FIXED EQUIPMENT NEWSLETTER

Volume 2021, March Issue

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Engineering Specifications

Pressure vessels, heat exchangers and storage tanks, in fact all process equipment, are built to one or several specifications. These specifications govern the design, materials, inspection, testing, installation etc. for the particular equipment. And like anything else in engineering, they are subject to revisions over time.

It is not uncommon to work with a specification that is under revision. What is worse is that the specification imposes requirements that is currently under study to be removed in the next revision. In such situations, the engineer-in-charge should evaluate the wisdom of having the vendor strictly adhere to those requirements. There are reasons that requirements was initially included in the specifications, and there are reasons why they are going to be taken away in the upcoming revision. May be the equipment in question at this time is subject to the same set of conditions that now warrant the removal of that requirement. If so, the vendor should be exempt from meeting those requirements in the specification.

Sometimes there is a tendency to make a specification so large and cumbersome that it baffles not just the vendors but also the engineers who are there to ensure that vendors are in compliance in the first place. This is a good reason to break up the specification into manageable sections that are easier to follow.

There are specifications that are written to be slight (or not) modifications of existing industry standards. API 660 for Shell-and-Tube Heat Exchangers is a good example. Many companies write specifications that are additions/ deletions/ modifications to the existing sections of the API 660. I am not a big fan of such specifications. They are generally written for a particular edition of the standard which may not be the current standard. And that leads to some degree of confusion.

Then there are specifications which refer to other specifications which themselves refer to other specification… you know where I am going with this. ASME Section VIII, Division 2 was completely rewritten in 2007 to get rid of these infinite (almost) recursions. I understand the necessity of referencing other sections in the specification – to prevent repetitions and to make future revisions easier. However, if just repeating a small section in more than one location makes the text more readable, doing it may be justifiable.

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Featured in this issue…

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CoDesign Engineering provides a wide range of engineering services for pressure vessels, heat exchangers, tanks and piping for process industries, and for power plant design with a mission to achieve engineering excellence, customer satisfaction and innovative solutions. We pride ourselves on providing high quality services to our clients that address our client's specific needs to enable them to optimize their resources.

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- Design, analysis and rerating of atmospheric storage tanks and low pressure storage tanks based API 650 and API 620 respectively
- Thermal design of shell-and-tube heat exchangers using HTRI and mechanical design and fabrication services per the requirements of ASME Section VIII, TEMA and API 660
- Cyclic service analysis for pressure vessels per ASME Section VIII, Division 2, Part 5
- Design and fabrication services for pressure vessels complying with the requirements of ASME Section VIII
- Review and certification of repair plans for pressure vessels

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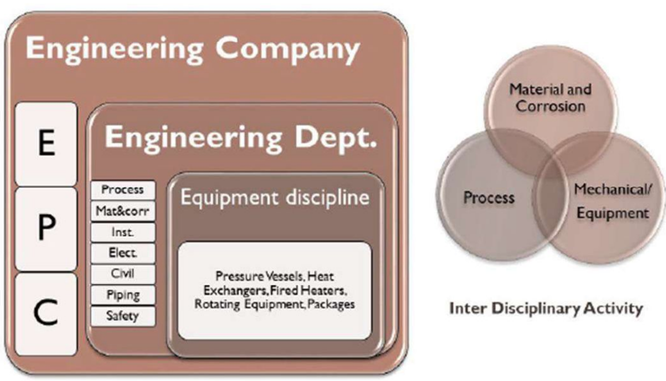
STATIC EQUIPMENT – A LOOK AT "HOW AND WHY" OF SPECIFICATIONS

This article was originally written by Navid Tajik, Sagar Gaikwad, Mansour Hamza, Marco Garofanello, VU Nathan, Rajiv Mukherjee, and Hervé Baron in December 2018. It is reproduced here with minor modifications (mostly to convert units from metric to US).

The majority of mechanical equipment found in oil and gas facilities belongs to the static equipment group, which comprises pressure vessels (drums, columns, reactors, filters), heat exchangers (shell and tubes, plate and frame, air coolers) and storage tanks. The guidelines presented in this article contain cost-effective recommendations for their design, materials, and fabrication. They aim to enable the project engineer, who is not an equipment specialist, to check that economical choices are made.

The specification and selection of the equipment is the responsibility of the static equipment engineer, based on requirements specified by other disciplines, including process, materials and plant layout. These other disciplines are not always aware of the impact of their demands on the cost/lead time of the equipment. Conversely, the static equipment discipline is not always aware of where the requirements of these disciplines come from and if the onerous ones could be challenged. Such interface data are the focus of this article, which aims to give a cross-discipline awareness.



Let's start with the review of the process equipment data sheet.

PROCESS EQUIPMENT DATA SHEET

In this example, the process equipment data sheet contains the following information:

- Inside diameter, tangent line to tangent line (TL) length, overall length,
- Service (type of fluid)
- Special service (hydrogen, sour, cyclic, lethal)
- Presence of chlorides
- Vessel orientation (vertical/horizontal)
- Maximum allowable working pressure design pressure (MAWP) and temperature (MAWT)

- Design for full or partial vacuum
- Minimum design metal temperature (MDMT)
- Type of heads
- Internals type and position (i.e., demister)
- Nozzles (process/instrumentation) list with sizes
- Skeleton vessel sketch
- Generic material of construction (wet parts) and corrosion allowance
- Type of nozzles (butt weld/flanged)
- Rating and type of flange (raised face/ring-type joint)
- Insulation (yes/no)
- Heat tracing/winterization, or steam coil
- Passive fire protection
- Site conditions (wind, seismic, blast; or reference to the project document containing such information, e.g., basic engineering design data
- Hazardous area classification

DESIGN DATA

Design Code

The selection of the design and fabrication code determines the vessel wall thickness, extent of NDE, and cost. It is better to leave the choice to the supplier unless a given code is mandatory for regulatory reasons. For offshore application, reduced weight would be another driving factor for selecting appropriate design and fabrication code.

Vessels are only classified as pressure vessels above a certain internal or external pressure, e.g., 15 psig under ASME. Below this pressure they are designed and manufactured as per manufacturer standard.

European codes have been known to be more economical than the ASME code for high-pressure vessels, as the allowable stresses are closer to the yield point (i.e., the safety margin is lower). For example, by changing from ASME to European code, approximately $25,000 can gained on a high-pressure column. If the applicable code is ASME Section VIII, it is better to leave the vendor the choice between Division 1 or Division 2. Division 2 allows for reduction in the wall thickness typically by 20% by doing more extensive calculations. It is worthwhile considering for high-thickness vessels.

Design Pressure

The process engineer defines the design pressure by applying common and reasonable margins above the maximum operating pressure, such as shown below.

Max. operating pressure	**Design pressure**
Atmospheric pressure	7.5 psig
Vacuum	Full vacuum and 50 psig min.
Between 0 and 150 psig	Max. operating pressure + 15 psig min.
Between 150 psig and 500 psig	Max. operating pressure + 10 % min.

Between 500 psig and 1000 psig	Max. operating pressure + 50 psig min.
Above 1000 psig	Max. operating pressure + 5 % min.

Design Temperature

The design temperature is usually set 100 – 150°F above the maximum continuous operating temperature.

- It does not take into account accidental temperatures which can happen for short duration only, during startup, shutdown, or in emergency conditions, e.g., loss of utilities, valve failure.
- It takes into account the potential bypass of the upstream heat exchanger for cleaning, as well as the scenario of stopped upstream air-cooler fan(s).
- It takes into account alternate operating conditions of significant duration, such as regeneration, dry-out, and steamout. However, the temperature reached in these conditions is not concurrent with the maximum pressure for which the vessel is designed. In such case, the combination of temperature and pressure in these conditions is considered together.

Minimum Design Metal Temperature (MDMT)

The MDMT is the lowest of minimum fluid temperature and the temperature caused by autorefrigeration upon fast depressurization, which is carried out, for instance, in case of emergency (gas leak). Be careful in selecting the correct MDMT because a lower-than-required MDMT could result in a change of material or, for carbon steel, special heat treatment or impact test, which adds to the cost. In cold climates, the MDMT does not need to be the minimum ambient site temperature. Indeed, the equipment could be started up slowly so that it warms up while its internal pressure is raised. It simply requires a proper startup procedure that ensures warm up before the full internal pressure is applied.

The thresholds that may require a change of material, special heat treatment, or impact tests are -20°F and -55°F. Specifying a design temperature below -55°F implies a special qualification of all welders and weld procedures, which many fabricators may not have developed.

Design for Vacuum

Vessels are designed for vacuum if they operate at lower than atmospheric pressure. Another usual case is when steam is used to clean the vessel. In case the vessel is isolated after being "steamed out," which could happen due to operator error (closing of the vent valve), vacuum could develop inside the vessel when the steam cools down. The vessel is therefore designed for vacuum for such an accidental case.

Design for vacuum will not affect the design of vessels with high internal design pressure. On the other hand, it could add stiffening rings or even increase the wall thickness of low-pressure vessels. Hence, for those vessels, check that "design for vacuum" due to steam-out is specified only when actually required, typically with dirty/viscous liquids such as heavy hydrocarbon. When steam-out is required, question the level of vacuum design specified. As standard, "Full Vacuum (FV)" is indicated on the process data sheet. This means that the vessel shall be designed for an internal pressure of 0 psia. Design for "partial vacuum", e.g., 7.5 psia, might be enough and result in smaller impact on vessel design.

Types Of Heads

The process engineer usually specifies 2:1 elliptical heads. These are cost-effective for low-wall-thickness vessels. When selecting the types of heads, the process engineer is only concerned with their volume. Hemispherical heads are a more economical choice at high pressure (600 psig and above), e.g., for steam drums, as their wall thickness is half that of elliptical heads. There should be no problem in changing to hemispherical heads as the volume is increased.

Nozzle Loads

The piping loads that the vessel nozzles shall be able to withstand from connecting pipes are not specified in the ASME BPV Code. If attached piping operates at more than 200°F, we suggest providing the fabricator with the nozzle loads in the form of a table for a reasonable nozzle stiffening. The problem is not the failure of the nozzle itself but at the shell. In some instances the shell thickness must be increased.

The purchaser shall specify that the adequacy of nozzle design for given piping loads shall be checked by the supplier as per WRC 107/297 and that finite element analysis (FEA) shall be performed if the geometry or size falls outside the ASME or WRC 107/297 limits. By providing the fabricator with a reasonable nozzle load, the vessel fabrication and piping design can proceed in parallel and avoid pipe stress/nozzle-loading issues months into fabrication.

SPECIAL SERVICES

Sour Service

In sour (i.e., wet H_2S) service, H_2S may react with water leading to hydrogen migrating into the carbon steel. When hydrogen accumulates in the carbon steel, it can lead to internal cracks. Stress, if present in carbon steel, exacerbates this phenomenon. Hence:

- The equipment exposed to H_2S and free (liquid) water must be clearly identified. This is done by the process engineer, who indicates "sour service" on the process data sheet.
- The requirements to be followed in sour service must be clearly specified
- Identification of "sour service" conditions is done using criteria of international standards, such as NACE MR 0175 for upstream facilities and NACE MR 0103 for downstream facilities, unless a client specification applies. NACE MR 0175 criteria are not straightforward and depend on the combination of the partial pressure of H_2S and pH. A proper assessment should be done by the process engineer and documented in order to ensure the identification is properly made and "Sour Service" is neither omitted nor unnecessarily specified.
- Requirements to be followed in sour service are that of the NACE standards referred to above, and in many locations, are considered a legal requirement. Client specification may impose additional requirements. The NACE MR0175 and NACE MR0103 requirements apply to raw material and manufacturing. The requirements for raw materials allows the use of the usual steel (A516 for steel plates, API 5L, A106, A333 for pipes), provided a few requirements are met, such as limits in chemical composition, maximum hardness, processing, and heat treatment. To comply with these requirements, the raw material must in practice be sourced from higher-quality mills, which may increase cost by up to 5–10%. Fabrication requirements include the maximum hardness of welds, which in practice requires post-weld heat treatment (PWHT), and stress relief in case of excessive cold deformation (e.g., of vessel heads).
- One type of cracking which could take place in sour service, whatever the amount of H S, is called hydrogen-induced cracking (HIC). This type of cracking is observed on steel plates only. NACE MR 0103 does not address this type of cracking. NACE MR 0175 imposes a very low sulfur content to prevent such cracking and leaves it to the equipment user to assess the risk of HIC testing and specify requirements to resist HIC. HIC-tested plates cost around 50% more. Additionally, as HIC resistance is affected by the steel manufacturing route, testing alone might not be considered sufficient to qualify the steel. Hence some client specifications do not accept steel plates that simply pass the test, which they call "pseudo-HIC," but impose that they are produced according to a specific manufacturing process, producing extra clean steel (for example, by means of deep degassing). This might restrict the supply of steel plates from only a few sources, impacting the cost and schedule.

Although the task of identifying “Sour Service” conditions falls to the process engineer, who indicates it on the process data sheet, that of specifying HIC resistance requirements usually does not. It is therefore the role of the equipment engineer to identify if such requirements are present in client/licensor specifications and, in the positive, to specify them.

Lethal Service

According to the ASME Section VIII Code, a lethal substance is a “poisonous gas or liquid of such a nature that a very small amount of the gas or the vapor of the liquid mixed or unmixed with air is dangerous to life when inhaled”. As per ASME Section VIII, it is up to the user to define if the vessel is in lethal service. “Lethal Service” designation has a big impact on equipment cost and manufacturing: only butt welds are allowed, they are be 100% X-rayed, PWHT must be done for carbon steel and low alloy, etc. In addition, some client specifications demand integral nozzles for vessels in lethal service. Classification as lethal service should be avoided wherever possible because pressure vessels are a negligible source of leak compared to piping flanges.

Cyclic Service

If a vessel is exposed to a very high number, typically ~100,000, pressure/temperature cycles over its life, it could fail due to fatigue, usually at a weld, unless preemptive measures are taken. These measures include specific welds, such as full penetration, and additional nondestructive evaluation (NDE). The number of cycles that classifies the vessel in cyclic service is given by the pressure vessel code. It is beyond the responsibility of the process engineer to review this. The process engineer simply indicates the frequency of change of process conditions so that the mechanical engineer along with the vessel manufacturer can check if the vessel falls within the cyclic service criteria of the ASME VIII Div. 2 code.

High Temperature Service

Vessels working at high temperature may experience creep, a permanent plastic deformation or rupture that happens even though the stress level in the material does not exceed the level allowed by ASME. The temperatures above which creep must be considered come from Welding Research Council (WRC) Bulletin 470 and are given in ASME. They are the ones for which the stress values are shown in italics in the maximum allowable stress values tables of ASME II part D. For SA-182 F22, for instance, creep is considered above 850°F as shown in Table 5A.

A time-dependent analysis is be performed when creep is to be considered. It shall be performed as per WRC Bulletin 470, “Recommendations for Design of Vessels for Elevated Temperature Service.” A typical case of vessels which could be subject to creep are reactors that are subject to occasional regeneration at high pressure. The regeneration condition, frequency, and duration, shall be communicated to the vessel vendor to enable them to perform the time-dependent analysis.

MATERIAL SELECTION

It is up to the purchaser, not the vendor, to select the right material of construction based on the fluids characteristics and life span of the equipment. The process engineer should indicate the basic material of construction (e.g, carbon steel) on the process equipment data sheet.

Nonhydrogen or Corrosive Service

For nonhydrogen or corrosive service, the material is selected according to the design temperature. The design temperatures are generally classified as follows:

Cryogenic Temperatures	below -150°F
Low Temperatures	-150°F to 32°F
Intermediate Temperatures	32°F to 775°F
Elevated Temperatures	above 775°F

The usual selection for materials is shown in the table below:

Design Temperatures, °F	Material (Plates, Pipes, Forgings, Fittings)	Bolting
-425°F to -320°F	Stainless Steels: SA-240-304.304L, SA-312-304/304L, SA-182-304/304L, SA-403-304/304L	SA-320-B8 with SA-194-8
-320°F to -150°F	9 Ni: SA-353, SA-333-8, SA-522-1, SA-420-WPL8	SA-320-B8 with SA-194-8
-150°F to -75°F	3½ Ni: SA-203-D, SA-333-3, SA-350-LF3, SA-420-WPL3	SA-320-L7 with SA-194-4
-75°F to -50°F	2½ Ni: SA-203-A, SA-333-3, SA-350-LF3, SA-420-WPL3	SA-320-L7 with SA-194-4
-50°F to -20°F	Carbon Steel: SA-516-55/60, SA-333-6, SA-350-LF2, SA-420-WPL6	SA-193-B7M with SA-194-2H
-20°F to 5°F	Carbon Steel: SA-516 (All grades), SA-333-1 or -6, SA-350-LF2, SA-420-WPL6	SA-193-B7 with SA-194-2H
5°F to 32°F	Carbon Steel: SA-516 (All grades), SA-53-B or SA-106-B, SA-105, SA-234-WPB	SA-193-B7 with SA-194-2H
32°F to 775°F	Carbon Steel: SA-516 (All grades), SA-53-B or SA-106-B, SA-105, SA-234-WPB	SA-193-B7 with SA-194-2H
775°F to 875°F	C-½ Mo: SA-204-B, SA-335-P1, SA-182-F1, SA-234-WP1	SA-193-B7 with SA-194-2H
875°F to 1000°F	1 Cr-½ Mo: SA-387-P12-C11, SA-335-P12, SA-182-F12, SA-234-WP12 1¼ Cr-½ Mo: SA-387-P11-C12, SA-335-P11, SA-182-F11, SA-234-WP11	SA-193-B7 with SA-194-2H
1000°F to 1100°F	2¼ Cr-1 Mo: SA-387-P22-C11, SA-335-P22, SA-182-F22, SA-234-WP22	SA-193-B5 with SA-194-3
1100°F to 1500°F	Stainless Steel: SA-240-347H, SA-312-347H, SA-182-347H, SA-403-347H Alloy 800: SB-424, SB-423, SB-425, SB-366	SA-193-B8 with SA-194-8
Above 1500°F	Alloy 800HT or Alloy X: SB-443, SB-444, SB-446, SB-366	SA-193-B8 with SA-194-8

Relative Cost of Raw Materials.

Material	Relative Cost
Carbon steel	0.2
1.25%Cr, 0.5%Mo	0.25
304/304L Stainless Steel	0.75
316/316L Stainless Steel	1
22%Cr Duplex	1
25%Cr Super Duplex	1.6
Alloy 625	4.9

Alloy 800	2.5
Titanium Grade 2	4.5

Cladding

When cladding is required, different methods can be applied: explosion bonding, hot roll bonding, overlay/ electroslag, overlay/submerged arc. Unless imposed in client specs, leave the choice to the vendor: weld overlay is cheaper than buying clad plates. For clad plates, there are two types of cladding: hot roll bonding and explosion bonding. Explosion bonding is cheaper but is prohibited in some client specifications. The minimum thickness of the undiluted overlay/clad thickness significantly affects the cost and schedule. It shall therefore be adequately specified, based on the rate of corrosion of the fluid and criticality of the equipment service. Internals welded to clad require the vendor to perform shear calculations or tests and report the allowable shear stress. For nozzles, solid material instead of cladding might be an economical alternative and shall be left as an option.

Other Material Considerations

- Dual-certified materials are often available in the market with almost no cost difference. They combine the properties of both “L” and “non-L” grades: 15–20% higher strength of non-L grades + prevention of unwanted sensitization during welding of L-grade. So specify dual-certified 304/304L to reduce the wall thickness by 15–20%.
- There is a tendency by process engineers to specify 316 as stainless steel. It costs 50 cents/lb more than 304. The only difference is its resistance to chlorides. Check if chlorides are present and, if not, challenge the selection of 316. In the presence of chlorides, the material selection must take into account the risk of chloride stress corrosion cracking. 316 only qualifies for certain chloride concentrations and temperatures. Duplex, super duplex, or high-nickel alloy might be required.
- In case of both sour service and the presence of chlorides, consult NACE MR 0175, which includes limitations of temperature for use of austenitic, duplex, and super duplex stainless steels.
- Specifying some duplex alloys can actually save cost as they have from 20% to 35% higher allowable code stresses, resulting in a thinner-wall vessel.
- For corrosive service, consult the material/corrosion specialist and ascertain the life cycle cost. Replacing the heat exchanger tube bundles is a classic example of a cheaper solution, over the life cycle cost, than using exotic materials.
- If the temperature does not exceed 300°F, consider coating the inside of the vessel. Coating a carbon steel vessel can be much more economical than selecting a high-alloy vessel or clad-carbon-steel vessel.
- Carbon and low-alloy steels in environments containing hydrogen could be subject to high temperature hydrogen attack at elevated temperatures. Use Nelson curves included in API RP 941 to identify the suitable material based on the *operating* temperature and H S partial pressure. 1.25Cr-0.5Mo or 2.25Cr-1Mo are commonly used in hydrogen service.
- If you have special alloy vessels, as raw material cost presents a large part of the cost, check how many material quotations the pressure vessel manufacturer got to prepare its bid.

NDE EXTENT

The amount of NDE (% of radiography of welds: full, spot, none) determines the vessel wall thickness: more radiography means less metal. Do not specify the extent of NDE. Leave it to the vendor to choose the most economical (wall thickness, NDE extent) combination in compliance with spec/lethal service requirements if applicable. Gamma rays, which save cost and significant time could be substituted for X-ray if the thickness does not exceed certain limits. Such substitution requires owner approval as per code. It should be assessed based on the criticality of the equipment.

CERTIFICATION AND STAMP

Third-party certification and stamp might be required for pressure vessels such as ASME's "U" stamp for pressure vessels designed and manufactured as per its code. This requires an ASME authorized third party to review documents and perform inspections, and requires ASME-certified materials. Such a stamp is not a requirement of the ASME code: all vessels designed and manufactured to ASME need not necessarily be stamped. The stamp is a requirement from the local regulations/law or the client. It brings significant additional cost, is a time-consuming process, involves stages of inspections by ASME authorized inspectors, and greatly affects documentation and inspection activities. Do not ask for it unless mandatory by law or client.

VESSEL SUPPORT

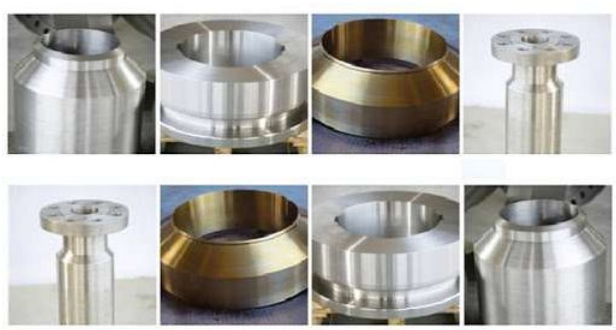
The vessel support type shall be specified: for vertical vessels either legs, brackets (if the vessel is supported on a structure), or skirt. The height of the legs/skirt up to the bottom tangent line of the vessel shall be specified on the purchaser's data sheet as it greatly affects wind/seismic design and combined loading design case. For reactors, specify triple forged ring at skirt base. Horizontal vessels are supported on saddles.

NOZZLE REINFORCEMENTS

Nozzle reinforcement can be done a number of ways, the easiest and cheapest is the reinforcing pad, also called doubler plate, which can usually and economically be of the same thickness as the shell plate.

Self-reinforced forged nozzles

These are nozzle necks that have extra wall thickness which avoids the needs for a reinforcing pad, and hence reduces the number of welds to the shell. Self-reinforced nozzles are advisable at high temperature (>700°F), high pressure (>1000 psig), Hydrogen service, low-alloy steel (Cr-Mo) vessels, wall thickness > 2 in. - to reduce the number of welds to the shell.



Long welding neck flanges

These are self-reinforced nozzles integral with a flange. They are often required in client specifications for 2 in. and below.

SCOPE OF SUPPLY

All welded internals shall be included in the vessel supplier's scope supply. For removable internals, it is different. Standard internals, whose type is defined by the purchaser, such as coalescer, mist eliminator, packing, and catalyst support (wedge wire screen), are best included in the scope of supply of the vessel vendor to prevent interface and guarantee issue. Non-standard internals, including trays, packing, distributors for columns, filter elements (cartridges), which are not standard but specifically designed to meet the process requirements specified on the process data sheet for internals, are best excluded from the scope of supply of the vessel vendor and purchased separately. This enables direct contact and selection of these internals, critical to the process performance, by the purchaser.

This, however, creates an interface issue as the trays/packing weight and loads have a major impact on the vessel wall thickness. It is therefore highly recommended to obtain weight/loads form the internals vendor and advise the same to the pressure vessel manufacturer before the purchase order, so that the latter can consider the same in the design, avoiding a claim. Internals shall therefore be selected/ordered early, preferably before the vessel itself. Another recommendation is to have a representative of the internals vendor attend the kickoff meeting with the vessel manufacturer. The design of the welded supports of these free issued internals shall be part of the internals vendor's scope of work. It shall be specified that removable internals are designed to pass through the vessel manhole(s) and allow easy installation and removal.

Filter vessels shall not necessarily be purchased from manufacturers of filter elements. It is economical to purchase only the design (number of filter elements hence diameter of the vessel) and the filter elements from the latter and to purchase the housing (filter vessel) including the tubesheet for filter elements separately. The filter housing manufacturer requires the number, size, and weight of filter elements. It shall therefore be communicated prior to the purchase order. It is obtained from the filter vendor upon issue of the process data sheet showing the filter functional requirements: filter type, service conditions, required performance, maximum pressure drop, and material.

Include clips on the vessel for supporting platforms, pipes, heat insulation, and fire proofing inside the scope of supply, but leave these items themselves outside.

The vessel supports (skirt/saddles/lugs/legs) are designed by the vendor along with the number, position, and sections of anchor bolts (no need to specify this as the vendor needs to do it as part of its mechanical design for seismic and wind loads). Shipping saddles may be included in the scope of supply for large columns/vessels in addition to service/original supports to mitigate shipping/transportation loads. Some client specifications call for skirt support to be a forged ring type or weld buildup, instead of just filled weld, for heavy-wall (defined as thickness >1.5 in. or >2 in.) vertical vessels. This is only justified in case of the repeated thermal stress due to transient loads.

Anchor bolts themselves do no need to be supplied by the vendor.

For large/heavy vessels, include a foundation template in the scope of supply. It is a ¼-in.-thick steel or wood plate that matches the actual equipment anchor bolt positions. This template shall be delivered at the installation site ahead of the vessel. It allows the civil contractor to cast the foundation, with accurate bolts position, ahead of the vessel delivery to save time. If no such template is provided, the civil contractor will wait for the vessel delivery to check the position of anchor bolts before casting the foundation. Indeed for large/heavy vessels, the base ring does not provide much allowance for out-of-tolerance bolt positions. The foundation template is a key component and great schedule improver in onshore applications.

VENDOR REFERENCES

Pressure vessels manufacturers are usually qualified and regularly weld carbon and stainless steel. This might not be the case of other materials (high nickel steel, etc.) or special processes (clad). If a welder has not used a specific welding process in the last 6 months, the ASME code requires the welder to requalify. Therefore, when preparing your bidder's list, call around to find suppliers who regularly weld this type of material as evidenced by recent deliveries.

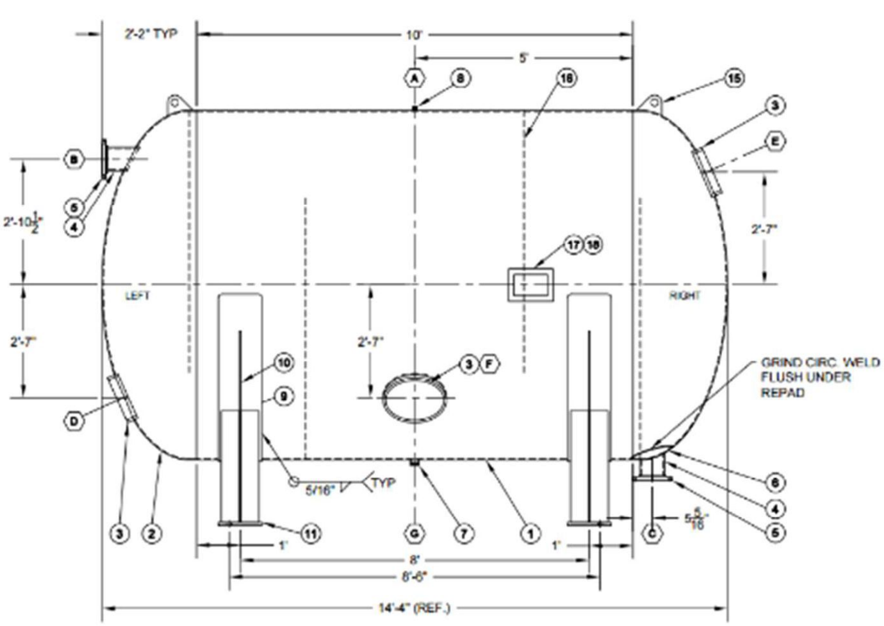
VENDOR DOCUMENTATION

The VDRS (Vendor Data Requirement Schedule) is issued as part of the vessel inquiry. It shall include the following design and fabrication documents, to be submitted by the purchaser. All documents issued shall be signed as checked. If a document has not been signed as checked it shall be returned as incomplete. These documents shall include at least the following:

- Outline and general assembly drawings that show all design basis and vessel data.
- Detailed drawings
- Installation, operation, and maintenance manual
- Welding documents to include at a minimum a weld map, welding procedures specification, and procedure qualifications
- Fabrication procedure to include at a minimum forming procedures for shell and head plates, post-weld heat treatment procedures, nondestructive testing procedures, and pressure test procedures
- Manufacturer data report. On completion of the vessel, the manufacturer shall issue a form X conforming to the code in order to certify that the vessel has been designed, constructed, and tested in every respect in accordance with code. This form X shall be countersigned by the inspection authority.
- Guarantees. The manufacturer shall guarantee the mechanical, design, and workmanship in the construction of vessels. When internals are included in the scope of supply, the supplier shall guarantee the process performance.

ENGINEERING DRAWING

Pressure vessels can be ordered either on the basis of a process data sheet, including a skeleton drawing or on the basis of an engineering (guide) drawing.



MECHANICAL DESIGN

The mechanical design of the vessel is best left to the equipment vendor. The wall thickness of every part of the vessel is calculated so that the stress under the combined loads does not exceed the allowable stress for the material. Loads include internal pressure, external pressure (for vessels operating under vacuum conditions), wind, seismic, blast loads, forces from connected pipes, self-weight, and weight of contents. Calculations are normally done using third-party commercially available software that includes code formula and material properties.

SHIPPING

Take into account the location of manufacturers, which affects delivery time and shipping costs. Shipping of large-diameter (above 12 ft) vessels can be a challenge and add to the cost and time because of road permits, requirement to ship by river when not feasible by road, etc. For such vessels supplied from vendors whose facilities are not near the sea, it is a good idea to ask the supplier, who knows the local transport restrictions, to quote free on board (FOB) related to an international port. For long-lead items, the required delivery time, consistent with project time schedule requirements, shall be specified in the inquiry.

PERFORMANCE GUARANTEE/MECHANICAL WARRANTY

As the design of pressure vessels is done by the purchaser, no performance guarantee is requested from the vendor but only a mechanical warranty, covering the 3 "Fs": faulty (mechanical) design, faulty material, faulty workmanship.

References:

See beginning of this article.

THE RIVER AND THE LION

"After the great rains, the lion was faced with crossing the river that had encircled him. Swimming was not in his nature, but it was either cross or die. The lion roared and charged the river, almost drowning before he retreated. Many more times he attacked the water, and each time he failed to cross. Exhausted, the lion lay down, and in his quietness he heard the river say, "Never fight what isn't here."

Cautiously, the lion looked up and asked, "What isn't here?"

"Your enemy isn't here," answered the river. "Just as you are a lion, I am merely a river."

Now the lion sat very still and studied the ways of the river. After a while, he walked to where a certain current brushed against the shore, and stepping in, floated to the other side."

From the Little Book of Letting Go by Hugh Prather

Is there something you are fighting? Take a moment to pause, quieten and study the situation. You may find that there is nothing to fight.

GASKET FUNDAMENTALS – PART 2

In the first part of this series, we discussed many aspects of gaskets used in pressure vessels such as forces in a flanged joint, relaxation, surface finish, styles of flanges and gasket installation. In this concluding article, we will discuss various types of gaskets used with pressure vessels.

Gaskets can be segregated into three (3) main categories:

- Non-metallic (soft)
- Semi-metallic
- Metallic

It should be noted that gaskets may be categorized differently in other documents i.e. ASME categorizes gaskets into two basic groups, metallic (ASME B16.20 "Metallic Gaskets for Pipe Flanges") and non-metallic (ASME B16.21 "Nonmetallic Flat Gaskets for Pipe Flanges"). For the purposes of this article illustrating the features and characteristics of gaskets have been segregated as noted above.

The mechanical characteristics, performance and capabilities of these categories will vary extensively, depending on the type of gasket selected and the materials from which it is manufactured. Obviously, mechanical properties are an important factor when considering gasket design, but the selection of a gasket is also influenced by:

- Temperature and pressure of the fluid to be contained
- Chemical nature of the fluid, compatibility with the operating fluid
- Mechanical loading affecting the gasket
- Variations of operating conditions (i.e. during cycling)
- Type of joint involved

NONMETALLIC (SOFT) GASKETS

Non-metallic materials are suitable for a wide range of general and corrosive chemical applications, and for low and high temperature applications depending on materials. Their use is generally limited from low to medium fluid pressure applications. Non-metallic gaskets are also typically the least expensive of the three (3) gasket categories, however, specialty materials used in them can be an exception. Types include: compressed fiber materials, flexible graphite, polytetrafluoroethylene (PTFE), and mineral based (i.e. vermiculite, mica).

Non-metallic (soft) gaskets are available as "ring type" (ID/OD gaskets), full face (ID/OD with bolt holes) and can be supplied in custom shapes for specialty flanges (square, rectangular, etc. with and without bolt holes). Technology today has given rise to various automated means of cutting non-metallic (soft) gasket material such as automated knife cutters, laser cutters and punches in just about any shape required. Typical material sheet width is sixty inches (60"), while the sheet length varies by manufacturer. It is not uncommon for non-metallic (soft) gaskets to be segmented for sizes larger than available sheet dimensions.

There are typical tests to help define and compare characteristics of non-metallic (soft) gasket materials. This may be found listed on data sheets from the manufacturers for the product, to help guide in selection of material(s) for a particular application.

Another consideration when selecting soft gasket material(s) is the gasket thickness. Typically nominal non-metallic (soft) gasket thicknesses are, in North America, 1/32", 1/16", 1/8" and, in Europe and Asia, 0.75mm, 1.0mm, 1.5mm, 2.0mm, and 3.0mm. Thicker and thinner gaskets are also available. Contact the manufacturer for specific tolerances on their gasket thickness and thickness variations within a sheet. It should be noted that thickness can affect the pressure/temperature rating of a gasket (refer to Chapter 3 Section A). Gasket thickness should also be noted by the end user when reviewing standardized test data and what particular material thickness was utilized to perform the test compared to the thickness being considered for an application.

For gaskets cut from sheets, it is recommended to use the thinnest material that the flange arrangement will allow. But thick enough to compensate for unevenness of flange surfaces, their parallelism, surface finish, rigidity, etc. The thinner the gasket, the higher the bolt load the gasket can withstand and the less loss of bolt stress, due to relaxation. Also, the thinner the gasket material, the lower the gasket area which will be exposed to attack from the internal pressure and aggressive fluid.

Non-metallic (soft) gaskets are typically either homogeneous (i.e. flexible graphite sheet, virgin PTFE) or they are a composite of several materials each serving a specific purpose (i.e. CNF, mineral based, filled PTFE). Of course, for each material within a gasket, consideration has to be given in terms of compatibility with fluid and temperature. Generally, a composite gasket has the following main components:

- Fiber - added for increased mechanical properties such as tensile and compression (i.e. aramid, cellulose, ceramic, glass)
- Binder - added to increase flexibility and act as a binding agent for the other materials utilized (i.e. NBR, SBR, EPDM)
- Filler - added for various reasons such as reducing cold flow, creep and cost reduction (i.e. silica, clay, mica, powdered graphite, barium sulfate)
- Coatings - added to both faces to facilitate easy release of gasket from flange face. (i.e. PTFE, silicone)

Current non-metallic (soft) gaskets encompass a broad spectrum of materials with a wide range of physical properties, which are suitable for various temperature and pressure ranges. New materials continue to appear in the market, as do variations of conventional products. The total number of materials on the market is extensive and arduous to list. A practical approach is to comment generally on materials commonly in use, which for the most part offer the gasket user a complete enough range to make a proper selection. The user should consult the manufacturer's literature for proper material selection.

ASTM F104 provides one framework for characterizing gasket material properties. The F104 call-out is an alphanumeric sequence which defines specific properties of the material. An end user may use a call-out to specify a gasket material for a particular application. The call-out may not be comprehensive, therefore, for critical applications it is recommended that further investigation of the material properties and suitability take place.

See the materials section below for a brief review of non-metallic (soft) gasket materials and types.

Please note that in the listings which follow, operating limits are indicative only. Many of the gasket materials are composites, containing a variety of binders, fillers, etc., the inclusion of which will modify the performance envelope of the gasket. Operating limits and suitability may vary significantly, dependent upon material constituents and specific operating conditions; under these circumstances, the advice of the gasket manufacturer is vital! Always consult the gasket manufacturer for guidance on suitability for specific applications and limits which may be achieved under specific operating conditions. Whichever gasket material or type is selected, ensure it is correct for the application!

Compressed Fiber Sheet Gasketing

Compressed sheets have been around since the 1890's. It is a composition of fibers, elastomers and fillers that is formed into sheets of finite dimensions with the process dictating maximum sheet width and maximum sheet length.

Fluid compatibility and acceptable application temperature range will be a function of the material utilized and material thickness. Different compressed sheets are available that can function over an extensive range of fluids, temperatures and pressures. End users should ensure they provide complete application service conditions to optimize in-service effectiveness and life.

Flexible Graphite

Flexible graphite refers to natural graphite flake that has been expanded and then compressed. It is a material with the essential characteristics of graphite and complementary properties of flexibility and resilience, as well as an ability to compress and conform.

A sheet density of 70 lbs/ft^3 is often typical of the processed material in the US, while a density of 62.4 $lbs./ft^3$ is typical in Europe and is widely used for the majority of industrial gasket applications. While this density is approximately fifty percent (50%) of the theoretical maximum density of graphite, the through-thickness sheet permeability to fluids, as measured by the helium admittance test, is extremely low. Characteristics of the flexible graphite can be tailored for specific gasket applications simply by changing the starting density of the sheet.

Polytetrafluoroethylene (PTFE) Gasketing

PTFE Gasketing is a material with unique chemical resistance and physical properties. PTFE is chemically inert to most chemicals, with the exception of molten alkali metals and free fluorine and can withstand a wide temperature range. PTFE also has excellent anti-stick, dielectric and impact resistance properties.

However, most PTFE gaskets are subject to cold flow or creep relaxation under compression, which means that gaskets lose thickness, expand in width and length under applied loads. Creep results in the loss of bolt load and ultimately gasket stress in an application. And frequently requires additional efforts to regain that lost stress in the field, which results in increased maintenance costs. Generally, initial seating stress decreases significantly in the first 4 to 24 hours after installation. Also creep increases as temperatures increase.

Rubber (Elastomers)

Because of rubber's many beneficial features and advantages as a sealing material, it has become a primary material used in the production of gaskets.

Today, a wide variety of rubber polymers and compounds, each possessing unique features and advantages, have been developed to produce the highest quality gaskets and sealing materials for many industries.

There are seven basic features of rubber which establish its advantages as an ideal gasket and sealing material:

1. Rubber is a naturally resilient material. It is elastic and squeezes into joint imperfections under relatively light bolt loading. As such, it provides effective sealing properties even under difficult conditions.
2. The availability of various rubber polymers provides a wide range of physical properties:
   - Durometer
   - Tensile strength
   - Elongation
   - Compressive Modulus
   - Compression Set
3. A variety of desired properties can be combined into a single compound to meet specific application needs.
4. Rubber can be reinforced with fabric or steel inserts to add strength and prevent creep, rupture or blowout.
5. Rubber can be compounded to resist the effects of temperature, oil, chemicals, ozone, weathering, aging and abrasion. The result is longer gasket life and reduced maintenance.
6. Rubber sheeting can be produced in an infinite variety of thicknesses, widths, lengths, surface finishes and colors to meet user needs and requirements.

7. Rubber can be specially formulated to meet specific requirements. For example, some Natural Rubber compounds are Food & Drug Administration (FDA) approved, using only ingredients generally recognized as safe and listed in the FDA Federal Register for Food Handling Materials.

As a result of rubber's excellent features and advantages, the actual uses of rubber sealing devices can range dramatically from very general, non-critical applications, such as plumbing; to very demanding and critical high technology service, as encountered in the aircraft industry. Rubber gaskets and sealing materials provide equally optimum results.

SEMI-METALLIC GASKETS

Semi–metallic gaskets are made by combining soft materials such as fillers, facings or insertions together with a metallic component to optimize the characteristics of the composite material as a gasket. In a composite or semi-metallic gasket, the metal generally provides the strength structural requirements and, depending upon configuration, increased resilience. Non-metallic material may also provide resilience and enhanced sealing characteristics. Many synthetic composites and/or mineral-based materials are used as well as elastomer based compounds. These soft materials may be inserted in a specifically designed metallic profile, may be applied to a metallic face or carrier, or may be partially or completely encapsulated by metal. Semi-metallic gaskets can be suitable for both low and high temperature and pressure applications, depending on the materials and configuration used. Types include: grooved metal gaskets with covering layers, metal eyelet, metal jacketed, metal reinforced non-metallic (soft) gaskets (including tanged metal or wire reinforced “sheet” materials), corrugated metallic and spiral wound gaskets among others. Each gasket style has a particular set of materials which must be defined based upon the components making up the gasket. The following is a brief description of the more popular semi-metallic styles and the components involved and considerations when choosing a material for each component.

Metal Reinforced Non-metallic Gaskets

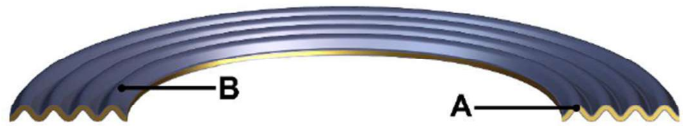
Typically made with a thin stainless, alloy core or wire mesh approximately .002"/.004" thick, it acts as a carrier and support for the soft sealing material. The material used is typically 316L stainless, however, nickel and other materials are also utilized.

A=Metal Insert; B=Non-metallic sheet material

Concerning the .002" /.004" thick cores, they can be either flat metal, perforated or tanged cores. If the core is flat metal, the soft sealing material is usually adhesively attached to the core, while if the core is perforated or tanged, the soft sealing material is mechanically pressed and clinched onto the core. Soft sealing materials such as flexible graphite, PTFE and mineral-based materials (i.e. vermiculite) are often used. Both the soft sealing material and metallic core material should be considered when looking at operating temperature, pressure and fluid.

Corrugated Gaskets

These gaskets consist of a thin metal that is corrugated or embossed with concentric rings and faced with a soft material such as flexible graphite. They utilize the substrate’s geometry to achieve conformability to flange irregularities and promote recovery over the life of the seal, they are essentially a line contact seal. Multiple concentric corrugations provide a labyrinth effect, along with mechanical support for the facing material.



A=Metal Corrugations; B=Soft Facing Material

Corrugations provide resilience, depending on pitch and depth as well as the type and thickness of the metal used. Again, both the thin metal and the facing material must be considered and be suitable for the fluid and operating conditions.

Jacketed Gaskets

Jacketed gaskets consist of a soft compressible filler, partially or wholly encased in a metal jacket. In some instances, corrugated metal is used in place of soft filler material and also may have a soft surface layer of material such as flexible graphite. The primary seal against leakage is the inner metal overlap, where the density of the gasket is the greatest when compressed.

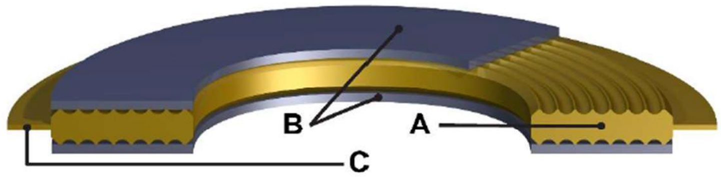
A=Metal Jacket (Outer Layer); B= Filler Material

This area cold flows it creates a seal. The entire outer lap, if any, provides a secondary seal between the flanges when compressed. Any intermediate corrugations, if they exist, may contribute to the labyrinth effect. These gaskets are used for circular as well as non-circular applications and for applications at temperatures up to those which limit the filler and metal endurance. These gaskets are normally specified in thicknesses of 2mm (3/32") or 3mm (1/8") nominal. The thickness of jacketed gaskets cannot be held to as precise dimensions as non-metallic (soft) gaskets, due to accumulated tolerances of the metal, filler and the metal spring back when it is formed. Because of limited resilience, they should not be used in joints requiring close maintenance of the compressed thickness. They can be made with or without pass bars for use in heat exchangers. If pass bars are utilized, the pass bars can be integral (not welded but formed from the same piece of material as the outer ring) or welded (pass bars are separate pieces and welded into the ID of the outer ring). Materials which must be considered are the metal jacket, material used and the filler material.

Grooved Metal Gaskets with Covering Layers (Kammprofile)

Kammprofile gaskets are a solid metal ring with grooved faces and a soft facing material is usually present on the grooved faces to improve sealability. Typical facing materials are flexible graphite, phyllosilicates (mica and vermiculite), or PTFE.

When the gasket is compressed the serrated faces create concentric rings of high stress, enhancing the sealing capabilities of the gasket. Typical configurations include a grooved sealing section or core with soft facing material, a serrated sealing section or core with an independent outer ring (outer ring made with separate piece of material) and a serrated sealing section or core with an integral outer ring. The function of the outer ring is to locate or center the sealing core onto the sealing face (i.e. flange raised face) utilizing the bolts in much the same way an outer ring on a spiral wound gasket would on a raised face flange. However, the outer ring on a kammprofile is not typically used as a torque stop and is thinner than the serrated sealing section of the gasket to ensure the bolt load is concentrated on the sealing section or core and soft facing material. Materials which must be considered are the metal core and soft facing materials used.

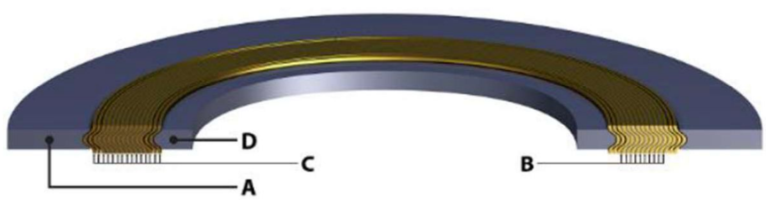


A=Metal Core; B=Soft Facing Material; C=Metal Outer Ring

Spiral Wound Gaskets

These gaskets are comprised of a preformed "V" or chevron shaped metal strips alternately wound with a conformable filler material. The metal windings provide strength and resilience, while the non-metallic filler portion conforms to the irregularities of the flanges aiding in the joint seal. These gaskets can be constructed in a variety of densities accommodating available bolting and pressure conditions.

Sealing is achieved through a combination of yielding and flowing of the "V" shaped metal material and conformable fillers during the compression phase. They can be made in several configurations, to accommodate various flange facing shapes. This gasket can be made with windings to include a solid metal outer ring, solid metal inner ring or both.



A=Outer Ring; B=Filler Material; C=Metal "V" Windings; D=Inner Ring

The solid metal inner and outer rings serve various functions. The outer ring serves to center the windings onto the sealing face, utilizing the inner edge of the bolts. The inner ring acts to help support the ID of the windings/ to help prevent inward buckling of the windings. Both inner and outer rings are typically made of a thickness that is within the optimal compression thickness range of the windings. Materials which need to be considered for the manufacture of such gaskets includes the inner ring metal, metal winding strip, filler material and outer ring. If an inner ring is present, it should be compatible with the fluid being contained and be able to withstand the temperatures encountered in the application. The metal winding strip has the same considerations as the inner ring, and is often made utilizing the same material type. The filler material utilized should be compatible with the fluid and again, be suitable for the temperatures to be encountered in the application. The outer ring should also be suitable for the temperatures encountered, but its material selection is less critical than the winding strip and inner ring material, as it is not exposed to the process fluid.

Envelope Gaskets

An envelope type gasket is a composite consisting of two parts; envelope (shield) and insert (filler). These gaskets are primarily used in conjunction with corrosive resistant equipment constructed of stoneware, glass, glass-lined metal, etc. The envelope serves as the corrosion resistant part of the gasket and is usually PTFE.

A=Slit Type; B=Folded Type; C= Machined/Square Type

There are basically three (3) designs of envelopes which are "Slit", "Machined" and the "Square" cut (inside diameter, flat) or "Folded" type (inside diameter, round). The "Slit" type is most commonly used with inside diameters of 24" and under. The "Machined" type is used where close tolerances, narrow flange widths or a reduction in the dead space is desirable. The "Folded" shield gasket is used on larger than 24" I.D. gaskets. "Slit" and "Machined" gaskets are lathe cut from billets or sleeves; the "Folded" shield is made from tape, which produces a continuous jacket or shield. The insert material may be selected for a particular environment or designed to cover a wide variety of conditions. It provides the gasket with good compressibility and recovery to allow the minimum seating stress and proper conformability that is required for this type of service. The insert may be made of any recognized gasket material, with or without metal reinforcing, taking into consideration temperature, pressure and corrosive conditions. The most popular insert materials are compressed and beater add products. Elastomeric materials have a tendency to flow and cause envelope splitting; whereas extremely hard materials require excessive bolt loading.

METALLIC GASKETS

Metallic gaskets can be fabricated from a single metal or a combination of metallic materials, in a variety of shapes and sizes. Metallic gaskets are suitable for high temperature and pressure applications. Higher loads are required to seat the gaskets. Types include flat, grooved, round cross-section solid metal, lens rings, ring type joints (RTJ's) and welded gaskets. A brief description of the more popular styles are described below.

Flat Metal Gaskets

These are defined as gaskets that are relatively thin compared to their width. They are cut from sheet metal and typically have a reduced area to increase unit load and improve sealability. Plain metal, washer shaped gaskets are relatively inexpensive to produce and can perform satisfactorily in simple applications. Surface finish on the gasket and flange facing is critical.

Serrated or Grooved Flat Metal Gaskets

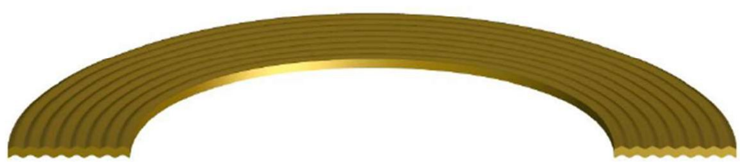
This is a flat metal gasket with concentric serrations or grooves, which reduce surface contact area between the gasket and flange face. Thus creating concentric rings of high stress when loaded.

Round Cross-Section Solid Metal Gaskets

These gaskets are generally made from round wire of the desired diameter cut to the length of the gasket mean circumference, then formed into a circle and welded. They provide positive, gas tight seals at relatively low flange pressures. Since only line contact occurs, they have high local seating stress at low bolt loads. The contact faces increase in width as the gasket is compressed, effectively flowing into the flange faces. Round solid gaskets are used on equipment designed specifically for them. Flanges are usually grooved or otherwise faced to accurately locate the gasket during assembly. However, there are some applications in which they are used between flat faces.

Corrugated Metal (No Filler of Facing)

Corrugated metal gaskets are plain metal with concentric corrugations. For low pressure (500 psi) applications such as valve bonnets, gas turbines and combustion lines.



Solid Metal-Heavy Cross Section Gaskets

These gaskets are machined from solid metal and are designed for high pressure, high temperature service where conditions require a special joint design. Solid metal-heavy cross-section gaskets may seal by initial line contact or wedging and coining action, causing high unit stresses and the metal surface to flow at this line contact. Surface finish and dimensional accuracy is critical on both elements. Another type of solid metal-heavy cross-section gaskets includes welded gaskets (i.e. weld rings and weld membrane gaskets). The more common solid metal-heavy cross-section gaskets are described below:

Style R Gaskets

The oval cross-section is the original ring joint design. The octagonal cross-section is an evolution of the oval design. Both oval and octagonal rings can be used with flanges having the standard ring joint flat bottom groove.

The former round bottom groove is no longer shown in the flange specifications and can only be used with an oval gasket. Standard sizes of these gaskets are manufactured to ASME B26.20 and API 6A specifications.

Style R Gaskets

Style RX Gaskets

Style BX Gaskets

Style SRX and SBX Gaskets

Lens Ring Gaskets

Bridgeman Gaskets

Delta Gaskets

Style RX Gaskets

The RX style ring joint has a unique self-sealing action. The outside bevels of the ring make the initial contact with the groove as the flanges are brought together with the flange bolting. This provides initial sealing of the joint with the gasket seating against the groove surfaces. During pressurization the gasket loading increases against the groove. Style RX ring joint gaskets as specified in ASME B16.20 and API 6A are completely interchangeable with the oval and octagonal series of identical reference numbers and are used in the same flange grooves.

Style BX Gaskets

The BX style ring is designed for use with grooved flanges on special applications involving high pressures from 5,000 psi to 15,000 psi. The pitch diameter of the ring is slightly larger than the pitch diameter of the groove, thus initial contact is made on the outside of the ring, pre-loading the gasket and creating a pressure-energized seal. Connections utilizing Style BX have a limited amount of positive interference, ensuring that the gasket will be “coined” in the flange grooves. Style BX ring joint gaskets can only be used with API BX flanges and are not interchangeable with the Style RX series.

Style SRX and SBX Gaskets

Style SRX and SBX ring joint gaskets are made per API 17D for subsea wellhead and tree equipment. These ring joint gaskets with "S" suffix designations indicate that these gaskets have cross-drilled holes which connects fluid volume located between the flange joint groove, the ring joint gasket and the bore or ID. This hole prevents fluid located between the joint groove and the ring joint gasket from interfering with proper seating of the gasket. During installation, the gasket is compressed into the flange groove and fluid is allowed to vent into the bore or ID.

Lens Ring Gaskets

These are for high temperature, high pressure applications on pipework, valves and pressure vessels. Lens rings have two (2) spherical faces and are used between flanges with straight tapered twenty degree (20°) faces. Providing a line contact seal approximately one-third across the gasket face, the specially designed cross-section affects a pressure-energized seal.

Bridgeman Gaskets

This pressure-activated design is used for pressure vessel and valve bonnet gaskets, at pressures 1500 psi and higher. This design has also been adapted to pipe joints which are subject to extreme thermal shock conditions.

Delta Gaskets

The pressure-activated Delta cross-section is a pressure vessel or valve bonnet gasket, useful for pressure ranges of 5000 psi and higher.

COMMON METALLIC GASKET MATERIALS

Aluminum	Has excellent corrosion resistance to organic acids except nitric acids.
Brass	Copper alloys are generally used with non-oxidizing acids, alkaline and neutral salt solutions.
Carbon Steel	The most commonly used material for manufacturing double jacketed gaskets. It has poor resistance to corrosion and should be used with caution when in contact with water or diluted acids.
Copper	Used successfully in acetic acids, nitrates and many organic chemicals
Hastelloy B	This is a corrosion resistant alloy resists corrosion of hydrochloric acid under most conditions, as well as, other halogen acids. It is also resistant to phosphoric acid and reducing conditions.
Hastelloy C	Offers exceptional resistance to severe oxidizing conditions encountered with nitric acid, free chlorine as well as strong aqueous and acid solutions.
Inconel	Withstands high temperatures and has excellent resistance to corrosion by halogen gases and compounds.
Lead	Good resistance to sulfuric, chromic and phosphoric acids. It is soft and malleable.
Monel	Excellent resistance to most acids and alkalis except extremely oxidant acids.
Nickel	Excellent resistance to caustic substances. Has a high degree of corrosion resistance to neutral and distilled water.
Titanium	Has a good resistance to wet chlorine and chlorine dioxide.
304 SS	This material is widely used in the manufacture of industrial gasketing, due to its low cost and excellent resistance to corrosion.
316/316L SS	This material generally offers a higher resistance to corrosion than type 304SS.
321 SS	This alloy is similar to 304SS but titanium is added. It is widely used in high temperature corrosive applications.
347 SS	This alloy is similar to 304SS but columbium and titanium are added. It has good performance in high temperature corrosive applications.
410 SS	This stainless steel is a heat treatable 12% chromium steel, which combines good general corrosion resistance with high strength.

References:

FSA (Fluid Sealing Association) Gasket Handbook

DESIGN AND CONSTRUCTION OF LNG STORAGE TANKS

INTRODUCTION

Prior to 1960s, natural gas had only been regarded as a by-product of crude oil production; there was no use for it and so it was either pumped back into the ground or flared. But all that has changed – natural gas currently accounts for 22% of global energy supplies. The use of natural gas involves transport and storage difficulties. Transport via pipelines is economical up to a distance of 2500 to 3000 miles, depending on the boundary conditions. In the case of difficult geographic circumstances, such as supplies to islands, or where it is necessary to cross mountain ranges, supplying gas via a pipeline is much more difficult and costly. Therefore, the method of liquefying natural gas and then transporting it over great distances in ships had already become established by the mid-20th century.

LNG has about 60 % of the Btu value of an equivalent volume of marine diesel, so it takes 1.7 gallons of LNG to produce the same power as one gallon of diesel. However, the lower cost of LNG combined with lower emissions gives LNG an advantage in operating costs. Various studies have put that advantage at anywhere from 15 to 30 % or more, depending on the price differential between the two fuels.

Complying with emissions requirements is difficult when using diesel and heavy oil as marine fuel. But using LNG as a marine fuel results in – compared with diesel – about 90% less nitrogen oxide, up to 20% less carbon dioxide and the complete avoidance of Sulphur dioxide and fine particles. There are about 30 LNG-powered vessels in service worldwide today and there are another 30 or so in design or construction. That is not counting the almost 400 LNG carriers, many of which are dual fuel, so they can decide on the fly whether to burn their boil-off or regasify it, based on the relative prices of LNG and other fuels.

LNG technology takes advantage of the physical material behavior of natural gas, the main constituent of which is methane. At the transition from the gaseous to the liquid state, the volume is reduced to 1/600. However, this requires the temperature of the gas to be lowered to -260°F. Only this extreme reduction in volume makes transport in ships economically viable. The entirety of the elements required for transporting LNG in ships is known as the "LNG chain", which consists of the liquefaction plant in the country supplying the gas, LNG tanks for intermediate storage of the liquefied gas, jetties as berths for the special LNG transport vessels, tanks for the intermediate storage at the receiving (i.e. import) terminal and a regasification plant in the country importing the gas.

THIS ARTICLE WILL ADDRESS THE LNG STORAGE TANKS.

It is common practice these days to build full containment tanks, which consist of an outer concrete secondary container surrounding an inner steel primary container. The prestressed concrete outer container serves to protect the thin-wall steel inner container against external actions and also functions as a backup container in the event of the failure of the primary container. The outer container must prevent uncontrolled leakage of vapors into the environment and must also be able to contain the liquefied gas and withstand any overpressure.

The great hazard potential of LNG is the risk of fire. If LNG changes to its gaseous state and mixes with air, the result is a combustible gas that can explode, and certainly burns very fiercely. Safe transport and storage are the technical challenges of LNG. At these low temperatures, the materials normally used in the construction industry exhibit a distinctly brittle behavior and fail abruptly. During normal operation, the steel inner container takes on the temperature of the liquefied gas and cools to -260°F. In order to guarantee sufficient ductility at this temperature, the inner container must be made from 9% nickel steel or stainless steel. Thermal insulation about 3 feet thick is placed between the steel inner and concrete outer containers.

Between the underside of the steel inner tank and the base slab of the concrete outer tank, the thermal insulation consists of loadbearing cellular glass (often called foam glass).The annular space between the inner and outer containers is filled with perlite, and a layer of elastic material (resilient blanket) is installed to compensate for the horizontal thermal deformation of the inner container. The insulation on the aluminum roof of the inner container is made from glass fiber or perlite. What at first sight seem to be very generous dimensions are necessary in order to keep the boil-off rate below 0.05% by volume per day. Should the inner container fail, the inside face of the concrete outer container cools to -260°F, and that calls for the use of special reinforcement that can resist such low temperatures.

The dynamic design for the seismic load case must take into account the action of the sloshing of the liquid and the interaction with the concrete outer container. The tank must be designed to withstand a so-called operating basis earthquake (OBE), i.e. is not damaged and remains operable, and also for a so-called safe shutdown earthquake (SSE).

REGULATIONS

The American Petroleum Institute was founded in 1919 and began publishing the series of specifications API 12A to API 12G in 1928, which dealt with riveted, bolted and welded tanks for the storage of oil. API 12C (welded tanks) led to the drawing up of one of the most influential standards for steel tanks – API 620 *Design and Construction of Large, Welded, Low-pressure Storage Tanks*. This publication regulates the design and configuration of welded flat-bottom tanks for the storage of liquids at ambient temperature and pressures up to 15 psi. It includes two important appendices: Appendix Q and Appendix R. Appendix Q covers design procedures for the storage of liquefied ethane, ethylene and methane at temperatures down to -265°F and max. 15 psi pressure. Appendix R deals with the design of tanks for the storage of refrigerated products at temperatures down to -60°F. Throughout the world, most of the inner containers for LNG storage tanks are still designed and constructed according to this publication.

British Standards (BS) followed the American lead and employed the same classification according to liquefied gases and temperature ranges. The first two standards were BS 4741 for temperatures down to -60°F, which was published in 1971, and BS 5387 for temperatures down to -320°F, which followed in 1976. The requirements in those standards corresponded to the state of the art of that period – a tank with just one wall, a so-called single containment tank.

In the next step the Engineering Equipment and Material Users Association (EEMUA) drew up its *Recommendations for the Design and Construction of Refrigerated Liquefied Gas Storage Tanks*, which appeared as publication No. 147 in 1986. The classification as single, double and full containment tanks was used for the first time in this document, something that was taken up by all subsequent standards and specifications. Prompted by the failure of a tank in Qatar, it was decided to raise the EEMUA regulations to a more binding, higher legal level and publish them as BS 7777, parts 1 to 4.The provisions of BS 7777 (since withdrawn) included references to other British Standards and was harmonized with those. Concrete structures were designed according to BS 8110. As European standards appeared, many of the provisions of BS 7777 were incorporated in EN 14620, which was published in 2006. Links to and alignment with other regulations were lost to some extent. Therefore, EN 14620 has a number of gaps, such as the definition of partial safety factors and load case superpositions, which then have to be specified in project documentation. Working group WG 9 of CEN TC265 initiated a revision of EN 14620 and the work began in the spring of 2015. Five countries are involved.

The adaptation and development of LNG standards was pursued vigorously in the USA. The aim was to draw up a completely new standard that would close the gaps in the existing standards, which tended to focus on steel tanks, and provide self-contained rules for LNG tanks made from concrete. It was during the ACI Convention in San Francisco in the autumn of 2004 that the newly established ACI 376 Committee met for the first time. By 2011 they were ready to publish the all-new ACI 376 *Code Requirements for Design and Construction of Concrete*

Structures for the Containment of Refrigerated Liquefied Gases. In terms of content and the many details provided, it goes far beyond the scope of EN 14620.

We will discuss in some detail the EEMUA Publication No. 147 and BS 7777, and Design and Construction of LNG Tanks – EN 14620.

EEMUA Publication No. 147 and BS 7777

Flat-bottom, vertical, cylindrical steel tanks built in situ for the storage of refrigerated liquefied gases were normally designed with a single-wall shell. They were surrounded by an earth embankment at a considerable distance. If a second steel single-wall shell was required, this was built to fix the insulation in position and protect it against the weather, thus maintaining its insulating function. The design and configuration of such tanks was carried out according to two standards:

- BS 4741 (1971): Specification for vertical, cylindrical, welded, steel storage tanks for low-temperature service: single-wall tanks for temperatures down to -60°F
- BS 5387 (1976): Specification for vertical, cylindrical, welded storage tanks for low-temperature service: double-wall tanks for temperatures down to -320°F

Up until the 1970s, it was usual to store all liquefied gas products in single containment tanks. After that there was a trend towards adding an earth embankment, wall or outer container around tanks for hydrocarbons and ammonia. If the inner container leaked, the enclosure or outer container would prevent the liquefied products from escaping uncontrolled into the surroundings. Although the earth embankment solution – either a smaller embankment at a greater distance from the tank or a higher embankment very close to the tank – increased the footprint, it did lead to enhanced protection for the surrounding area. It is still customary these days to store liquid oxygen, nitrogen and argon in single containment tanks.

BS 4741 and BS 5387 only applied to single-wall tanks; they did not contain specifications or requirements for the choice of material, design, calculations, load cases, construction details, etc. for double or full containment tanks. In order to rectify this shortcoming, the EEMUA's Storage Tank Committee published its *Recommendations for the Design and Construction of Refrigerated Liquefied Gas Storage Tanks* as publication No. 147 in 1986. The aim of the EEMUA here was to create a basis for a subsequent British Standard – and in 1993, BS 7777 was introduced to replace BS 4741 and BS 5387. BS 7777 was divided into four parts:

- Part 1: Guide to the general provisions applying for design, construction, installation and operation
- Part 2: Specification for the design and construction of single, double and full containment metal tanks for the storage of liquefied gas at temperatures down to -265°F
- Part 3: Recommendations for the design and construction of prestressed and reinforced concrete tanks and tank foundations, and for the design and installation of tank insulation, tank liners and tank coatings
- Part 4: Specification for the design and construction of single containment tanks for the storage of liquid oxygen, liquid nitrogen and liquid argon

Design and Construction of LNG Tanks – EN 14620

EN 14620, Design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0◦C and −165◦C, is divided into five parts:

Part 1: General
Part 2: Metallic components
Part 3: Concrete components
Part 4: Insulation components
Part 5: Testing, drying, purging and cool-down

Part 1 defines general requirements regarding the conception and selection of tank types and general performance criteria. The conception and selection of tanks is explained in detail here. The scope of applicability covers temperatures from 0 to -265°F and overpressures up to 7.5 psi. Where the pressure exceeds 7.5 psi, we speak of a pressure vessel, which falls within the scope of EN 13445.

From the constructional viewpoint, this standard is restricted to primary containers of steel only, and explicitly excludes inner containers made from prestressed concrete. Large amounts of methane, ethane, propane, butane, ethylene, propylene, liquefied natural gas (LNG) and liquefied petroleum gas (LPG) are stored in these tanks. All these gases fall under the heading of “refrigerated liquefied gases” (RLGs). The physical properties of these gases are given in Table 1. EN 14620 does not apply to the storage of argon (-303°F), oxygen (-297°F) or nitrogen (-303°F); these gases will be covered by EN 14620 Part 6, which is currently in preparation.

Table 1: Physical Properties of Gases According to EN 14620-1

Name	Chemical Formula	Boiling Point [°F]	Liquid Density at Boiling Point [lb/ft^3]	Volume of Gas Liberated by 1 ft^3 of Liquid [ft^3]
n-butane	C_4H_{10}	31.1	37.5	239
Isobutane	C_4H_{10}	10.9	37.0	236
Ammonia	NH_3	-27.9	42.5	910
Butadiene	C_4H_6	23.9	40.5	279
Propane	C_3H_8	-43.6	36.3	311
Propylene	C_3H_6	-53.9	38.3	388
Ethane	C_2H_6	-127.5	34.0	432
Ethylene	C_2H_4	-154.7	35.4	482
Methane	CH_4	-258.7	26.3	630

The possible variations in these tanks with respect to stored product, volume and configuration are enormous, and so the content of the EN 14620 series cannot cover every eventuality, every detail. In the definition of the scope of the standard given in Part 1, it is explicitly mentioned that if complete requirements for a specific design are not provided, it is up to the designer to agree the design principles and details plus the appropriate reliability with the purchaser’s authorized representative. What happens in practice is that the configuration is specified as part of a front end engineering design (FEED) for an LNG terminal.

A specification for the LNG storage tanks for a particular project is drawn up which defines the regulations, assumptions, analyses and construction details.

LNG storage tanks normally consist of a steel inner container and concrete outer container which are designed and built by different specialist firms. The design and, more specifically, the fabrication/construction cannot be carried out separately. Therefore, section 7 clearly assigns the responsibilities for the steel, concrete and insulation components as well as the overall responsibility for the coordination. The design and configuration details are outlined in the respective sections.

EN 14620 Part 2 specifies the general requirements relevant to the materials, design, fabrication, welding methods, welding, construction and installation of metal components for tanks. The types of steel required are defined depending on the liquefied gas to be stored, and hence the respective temperature and type of tank (See Table 2).

The permissible stresses in plates and weld seams during normal operation and testing are defined, also the minimum thickness of the metal shell, which is 1.5 in for butane and propane tanks, 2 in for ethane and LNG tanks. The maximum stress in the metal container results from the volume of liquid in the tank and seismic action. The minimum thickness for the metal plates indirectly limits the volume of the tank. Part 2 also includes information on design and calculations, fabrication and welding. Minimum plate thicknesses or cross-section dimensions are prescribed for many parts depending on the diameter of the tank.

Table 2: Type of Steel Depending on Stored Product and Type of Tank

Stored Product	Single Containment Tank	Double or Full Containment Tank	Membrane Tank	Normal Storage Temperature of Liquefied Gas
Butane	Type II	Type I		14°F
Ammonia	Type II	Type I		-31°F
Propane/ Propylene	Type III	Type II	Type V	-58°F
Ethane/ Ethylene	Type IV	Type IV	Type V	-157°F
LNG	Type IV	Type IV	Type V	-265°F

Part 3 describes principles and details for the design and construction of concrete components, i.e. the secondary or concrete outer container, as according to the definition in Part 1, the primary (inner) container is made of steel. Requirements regarding the materials (concrete, conventional reinforcement, prestressing steel) take up only one page. In the case of concrete, the user is referred to EN 1992-1-1 and EN 206. The information provided in Annex A.1 merely calls for concrete class C40/50 for prestressed concrete components, a low water/cement ratio and a suitable percentage of entrained air, and permits the use of a reduced expansion coefficient and thermal material properties in the calculations.

Prestressing steel, anchorages and ducts must comply with EN 1992-1-1. Furthermore, it is necessary to verify that the prestressing steel and the anchorages are suitable for the low temperatures to which they will be exposed. The section on conventional steel reinforcement distinguishes between temperatures above and below -4°F, as in the preceding standard, BS 7777. Conventional reinforcement for design temperatures that do not drop below -4°F during normal operation or abnormal conditions only has to comply with EN 1992-1-1. Reinforcement and socket couplers in tension components and subjected to temperatures below -4°F must satisfy additional requirements.

“Cryogenic reinforcement”, i.e. reinforcement with a higher content of nickel and other alloying constituents, is normally used for the inside face of the concrete wall because the temperature at the level of the reinforcement can drop to about -238°F during the “liquid spill” load case. The base slab is not affected by this requirement as it is protected against such temperatures by a so-called secondary bottom made from 9% nickel steel placed within the insulation. Normal reinforcement can be used in the outside face of the wall, even if temperatures below -4°F can occur in winter. It should be remembered that a temperature range of -40 to +212°F is defined in EN 1992-1-1, Annex C.

Annex A.3 provides details of tensile tests at low temperatures. Annex B contains very general information on prestressed concrete tanks, does not specify any particular requirements. Theoretically possible fixed (= monolithic), sliding and pinned joints are illustrated for the junction between the wall and the base of the tank. In the case of LNG, the boundary conditions with regard to subsoil, loads and temperature are such that only monolithic connections will satisfy the ultimate and serviceability limit state analyses.

Part 4 contains details of the design requirements for and selection of insulating materials, the design of the vapor barrier against the infiltration of water vapor from outside and the vapor of the stored product from the inside, the design of the insulation system, the installation of the insulation, commissioning and maintenance. The liquefied gas stored in LNG tanks has a boiling point that is below the ambient temperature. It is therefore essential to prevent the uncontrolled or excessive infiltration of heat of evaporation. The primary functions of the insulation are to maintain a defined temperature below the boiling point, protect the components of the outer container which are not designed for such low temperatures and to limit the boil-off rate. Thermal insulation and foundation heating systems prevent the soil from freezing and the ensuing frost heave plus the formation of condensation and ice on the surfaces of the outer container. The annex to Part 4 contains recommendations for the use of various insulating materials for individual tank components and different types of tank.

In the case of LNG tanks, the thermal insulation is by no means an unimportant component, instead a vital element that is necessary if the functionality and economics of the tank system are to be guaranteed. The standard does not specify a permissible value for the quality of the thermal insulation, i.e. the maximum boil-off rate per 24 hr. The value customarily taken is 0.05% of the tank volume. The boundary conditions for the analysis are ambient temperature, solar radiation and wind speed, which are laid down in the tank specification.

Part 5 defines the requirements regarding testing, drying, purging and cool-down of tanks. Tank tests are divided into hydrostatic and pneumatic tests. When using single-wall tanks, these two tests are carried out together. The testing pressure is applied in the vapor space above the water. In the case of double-wall and full containment tanks, the two tests can be performed simultaneously or separately. The pressure test involves applying a pressure that is 1.25 times the design pressure. Prior to testing, pressure-relief valves must be installed and set to this pressure; they are removed again after the test. The tank is also tested for a partial vacuum, which corresponds to the design negative pressure of the tank, normally 0.07 or 0.145 psig. The partial vacuum is achieved with a pump or simply by lowering the level of the water.

The liquid-tightness test distinguishes between the hydrostatic pressure at full height (FH) and at partial height (PH). In the former, the inner container is filled with water to its maximum design level. In the latter, the filling level results from the product of 1.25 times the maximum design liquid level and the density of the respective liquid gas.

A combination of filling with water and internal pressure increases the load on the base slab and foundation on the one hand, but, on the other, a tank filled with water considerably reduces the volume to which the internal pressure can be applied. In addition, it reduces the duration. The decision regarding the method depends very much on the local conditions.

LOOK IN THIS SPACE IN A FUTURE ISSUE OF THE NEWSLETTER FOR A COMPREHENSIVE DISCUSSION ON DIFFERENT TANK TYPES AND CONSTRUCTION OF LNG TANKS.

References:

Design and Construction of LNG Storage Tanks by Josef Rotzer

DUPLEX STAINLESS STEELS

INTRODUCTION

Duplex stainless steels are a family of grades combining good corrosion resistance with high strength and ease of fabrication. Their typical properties are between those of austenitic and ferritic stainless steels but tend to be closer to those of ferritics and to carbon steels. The chloride pitting and crevice corrosion resistance of duplex stainless steels is a function of chromium, molybdenum, tungsten and nitrogen content. It may be similar to that of Type 316 or range above that of sea water stainless steels such as 6% Mo austenitic stainless steels. All the duplex stainless steels have chloride stress corrosion cracking resistance significantly greater than that of 300-series austenitic stainless steels. They all provide significantly greater strength than austenitic grades while exhibiting good ductility and toughness.

Figure 1: Alloy 2205 Continuous Sulfate Pulp Digester and Impregnation Tower

The grade is generally not suitable for use at temperatures above 570°F or below -58°F because of reduced toughness outside this range. You are most likely to encounter 2205 stainless steel being used in industrial environments such as petrochemical, chemical, oil, gas and paper plants. Alloy 2205 has been available for several years in UNS grade designation S31803, and more recently as higher corrosion resistant composition S32205 (Table 1). Unless otherwise stated in the specification, alloy 2205 refers to S32205 composition.

Table 1: Composition of 2205 and Alternative Grades (Single Values are Maximum)

Grade	Common Name	C%	Mn%	Si%	P%	S%	Cr%	Ni%	Mo%	N%
S31803	2205	0.030	2.00	1.00	0.030	0.020	21.0-23.0	4.5-6.5	2.5-3.5	0.08-0.20
S32205	2205	0.030	2.00	1.00	0.030	0.020	22.0-23.0	4.5-6.5	3.0-3.5	0.14-0.20

BRIEF HISTORY

The early grades of duplex stainless steels were alloys of chromium, nickel and molybdenum, and were developed to increase the intergranular corrosion problems in the early high carbon austenitic stainless steels. These first generation duplex stainless steels provided good performance characteristics but had limitations in the as-welded condition. The heat affected zone (HAZ) had low toughness because of excessive ferrite and significantly lower corrosion resistance than that of the base metal. In 1968, the invention of the stainless steel refining process, argon oxygen decarburization (AOD) opened the possibility of a broad spectrum of new stainless steels. In particular, it made possible deliberate addition of nitrogen as an alloying element. Nitrogen alloying of duplex stainless steels makes possible HAZ toughness and corrosion resistance which approximates that of the base metal in the as-welded condition.

The second generation duplex stainless steels are defined by their nitrogen alloying. This new commercial development, which began in late 1970s, coincided with the development of offshore gas and oil fields in the North Sea and the demand for stainless steels with excellent chloride corrosion resistance, good fabricability and high strength. Alloy 2205 duplex stainless steel became the workhorse of the second generation duplex grades and was used extensively for gas gathering line pipe and process application on offshore platforms. The high strength of these steels allowed for reduced wall thickness and reduced weight on platform and provided considerable incentive for their use. Today, Alloy 2205 duplex stainless steel accounts for more than 80% of all duplex stainless steel usage.

CHEMICAL COMPOSITION

It is generally accepted that the favorable properties of the duplex stainless steels can be achieved for phase balances in the range of 30 to 70% ferrite and austenite. However, duplex stainless steels are most commonly considered to have slightly equal amounts of ferrite and austenite, with current commercial production just slightly favoring the austenite for best toughness and processing characteristics. Following is a brief review of the effects of the most important alloying elements on the mechanical, physical and corrosion properties of duplex stainless steels:

<u>CHROMIUM</u>: A minimum of 10.5% chromium is necessary to form a stable chromium passive film that is sufficient to protect the steel against mild atmospheric corrosion. The corrosion resistance of the stainless steels increases with increasing chromium content. Chromium is a ferrite former, meaning that the addition of chromium promotes the body-centered cubic structure of iron. At higher chromium contents, more nickel is necessary to form an austenitic or duplex (austenitic-ferritic) structure. Higher chromium also promotes the formation of intermetallic phases. There is usually at least 16% chromium in austenitic stainless steels and 20% chromium in duplex grades. Chromium also increases the oxidation resistance at elevated temperatures. This effect is important because of its influence on the formation and removal of oxide scale (heat tint) resulting from heat treatment or welding. Duplex stainless steels are more difficult to pickle and heat tint removal is more difficult than that with austenitic stainless steels.

<u>MOLYBDENUM</u>: Molybdenum acts to support chromium in providing pitting corrosion resistance to stainless steels. When the chromium content of stainless steels is at least 18%, addition of molybdenum becomes about three times as effective as chromium additions against pitting and crevice corrosion in chloride-containing environments. Molybdenum is also a ferrite former, and increases the tendency of stainless steel to form detrimental intermetallic phases. For this reason, it is usually restricted to less than about 7.5% in austenitic stainless steels and 4% in duplex grades.

<u>NITROGEN</u>: Nitrogen increases the pitting and crevice corrosion resistance of austenitic and duplex stainless steels. It also substantially increases their strength and, in fact, it is the most effective solid solution strengthening element and a low-cost alloying element. The improved toughness of the nitrogen bearing duplex stainless steels is due to their greater austenite content and reduced intermetallic content. Nitrogen

does not prevent the precipitation of intermetallic phases but delays the formation of intermetallics enough to permit processing and fabrication of duplex grades.

Nitrogen is a strong austenitic former and can replace some nickel in the austenitic stainless steels. In duplex stainless steels, nitrogen is typically added and amount of nickel is adjusted to achieve the desired phase balance.

NICKEL: Nickel is an austenite stabilizer, which promotes a change of crystal structure of stainless steel from body-centered cubic (ferritic) to face-centered cubic (austenitic). Ferritic stainless steels contain little or no nickel, duplex stainless steels contain low to intermediate amount of nickel (1.5 to 7%) and the 300-series austenitic stainless steels contain at least 6% nickel (See Figure 2). The addition of nickel delays the formation of detrimental intermetallic phases in austenitic stainless steels but is far less effective than nitrogen in delaying their formation in duplex stainless steels. The face-centered cubic structure is responsible for the excellent toughness of the austenitic stainless steels. Its presence in about half of the microstructure of duplex grades greatly increases their toughness relative to ferritic stainless steels.

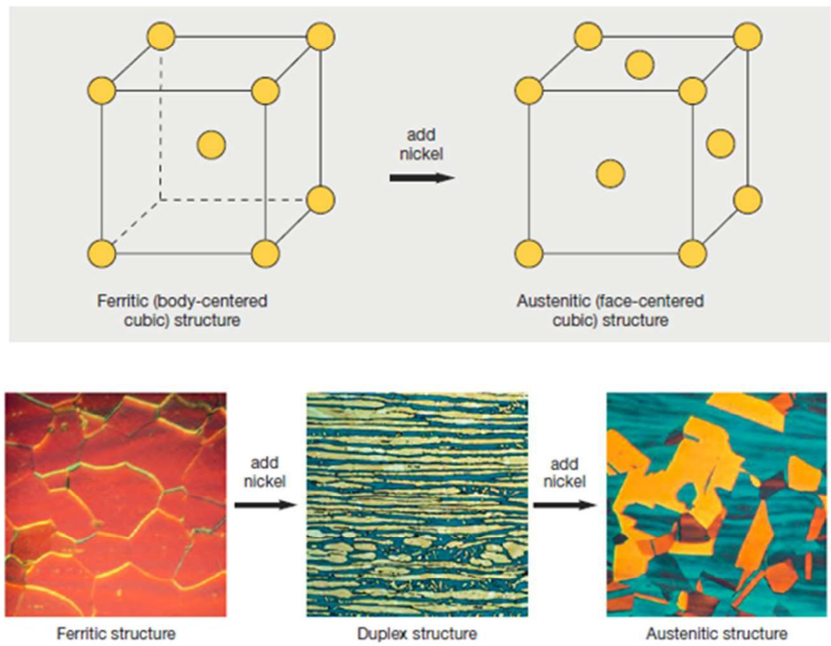


Figure 2: Change in Microstructure of Stainless Steel by Addition of Nickel

CORROSION RESISTANCE

Duplex stainless steels exhibit a high level of corrosion resistance in most environments where the standard austenitic grades are used. However, there are some notable exceptions where they are decidedly superior. This results from their high chromium content, which is beneficial in oxidizing acids, along with sufficient molybdenum and nickel to provide resistance in mildly reducing acid environments. The relatively high chromium, molybdenum and nitrogen also give them very good resistance to chloride induced pitting and crevice corrosion. Their duplex structure is an advantage in potential chloride stress corrosion cracking environments. If the microstructure contains at least 25 to 30% ferrite, duplex stainless steels are far more resistant to chloride stress corrosion cracking that austenitic stainless steel types 304 and 316. Ferrite is, however, susceptible to hydrogen embrittlement. Thus duplex stainless steels do not have high resistance in environments or applications where hydrogen may be charged into the metal and cause hydrogen embrittlement.

RESISTANCE TO ACIDS

- Duplex stainless steels outperform many high-nickel austenitic stainless steels in solutions containing up to about 15% acid.

	▪ They are better than Type 316 or Type 317 stainless steels through at least 40% acid. ▪ Duplex stainless steels do not have sufficient nickel to resist the strong reducing conditions of mid-concentration sulfuric or hydrochloric acids. ▪ They are good candidates for nitric acid service and strong organic acids. ▪ Duplex stainless steels are also used in processes involving halogenated hydrocarbons because of their resistance to pitting and stress corrosion.
<u>RESISTANCE TO CAUSTICS</u>	▪ High chromium content and presence of ferrite provides for good performance of duplex stainless steels in caustic environments. ▪ At moderate temperatures, corrosion rates are lower than those of the standard austenitic grades.
<u>PITTING AND CREVICE CORROSION RESISTANCE</u>	▪ For a particular chloride environment, each stainless steel is characterized by a Critical Pitting Temperature (CPT) below which pitting corrosion will not occur. ▪ Similarly, there is a Critical Crevice Temperature (CCT) that is dependent on the stainless steel, the chloride environment and the nature of crevice. ▪ Typically, CCT will be 27 to 36°F lower than the CPT for the same steel and same corrosion environment. ▪ The CPT and CCT for 2205 duplex stainless steel are well above those of Type 316 stainless steel which makes 2205 a versatile material in applications where chlorides are concentrated by evaporation, such as in vapor spaces of heat exchangers. ▪ 2205 duplex stainless steel does not have crevice corrosion resistance to withstand seawater in critical applications such as thin-wall heat exchanger tubes, or where deposits or crevices exist.
<u>STRESS CORROSION CRACKING (SSC) RESISTANCE</u>	▪ Compared with austenitic stainless steels with similar chloride pitting and crevice corrosion resistance, duplex stainless steels exhibit significantly better SSC resistance. ▪ However, duplex stainless steels may be susceptible to SSC in high temperature chloride containing environment, or when conditions favor hydrogen induced cracking.

MECHANICAL PROPERTIES

Duplex stainless steels have exceptional mechanical properties. They are listed for the Alloy 2205 duplex grade in Table 2. The room temperature yield strength in the solution-annealed condition is more than double that of the standard austenitic stainless steels not alloyed with nitrogen. Because of the danger of 885°F embrittlement of the ferritic phase, duplex stainless steels should not be used in service at temperatures above those allowed by the applicable pressure vessel design code for prolonged periods of time.

Table 2: Minimum ASME Mechanical Property Limits for Alloy 2205 Duplex Stainless Steel

UNS Number	S32205
Yield Strength	65,000 psi
Tensile Strength	95,000 psi
Elongation in 2”	25%

The mechanical properties of wrought duplex stainless steels are highly anisotropic, that is, they may vary depending on the orientation. While the solidification structure of duplex stainless steel is typically isotropic, it is rolled or forged, and subsequently annealed with both phases present. The strength is higher perpendicular to rolling direction than in the rolling direction. The impact toughness is higher when the notch is positioned perpendicular to rolling direction than in the rolling direction.

Despite the high strength of duplex stainless steels, they exhibit good ductility and toughness. Compared with carbon steels or ferritic stainless steels, the ductile-to-brittle transition is more gradual. They retain good toughness even to low ambient temperatures, for example, -40°F; however, ductility and toughness of duplex stainless steels are in general lower than those of austenitic stainless steels.

While the high yield strength of duplex stainless steel can allow down gauging, depending on buckling and Young's Modulus limitations, it can also pose challenges during fabrication. Because of their higher strength, plastic deformation requires higher forces. The springback in bending operations is larger than with austenitic stainless steels because of the higher bending forces required for duplex stainless steels. Duplex stainless steels have less ductility than austenitic stainless steels and increased bend radii may be required to avoid cracking. Annealing cycles may be needed between forming or bending operations.

PHYSICAL PROPERTIES

Ambient temperature physical properties for 2205 duplex stainless steel is given in Table 3. Data are included for carbon steel and austenitic stainless steels for comparison. In most cases, physical property values of 2205 duplex stainless steel falls between those of austenitic stainless steels and carbon steels, but tends to be closer to austenitic stainless steels.

Table 3: Physical Properties of Grade 2205

		Carbon Steel	Type 304	Type 316	2205
UNS Number		G10200	S30400	S31600	S32205
Density	lb/in^3	0.278	0.290	0.290	0.281
Specific Heat	Btu/ lb-°F	0.107	0.120	0.120	0.119
Electrical Conductivity	micro Ω in	3.9	28.7	29.5	31.5
Young's Modulus	x 10^6 psi	30.0	28.0	28.0	29.0

WELDING DUPLEX STAINLESS STEELS

LOOK IN THIS SPACE IN A FUTURE ISSUE OF THE NEWSLETTER FOR A COMPREHENSIVE DISCUSSION ON WELDING OF DUPLEX STAINLESS STEELS.

DUPLEX STAINLESS STEEL APPLICATIONS

FLUE GAS DESULPHURIZATION

Flue gas desulphurization is one method for reducing SO_2 emissions from coal-fired electric utilities. The use of lime or limestone slurries for "wet scrubbing" SO_2 from a flue gas is a mature technology, as the basic system has been applied to utility boiler systems since the 1970s. Modern scrubbers are now capable of removing over 90% of the SO_2 from the exhaust gas. Modern FGD units are comprised of several zones that have different temperatures, chloride concentrations, and pH. Type 2205 stainless steel has been used for FGD applications because of their lower cost and enhanced corrosion resistance when compared to austenitic stainless steels.

DESALINATION

Desalination presents one of the most severe tests to materials owing to the high-chloride, high temperature corrosive process environment. The benefits of duplex stainless steels for this application are high strength –

double that of conventional austenitic grades – combined with high corrosion resistance. As a result, duplex stainless steel evaporators can be built with thinner plates, requiring less material and less welding. Examples of use of duplex stainless steels in desalination plants are evaporators in the Melittah MSF plant and the Zuara MED plant in Libya, and MSF plants in Abu Dhabi, Dubai and Qatar.

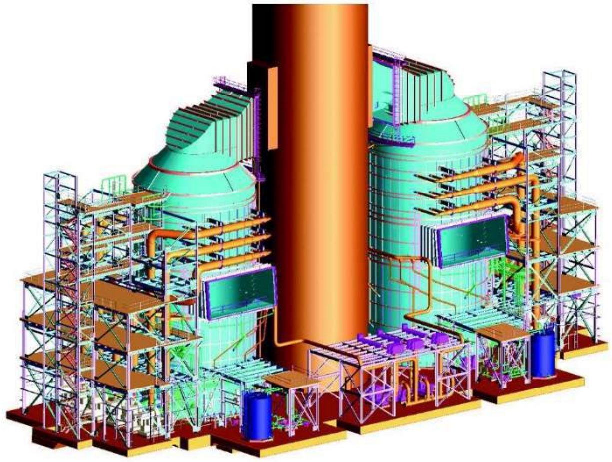


Figure 3: Alloy 2205 Wet FGD Units in a 676 MW Plant

OIL AND GAS

Duplex stainless steels play an important role in Oil and Gas industry not only due to their corrosion resistance and mechanical strength, but also because their pitting and crevice corrosion resistance is superior to that of standard austenitic alloys.

Figure 4: Alloy 2205 Stainless Steel Tube Bundle

Main applications for duplex stainless steels are flow lines, process piping systems and equipment like separators, scrubbers and pumps. In Subsea, the 2205 materials are used in downhole production tubing, piping and manifolds, Christmas tree components, flowlines and pipelines transporting corrosive oil and gas. Most commonly used materials for Umbilicals – used for controlling wellhead functions using hydraulic lines and for chemical injection – are duplex stainless steels.

ARCHITECTURE

Duplex stainless steel continues to play an important role in the construction of bridges wherever corrosion and saline conditions combine with the need for high load-bearing strength. Two examples, both from Asia, are Hong

Kong's Stonecutters Bridge, and Singapore's Marina Bay Pedestrian Bridge, both of which use Alloy 2205 stainless steel

For Stonecutters Bridge, 2000 tons of 2205 duplex stainless steel plate and pipe were used in 2006. The plates were polished and shot-peened to provide the optimum level of reflection during both day and night.

Figure 5: Marina Bay Pedestrian Bridge, Singapore

Marina Bay Pedestrian Bridge uses 570 tons of duplex stainless steel. The bridge's stunning design comprises two spiraling tubular stainless steel members resembling the structure of DNA, and it is the double-helix and support structures that use duplex 2205 pipes and plates respectively. The stainless steel surfaces provide nighttime illumination by reflecting lights programmed to enhance the design.

ASME SPECIFICATIONS

2205 duplex stainless steel products are widely used in ASME pressure vessel construction. The specifications used in ASME Section VIII, Division 1 construction are:

Plates	SA-240-S32205
Bars	SA-479-S32205
Smls and Wld Pipes	SA-790-S32205
Forgings	SA-182-F60-S32205
Smls and Wld Tubes	SA-789-S32205

References:

Practical Guidelines for the Fabrication of Duplex Stainless Steels – TMR International, Pittsburgh, USA

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