if ΔT exceeds 100°F, a four times factor if more than 150°F, and see Div. 2 for more than 250°F; and N_4 is the number of thermal cycles for welds attaching dissimilar materials in which $(\alpha_1 - \alpha_2)\Delta T$ (where α is the thermal expansion coefficient) exceeds 0.00034, or for carbon steel welded to stainless steel, the number of cycles where $2\Delta T$ exceeds 340.

Equipment and piping in continuous processes also can experience fatigue due to the relentless mechanical loading/unloading of reciprocating compressors, piston pumps, bin vibrators or from vibration, etc., from any type of mis-aligned rotating equipment.

VESSEL AND HEAT EXCHANGER NOZZLE LOADS

FORCE	LOAD*
Lateral force in any direction	$F \times 450D$ lbs
Bending or torsional moment	$F \times 1,100D^2$ ft-lbs

*Note: D is pipe diameter in inches and F is flange rating factor: for 150-lb flange rating, F = 0.6; for 300, 0.7; for 600, 0.8; for 900, 1.0; for 1,500, 1.1; and for 2,500, 1.2. For API-specified equipment, refer to the respective standard for nozzle loads.

Table 2. Use these loads if attached piping operates at $\geq 200^\circ\text{F}$ and formal stress analysis hasn't been done. Contact OEM for glass-lined equipment.

IMPROVED FATIGUE RESISTANCE

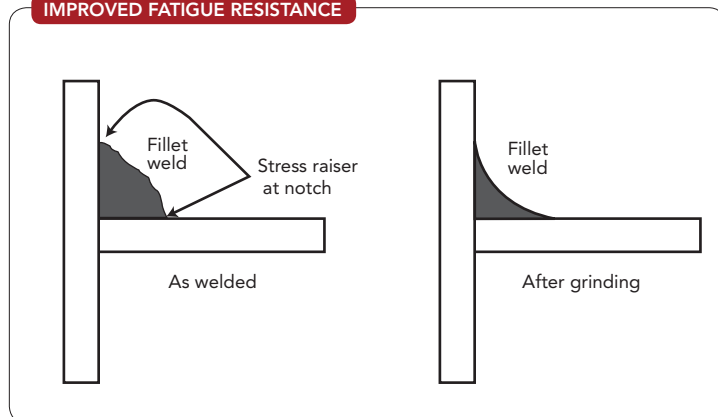
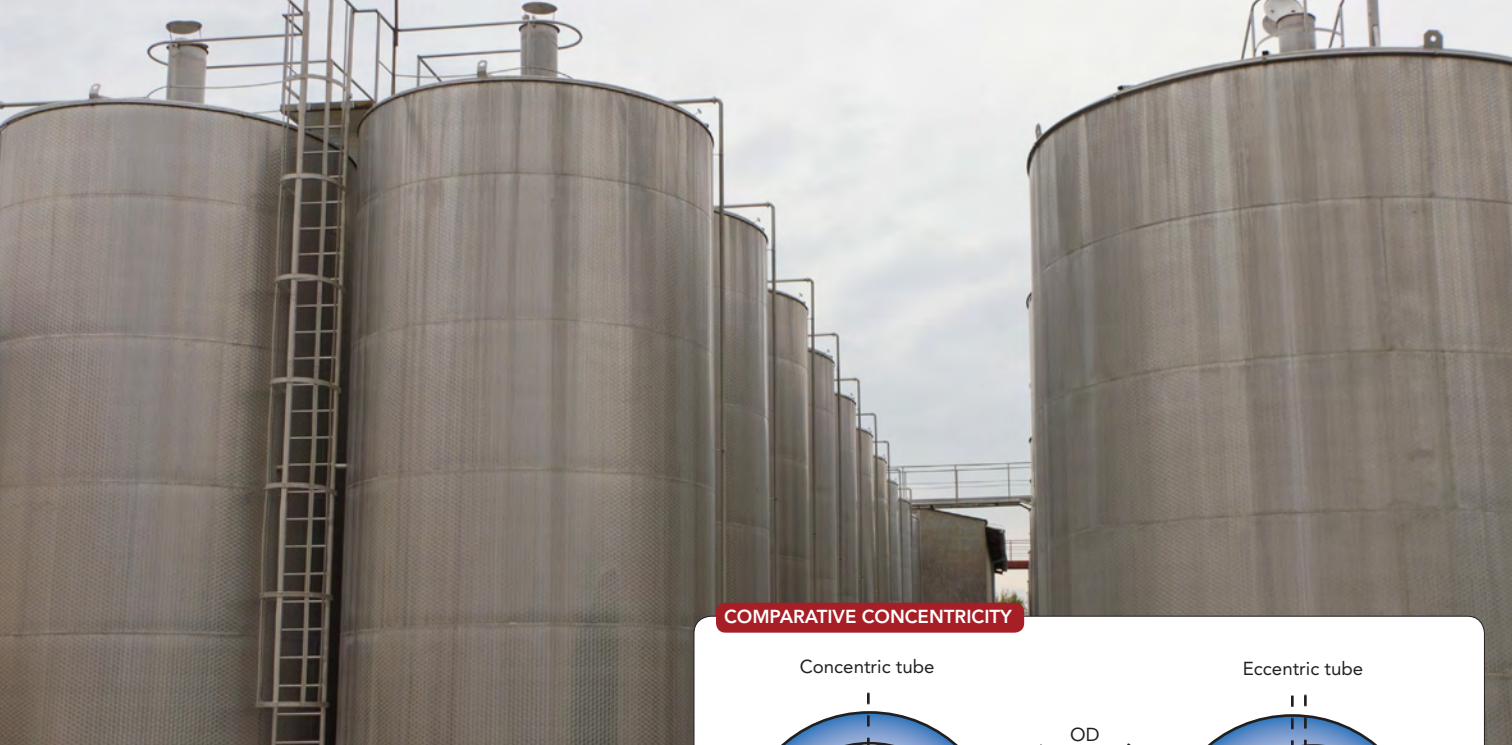


Figure 2. Blend grinding of fillet weld can prevent fatigue but the throat of the weld (the distance from face to root) must meet code requirements after grinding.

Fatigue failures in welded equipment most commonly occur in fillet welds where there's an abrupt change in equipment geometry. Division 2 of the ASME Code designs around fatigue cracking in nozzles by limiting the use of fillet welds. However, fillet welds and sharp corners are ubiquitous



COMPARATIVE CONCENTRICITY

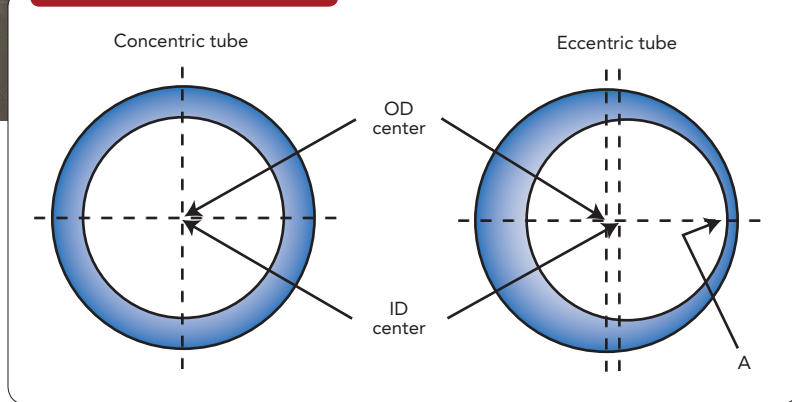


Figure 3. Welded tubing (left) is inherently more concentric than seamless tubing (right). Eccentricity exaggerated for illustration purposes; “A” is the governing dimension, minimum wall thickness.

in Div. 1 designs and can't be avoided without cost.

Crack initiation usually begins at the surface due to small microcracks. Therefore, surface smoothness is a good defense. Polished surfaces have four times the fatigue resistance [6] but polishing generally can't be justified for fatigue life alone. Shot peening imparts compressive stresses into the metal surface that impede crack initiation but, again, only high-end applications can economically justify peening. For mid- to small-size process vessels, good weld quality often is the most economical defense against fatigue; so, state requirements in the equipment specifications. Because fatigue cracks often initiate at the toe or root of fillet welds, grinding the face to gently blend the weld into the base metal with a generous radius remarkably reduces stress risers (Figure 2). Another method to reduce stress risers is to TIG (tungsten-inert-gas) wash a weld toe to improve smoothness and remove microcracks. Initially target welds where cyclic loading is occurring. Experience has shown that most fatigue problems occur due to inadequately supported attachments or where saddles/supports lacked wear pads or rounded corners.

10. *Tubing.* This can be a significant cost element when ordering large heat exchangers. Cost can vary appreciably depending on the fabrication requirements specified. It's not our intent to steer you away from the highest quality tube but merely to point out subtleties that can noticeably affect price.

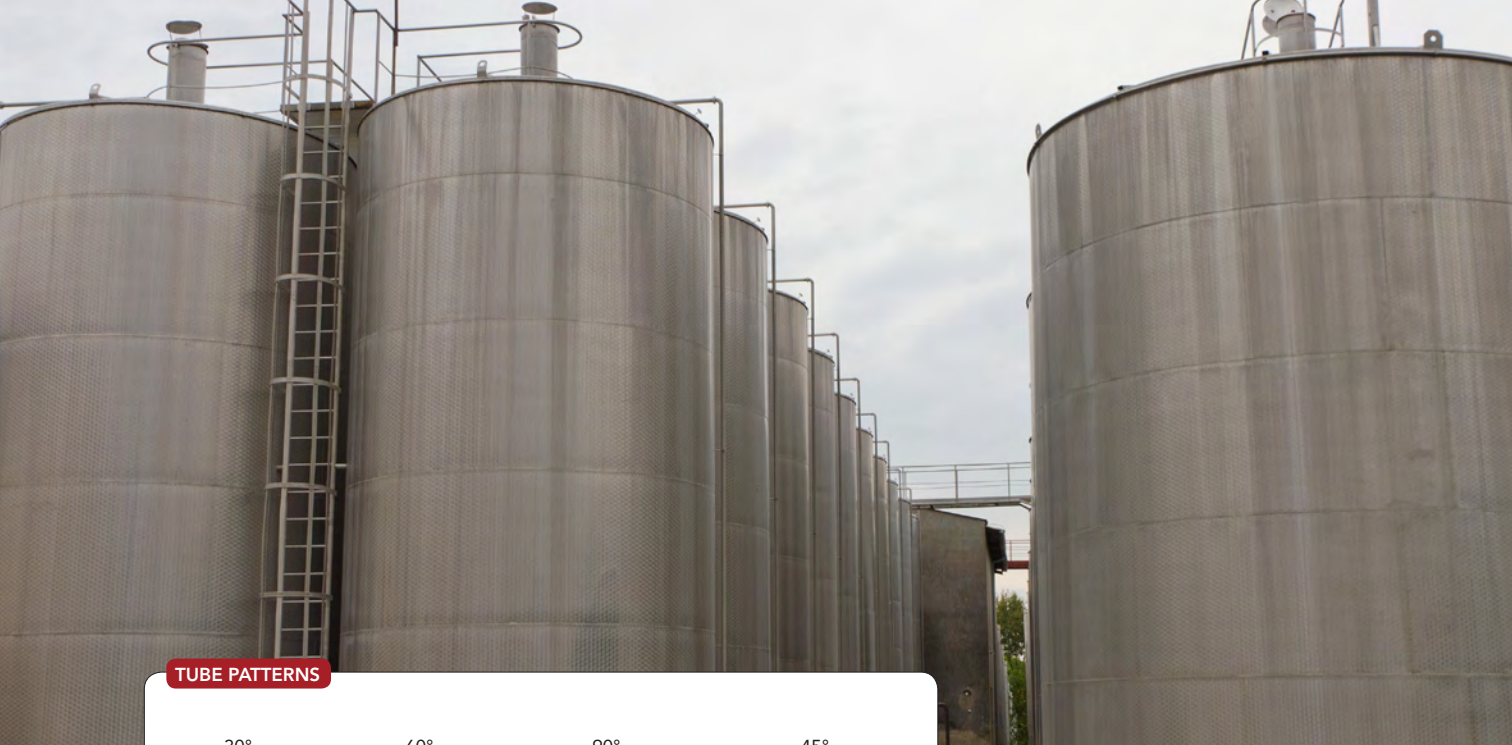
- *Diameter.* Tubing is specified based on OD. For quickest delivery, stick to commonly stocked sizes, typically ¾-in. and 1-in. tubes for the chemical industry. Specifying smaller tubes (e.g., ½ in.) will increase the exchanger's tube count and cost; this will improve duty but will cause higher pressure drop and may make mechanical cleaning more difficult. Therefore, only consider tubes smaller than ¾ in. for cleaner services or when

increasing the shell diameter/length isn't an option. Larger tubes (>1 in.) have the opposite effect but may be necessary to satisfy process conditions. Another option to increase effective surface area without changing tube diameter is to specify finned tubes or twisted tubes — but those are limited to clean applications.

- *Length.* Tubes are stocked in 20-ft lengths. Seamless tubes are made from individual billets or hollows and so can vary in length by one to two feet. The length of welded tubes is more exact because they're produced from a continuous strip coil. The most wasteful and costly option for stocked tubes is ordering units just over 10 ft in length because nearly 50% of the tube is discarded. As tube count increases, direct mill orders become economically attractive; in such cases, any length tube can be supplied, if your schedule allows. Mills have minimum orders (i.e., 2,000 lb.–2,500 lb.), though “mini-mills” will take orders at half these quantities.

- *Gauge.* Tubes come in different wall thicknesses (or gauge). Industry standards [7] detail the appropriate wall thickness based on material type and service. Table 3 provides guidance for a ¾-in. tube where no prior service history is available.

- *Corrosion allowance.* This typically isn't added because tubes are considered a replaceable feature of the exchanger. If designing for a corrosive service, specifying the next-heavier-gauge wall thickness or choosing a higher alloyed



TUBE PATTERNS

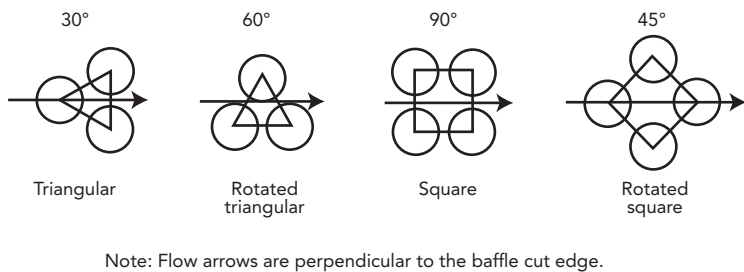


Figure 4. More tubes can fit with 30° and 60° configurations but mechanical cleaning may be harder.

tube material is more appropriate.

• *Seamless versus welded tube.*

There's a perception that seamless tubes are more reliable than welded tubes. This is currently less valid as some manufacturers have developed specialized techniques for making welded tubing that give products that show no preferential

weld corrosion and have properties equal to those of seamless tubing [8,9]. Seamless tubing will cost more and usually has longer delivery. Welded tubing requires a greater amount of non-destructive examination (NDE), but this typically only adds pennies per foot of tubing if done at the mill [8,9].

Eccentricity is inherent in producing seamless tubes [10]. They typically are made by piercing, extrusion or pilgering. The inner mandrel/die can't stay perfectly centered during the tube forming process. Welded tubes on the other hand begin with strip material that is very consistent in wall thickness. So, welded tubes tend to be more concentric (Figure 3). Seamless tube standards permit larger wall-thickness tolerances than those allowed by welded tube standards [11].

• *Minimum versus average wall thickness.*

Minimum wall tubes cost a bit more than average wall tubing. When it's unnecessary to use minimum wall tubing, such as for high pressure or corrosive service where metal loss is anticipated, it may be more economical to permit the

TUBE MATERIAL SELECTION

MATERIAL	SERVICE	GAUGE	WALL THICKNESS, IN.
Carbon steel	Harsh	12	0.109*
	Mild	14	0.083*
Aluminum	Mild	14	0.083*
Stainless steel and high alloy	Harsh	14	0.083†
	Mild	16	0.065†
Copper	Mild	16	0.065*
Titanium and zirconium	Harsh	18	0.049†
	Mild	20	0.035†
Niobium and tantalum	Harsh	N/A	0.020†
	Mild	N/A	0.015†

* minimum
† average

Table 3. When using ¾-in. tube and not having a history of materials in the particular service, follow these guidelines.



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use of average wall welded tubing and specify additional NDE or corrosion evaluation of the tube seam.

• *Tube pattern.* Shell and tube heat exchangers typically are fabricated with one of four types of tube patterns — 30°, 60°, 45° and 90° (Figure 4). Duty, pressure drop, cleanability, cost and vibration all depend on which pattern is chosen. Consider process needs, not cost, when making the selection.

A 30° or 60° pattern is laid out in a triangle configuration. The main benefit is that about 10% more tubes can fit in the same area as a 45° or 90° pattern. There's very little difference between the 30° and 60° patterns. Often a thermal designer will run analyses of both and select the one that provides the best pressure drop and vibration results. The disadvantage of a 30° or 60° pattern is that it's difficult to mechanically clean on the shell side. Therefore, such a pattern is chosen for cleaner services; frequently the bundle isn't removable.

The 45° or 90° pattern is selected if shell-side mechanical cleaning is required. Such a pattern also requires a removable bundle. The 45° is more common than the 90° because it provides more shell-side flow disturbance, which improves heat transfer. A 90° pattern is used to reduce pressure drop at the expense of duty and often is employed in boiling service to enable better vapor disengagement.

MAKE THE RIGHT CHOICES

In today's chemical industry, too many engineers given the task of specifying welded equipment such as vessels, heat exchangers and tanks aren't well versed in what's necessary to develop an economic design that provides suitable safety and performance. Myriad choices must be made — and each will incrementally add to the final cost and schedule. When looking for savings, cutting the wrong corners may turn out to be very costly over the equipment's service life. ●

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