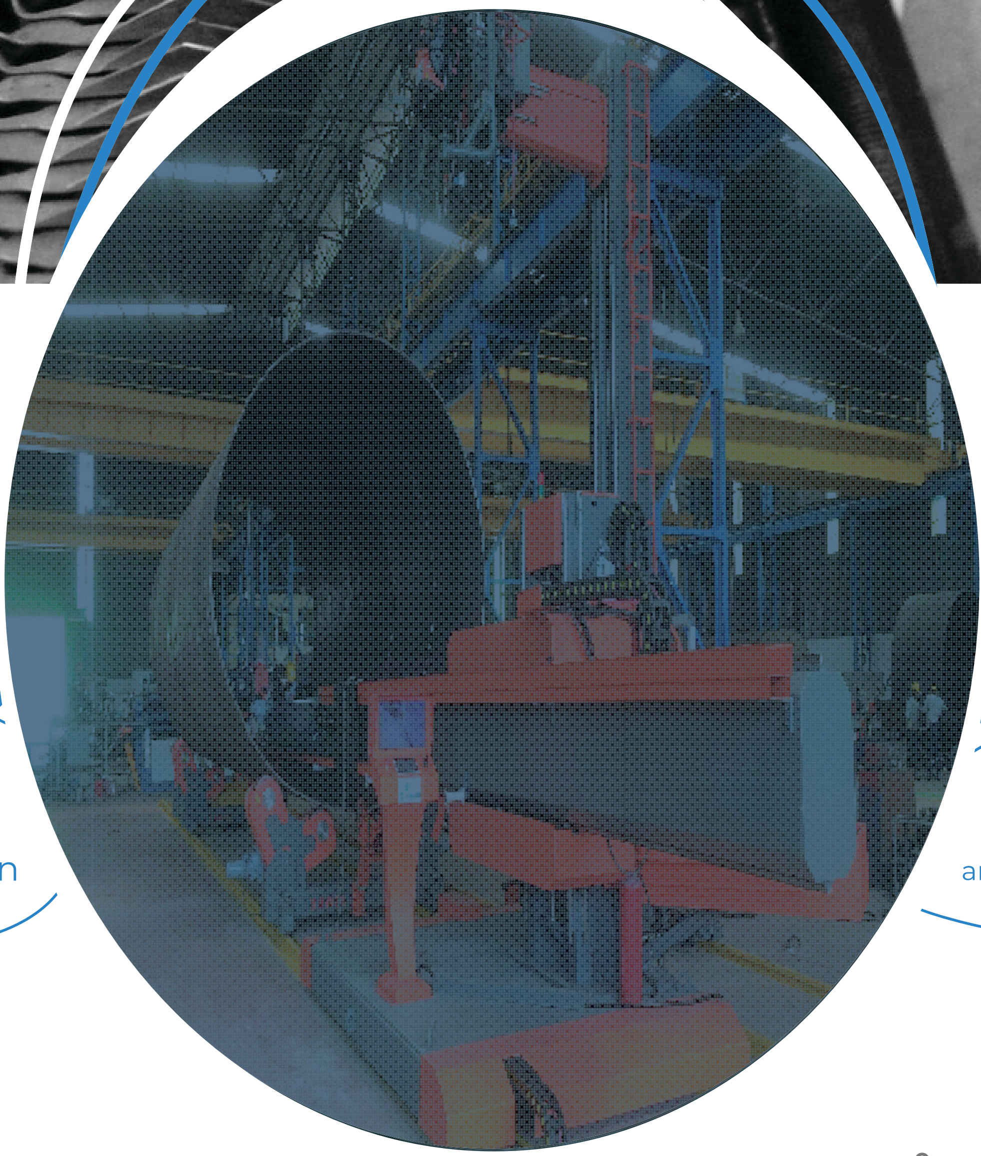
Fixed Equipment Newsletter

VOLUME 2020 , MARCH ISSUE



Allowable Stresses in ASME Code

Brittle Materials in Pressure Vessel Construction

Checklist for Shell-and-Tube Heat Exchangers (API 660)

5 Success Behaviors to Stay Positive and Be Productive in Small Spaces

Serving the Fixed Equipment Community Since 2007

FOURINOX

FOURINOX *is a custom fabrication company specializing in the manufacturing of ASME code pressure vessels, API certified, Atmospheric tanks, Shell & Tube Heat Exchangers for various national and international customers. At FOURINOX, we know complex projects, we've been doing since 1974.*

Heat Exchangers and Vessels:

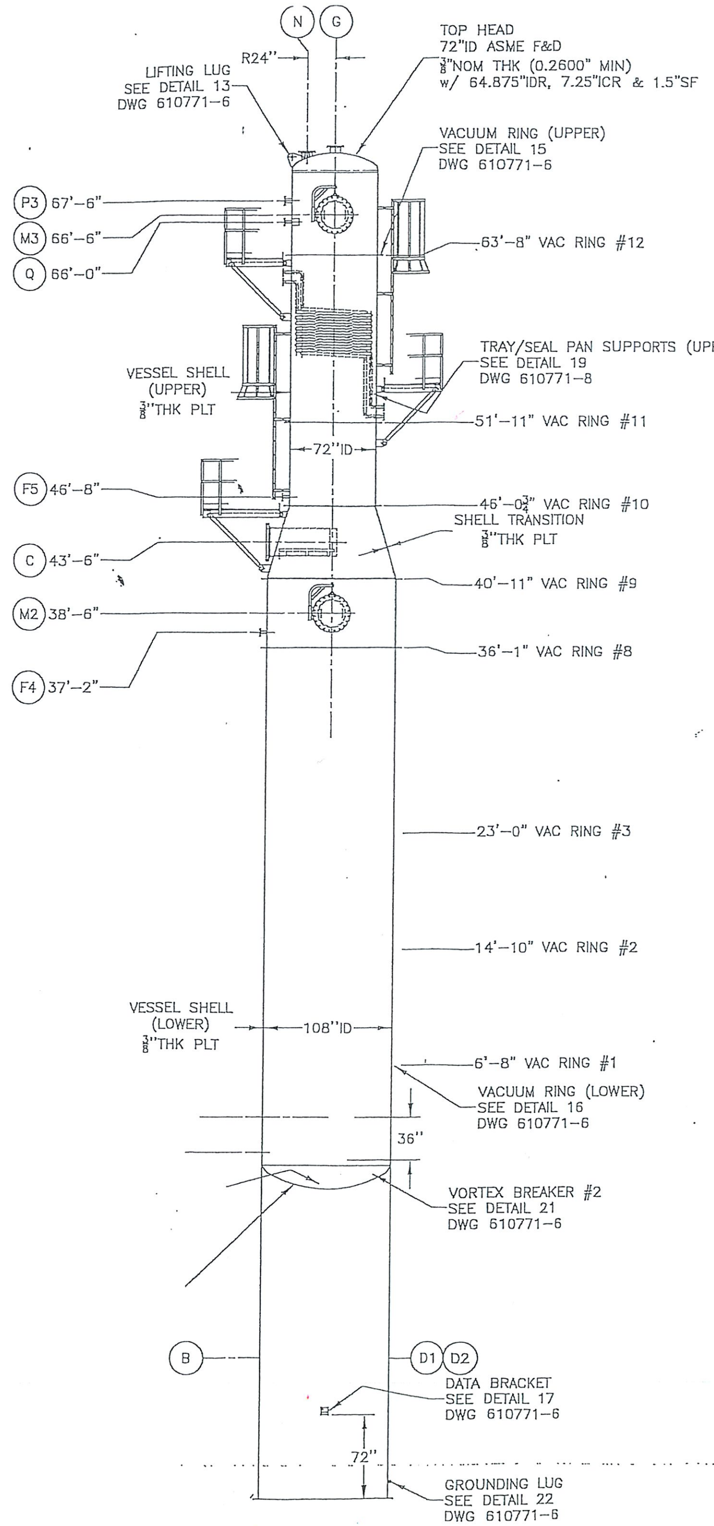
- *ASME Vessels*
- *Heat Exchangers (Shell & Tube)*
- *Columns*
- *Evaporators*
- *Reactors*
- *Jacketed Vessels*
- *API-650 Tanks*
- *Clad & Insulated Vessels*

Industries served:

- *Chemical*
- *Water Process*
- *Petro-Chem*
- *Oil & Gas*
- *Defense*

Materials:

- *Stainless 304 & 316L*
- *Duplex Stainless Grades*
- *High Alloy's*
- *C276*
- *Titanium*
- *Carbon Steel*



To hear more of our custom engineered fabrications & capabilities we invite you to Contact:

Mark Maratik
Vice President of Sales & Marketing
1015 Centennial Street / Green Bay, WI / 54304
Mobile: 920-492-9899
Email: mark.maratik@fourinox.com
Website www.fourinox.com :

COVID-19: WHO Director shares 5 ways to stay healthy:

Statement from WHO Director Tedros Adhanom Ghebreyesus

We know that for many people, life is changing dramatically. My family is no different; my daughter is now taking her classes online from home because her school is closed. For the rest of the world, that even the most severe situation can be turned around. But the experience of cities and countries that have pushed back this virus gives hope and courage to the rest of the world. During this difficult time, it is important to continue looking after your physical and mental health. This will only help you in the long term.

***First**, eat a healthy and nutritious diet, which helps your immune system to function properly. **Second**, limit your alcohol consumption and avoid sugary drinks. **Third**, don't smoke. Smoking can increase your risk of developing severe disease if you become infected with COVID-19. **Fourth**, exercise. WHO recommends 30 minutes of physical activity a day for adults, and one hour a day for children. If your local or national guidelines allow it, go outside for a walk, a run, or a ride; and keep a safe distance from others. If you can't leave the house, find an exercise video online, dance to music, do some yoga, or walk up and down the stairs. If you are working at home, make sure you don't sit in same position for long periods. Get up and take a 3-minutes break every 30 minutes. **Fifth**, look after your mental health. It is normal to feel stressed, confused, and scared during a crisis. Talking to people you know and trust can help. Supporting other people in your community can help you as much as it does them. Check on neighbors, family and friends. Compassion is a medicine. Listen to music, read a book or play a game, and try not to read or watch too much news if it makes you anxious. Get your information reliable sources once or twice a day.*

COVID-19 is taking so much from us, but it is also giving us something special. The opportunity to come together as one humanity to work together, to learn together, and to grow together. I thank you.

Ramesh K Tiwari
ramesh.tiwari@codesignengg.com

In this issue…

This page left intentionally blank.

ALLOWABLE STRESSES IN ASME CODE

FACTORS OF SAFETY

In order to provide a margin of safety between exact formulas, which are based on complex theories and various modes of failure, and the actual design formulas used for setting the minimum required thicknesses and the stress levels, a factor of safety (FS) is applied to various materials' properties that are used to set the allowable stress values. The factors of safety are directly related to the theories and modes of failure, the specific design criteria of each code, and the extent to which various levels of actual stresses are determined and evaluated.

ALLOWABLE TENSILE STRESS IN THE ASME CODE

The basis for setting the allowable stress values or the design stress intensity values is directly related to many different factors depending upon the section of the code used. The criteria for setting allowable tensile stresses for each section of the ASME Boiler and Pressure Vessel Code are as follows:

For Section VIII-1, *Pressure Vessels*, except for bolting whose strength has been enhanced by heat treatment, the factors used to set the allowable tensile stresses, at temperatures in the tensile strength and yield strength range, are the least of:

1. 1/3.5 of the specified minimum tensile strength
2. 1/3.5 of the tensile strength at temperature
3. 2/3 of the specified minimum yield strength
4. 2/3 of the yield strength at temperature (except as noted in the following where 90% is used)

At temperatures in the creep and rupture strength range, the factors are the least of:

1. 100% of the average stress to produce a creep rate of 0.01 per 1000 h (1% in 10^5 h)
2. 67% of the average stress to produce rupture at the end of 100,000 h
3. 80% of the minimum stress to produce rupture at the end of 100,000 h

In the temperature range in which tensile strength or yield strength sets the allowable stresses, higher allowable stresses are permitted for austenitic stainless steels and nickel-alloy materials where greater deformation is not objectionable. In this case, the criterion of 2/3 yield strength at temperature may be increased to 90% yield strength at temperature. However, the factor 2/3 specified minimum yield strength is still maintained.

For the ASME Code, VIII-1, bolting material whose strength has been enhanced by heat treatment or strain hardening is subject to the additional criteria of (i) 1/5 of the specified minimum tensile strength and (ii) 1/4 of the specified minimum yield strength.

For the ASME Code, Section VIII-2, the factor used to set the allowable stress values for all materials except bolting is the least of:

1. 1/2.4 of the specified minimum tensile strength
2. 1/2.4 of the tensile strength at temperature
3. 2/3 of the specified minimum yield strength

4. 2/3 of the yield strength at temperature (except as noted earlier where 90% is used)

At temperatures in the creep and rupture strength range, the factors are the least of:

1. 100% of the average stress to produce a creep rate of 0.01 per 1000 h (1% in 10^5 h)
2. 67% of the average stress to produce rupture at the end of 100,000 h
3. 80% of the minimum stress to produce rupture at the end of 100,000 h.

There are two criteria for setting bolting design stress intensity values in the ASME Code, VIII-2. For design by Appendix 3, the criteria are the same as for the ASME Code, VIII-1, because these values are used for the design of bolts for flanges. For design by Appendix 4 of the ASME Code, VIII-2, the criteria for setting bolting design stress intensity values are the lesser of the following: (i) 1/3 of the specified minimum yield strength and (ii) 1/3 of the yield strength at temperature.

Table 1: Multiplying factors on materials' properties to determine maximum allowable tensile-stress or design-stress intensity values for the ASME Boiler and Pressure Vessel Code

Code Section	Note	Minimum Specified Tensile Strength	Tensile Strength at Temperature (a)	Minimum Specified Yield Strength	Yield Strength at Temperature	Creep Rate of 0.01% in 1000h Average	Stress to Rupture in 100,000 h	
							Average	Minimum
ASME VIII-1	1	1/3.5	1/3.5	2/3	2/3	1.0	0.67	0.8
	2	1/3.5	1/3.5	2/3	0.9	1.0	0.67	0.8
ASME VIII-1	1	1/2.4	1/2.4	2/3	2/3	1.0	0.67	0.8
	2	1/2.4	1/2.4	2/3	0.9	1.0	0.67	0.8
Bolting	1	1/4	1/4	2/3	2/3	1.0	0.67	0.8
	2	1/5	1/5	2/3	0.9	1.0	0.67	0.8

(a) Values in this column are multiplied by 1.1

Notes: 1) Minimum for all materials

2) For austenitic SS and nickel alloys only.

ALLOWABLE EXTERNAL PRESSURE STRESS AND AXIAL COMPRESSIVE STRESS IN THE ASME CODE

Within the ASME Boiler Code, simplified methods are given to determine the maximum allowable external pressure and the maximum allowable axial compressive stress on a cylindrical shell without having to resort to complex analytical solutions. Various geometric values are contained in the geometry chart, whereas materials' properties are used to develop the materials charts.

The allowable compressive stress in the ASME VIII-1 is as follows:

External Pressure in Cylindrical Shells

1. A knock down factor of 1.0 is applied to the theoretical external pressure buckling interaction chart
2. A design factor of 3.0 is applied to the external pressure design equation
3. The allowable external pressure obtained from aforementioned 1 and 2 cannot exceed the allowable tensile stress.

External Pressure in Spherical Shells

1. A knock down factor of 1.25 is applied to the theoretical external pressure buckling equation
2. A design factor of 4 is applied to the external pressure chart correlating compressive stress with strain factor A
3. The allowable compressive stress obtained from aforementioned 1 and 2 cannot exceed the allowable tensile stress

Axial Compression in Cylindrical Shells

1. A knock down factor of 5 is applied to the theoretical axial buckling equation of a long cylinder
2. A design factor of 2 is applied to the external pressure chart correlating axial compression to strain factor A
3. The allowable compressive stress obtained from aforementioned 1 and 2 cannot exceed the allowable tensile stress.

References:

Structural Analysis and Design of Process Equipment – Maan H. Jawad and James R. Farr, *Third Edition*

CONVERSION TABLES

CONVERSION TO METRIC UNITS

Multiply customary units	***By factor***	***To get metric units***
Inches	0.0254	Meters
US gallons	0.003785	m^3
ft^3	0.02832	m^3
Pound mass	0.4536	Kilograms
Pounds force	4.448	Newtons
psi pressure	6894.8	Pascals
Bars	100,000	Pascals
Btu	1005.056	Joules
Horsepower (500 ft-lb/s)	745.7	Watts
Ksi-$\sqrt{\mathrm{in}}$ fracture toughness	1.1	MPa-$\sqrt{\mathrm{m}}$
°F	(°F-32)/1.8	°C

CONVERSION TO METRIC UNITS

Multiply	***By factor***	***To get***
ft^3	7.48	US gallons
Bars	14.50	psi
Miles	5280	feet

.

BRITTLE MATERIALS IN PRESSURE VESSEL CONSTRUCTION

INTRODUCTION

Brittle materials are those which have little ductility. Cast iron, glass and concrete at room temperature are examples of such materials. They crack normal to the tensile stress; and accordingly, for designs involving combined stresses, the "maximum stress" theory of failure is applicable. These materials have low toughness since they undergo little deformation prior to fracture. They substantially follow Hooke's law up to fracture so that the tensile test diagram is represented by a straight line in Figure 1.

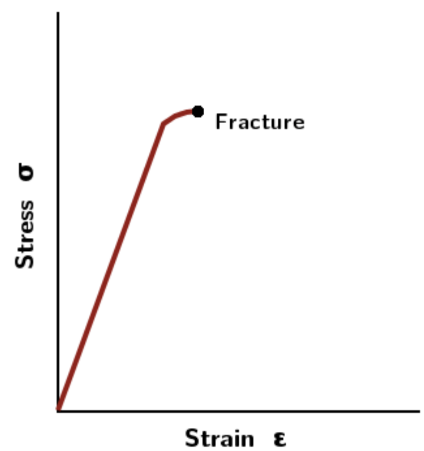


Figure 1: Stress-Strain Diagram for a Brittle Material

In brittle materials, the high stress concentrations associated with notches, flaws, etc., remain right up to the breaking point since the material has little ductility or ability to stretch and hence redistribute the local high stress more uniformly. Accordingly, points of stress concentration have a great weakening effect and must be minimized by the judicious addition of properly disposed reinforcing material at these locations.

Materials that exhibit a ductile behavior in a normal environment can also act brittlely with a change in environment, such as a lower temperature. Pressure vessels that have been satisfactorily pressurized have experienced brittle fracture when subjected to the same pressure at a lower temperature. Brittle fracture can occur at stresses considerably below the yield point, and without prior noticeable deformation as seen in Figure 2. It is characterized by a very rapid crack propagation of speeds up to six thousand feet per second. The fractures occur normal to the wall surface and are of crystalline texture indicating that the individual grains of the steel have failed by cleavage of crystal plane. The point of initiation of a brittle fracture is usually a point of severe stress concentration, such as a design geometry, fabrication flaw or material defect. This is in contrast with ductile fracture with its 45° tear involving large plastic deformation and accompany high energy absorption.

PREVENTING BRITTLE FRACTURE

Brittle fracture requires simultaneous occurrence of three conditions:

1. a high stress field,

2. a material prone to brittle behavior by virtue of its environment, such as operating at a temperature below its nil ductility temperature (NDT),
3. a trigger such as a notch or a flaw.

[*NDT is the transition temperature at which the basic mode of failure changes from ductile to brittle.*]

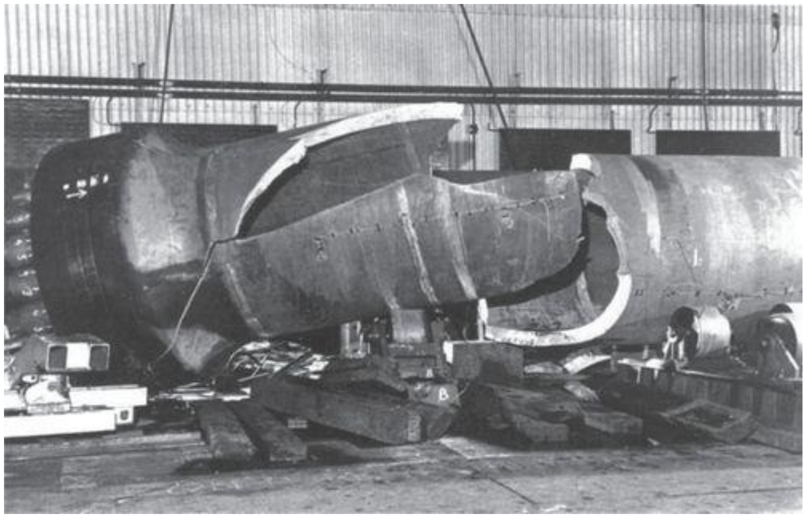


Figure 2: Brittle Fracture of a High Pressure Thick-Walled Reactor Vessel

The key to preventing brittle fracture is to prevent all three of these conditions from occurring simultaneously. This gives the following three basic design approaches:

<u>LOW STRESS FIELD DESIGN APPROACH</u>

This is a design approach applicable to all materials that act brittley in their operational environment and contain notches, flaw, etc. It consists of employing a low allowable stress (high factor of safety) thereby avoiding the first condition for brittle fracture.

Pressure vessels for the nuclear, power, chemical or petrochemical industry, however, are subject to high stresses because of the very high pressures these vessels must contain; hence, this approach of permitting only very low stresses cannot be used. Accordingly, it is necessary to resort to the following two design approaches to prevent brittle fracture.

<u>TRANSITION TEMPERATURE DESIGN APPROACH</u>

Low carbon and alloy steels frequently exhibit a transition from “ductile” behavior (failure by excessive plastic deformation) to “brittle” behavior (failure with little deformation at nominal computed stresses below the yield point) over a very small temperature range called the “Transition Temperature” as shown in Figure 3. The basis of this approach is to restrict the temperature of operation to a temperature at which the material always behaves ductiley. This avoids the second requirement for brittle fracture.

The general effects of temperature on the fracture stress transition of steels are shown in Figure 4. A flaw-free steel shows an increasing tensile strength and still greater increasing yield strength with decreasing temperature. These coincide at some very low temperature at which the plastic flow properties of elongation and reduction in areas are nil. This temperature is the nil ductility transition temperature in the absence of a flaw (NDT no-flaw). If the vessel material is flaw-free, there is no need to consider the brittle fracture properties of steel. Likewise, the closer a material approaches this condition the less susceptible it is to brittle type fracture; *hence the importance of quality control of base material and manufacturing processes*.

Commercial materials do have flaws or inherent minute defects to which may be attributed the fracture stress decrease in the region of the material transition temperature. The highest temperature at which the decreasing fracture stress for fracture initiation due to these small flaws becomes contiguous with the yield strength curve of the steel is called the nil ductility transition temperature (NDT). Below the NDT temperature, the fracture stress curve for these small inherent flaws follows the course of the yield strength curve to lower temperatures as indicated by the dashed curve (Figure 4). At the NDT, increases in flaw size result in a progressive lowering of the fracture stress curve to lower values of nominal stress. This decrease in the fracture stress is approximately inversely proportional to the square root of the flaw size.

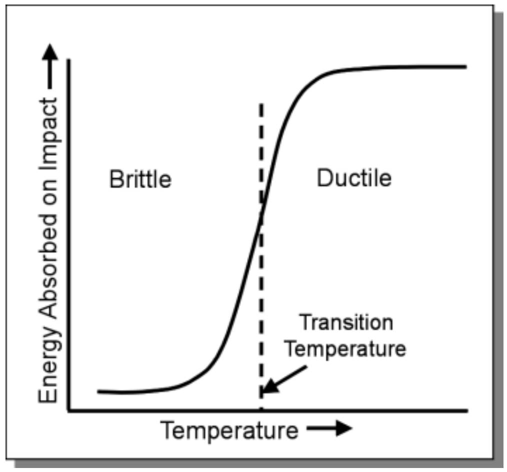


Figure 3: Typical Impact Energy Transition Curve for Carbon Steel

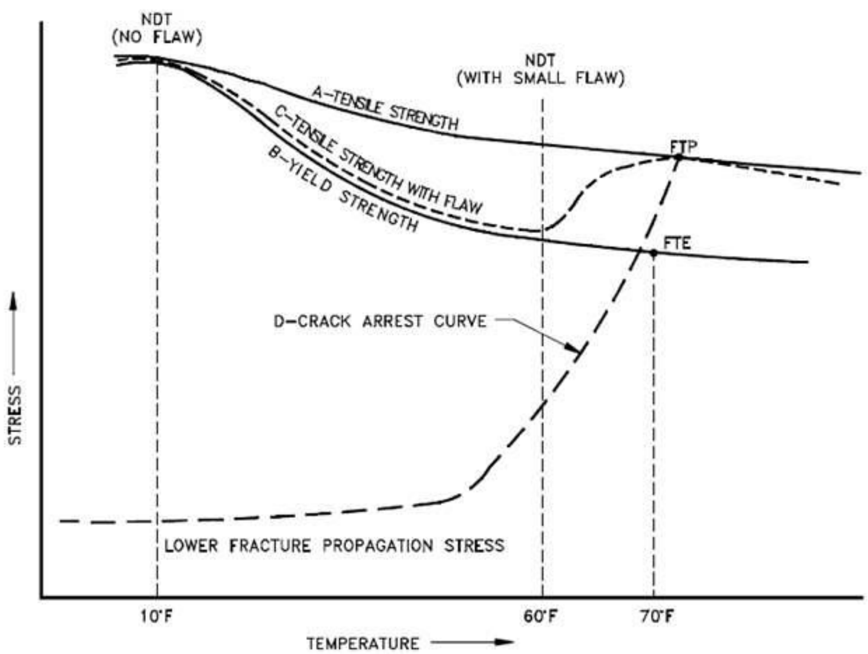


Figure 4: Transition Temperature Features of Steel

The lowering of the nominal stress with increasing flaw size results in a family of fracture stress curves that show a marked increase in stress required for fracture as the temperature is increased above the NDT temperature. The lowest boundary curve of this family is called the crack arrest temperature (CAT) curve. This curve establishes the temperature of arrest of a propagating brittle fracture for various levels of applied nominal stress. This curve is the key to pressure vessel design and operation and has three significant features:

1. The lower shelf of stress level of 5-8 psi below which fracture propagation is not possible because of the amount of elastic strain energy release required for continued propagation of brittle fracture is not attained with this low stress. This prevails below the NDT.
2. The crack arrest temperature for a stress level equal to the yield strength is called the fraction transition elastic (FTE) temperature and is the highest temperature of fracture propagation for purely elastic stress levels. This is approximately 60° above the NDT.
3. The crack arrest temperature for a stress level equal to the tensile strength is called the fraction transition plastic (FTP) temperature and is the temperature above which fractures are entirely of the shear type occurring at the tensile strength of the material. This temperature is approximately 120° above the NDT.

In Figure 4, the stress is that due the acting loads plus the residual stresses resulting from the fabricating processes (such as welding). The load stresses and residual stresses are additive if superposition does not cause yielding or partial fracture. Welded vessels contain residual stresses which are not eliminated by the final stress relieving heat treatment they receive. The amount remaining depends upon the creep strength of the material at the stress relieving temperature, and this may be conservatively taken as the short term yield strength of the material.

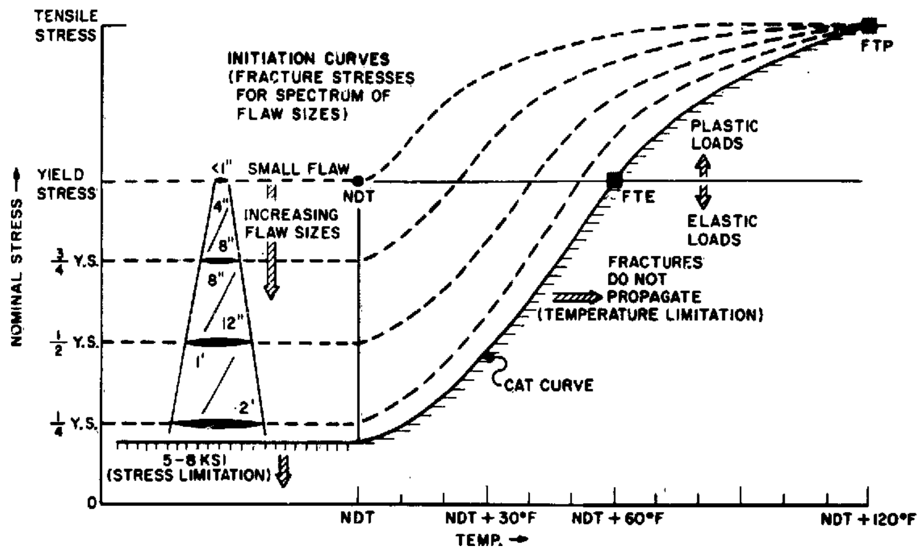


Figure 5: Fracture Analysis Diagram for the Engineering Selection of Fracture-safe Steels based on the NDT Temperature

The fracture analysis diagram (Figure 5) has four primary reference points which may be used as the design criteria for the engineering selection of fracture-safe steels, design stresses, or minimum service temperatures

NDT Temperature Design Criterion

This is based on the existence of an acting yield point stress level, and coexistence of only small flaws less than one inch in size. Restricting the service temperature to above this value assures ductile behavior. It provides fracture protection by preventing crack initiation; however, it does not provide for arrest of a propagating crack.

NDT Plus 30°F Design Criterion

This criterion is based on a stress level of the order of 1/2 yield strength, commonly used for commercial pressure vessel design, and its relation to the CAT curve. Restricting service temperature to above this value obviates the flaw size evaluation problem. That is, fracture cannot initiate, or cannot propagate in this stress field.

NDT Plus 60°F Design Criterion

This criterion is based on the same considerations as the previous design criterion, except the level of stress is the yield strength of the material. It is applicable to vessels designed to high stress levels, or which are subject to high test pressures, or to several thermal stress conditions.

NDT Plus 120°F Design Criterion

This criterion is based on the premise that the vessel will be subject to a stress level above the yield point of the material. This restricts service to full shear fracture temperatures in order to develop maximum fracture resistance.

To illustrate the use of this diagram, assume that engineering judgment dictates the use of the second design criterion, NDT Plus 30°F, and that 40°F if the lowest expected service temperature. The highest permissible NDT temperature of the material to be used is then determined from the temperature scale of the diagram as 40°F-30°F=10°F.

FRACTURE MECHANICS DESIGN APPROACH

Linear Elastic Fracture Mechanics

The fracture analysis diagram is a useful design approach for low and medium alloy steels that exhibit a marked transition temperature behavior. However, for high strength steels (above 150,000 TS), aluminum and titanium alloys, such a marked transition temperature is not observed. Rather a broad diffuse transition exists; and accordingly, this approach for design against brittle fracture cannot be used. Instead, methods of fracture mechanics which reconcile material properties, defect geometry and stress field must be used. The basis of this approach is to restrict the size of the crack or defect to that critical size consistent with the material toughness and applied stress.

A crack may be considered as the limiting form of an ellipse of decreasing minor axis. Defining 'ρ' as the radius of curvature at the end of the crack, and 'a' as the half crack length equal to semi-major axis of the ellipse, the stress concentration factor is proportional to $\sqrt{a/\rho}$. The low fracture strengths of brittle solids can be explained by assuming that the stress concentrating flaw gives rise to local stresses exceeding the theoretical fracture strengths. The mathematical treatment of stability conditions in localized cracks or other sources of stress concentration is called "linear elastic fracture mechanics", and is based on elastic analysis which assumes that stress is proportional to strain.

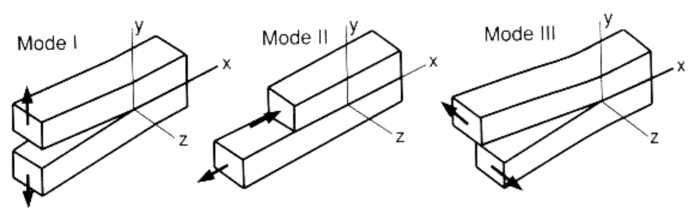


Figure 6: Three Basic Modes of Crack Surface Displacement

The local stresses near a flaw depend on the product of the nominal stress and the square root of the flaw size 'a'. This product is called "stress intensity factor" to emphasize this fundamental relationship. The stress intensity factor, K, is proportional to the limiting value of the elastic stress concentration factor K_t as the root radius approaches zero. Thus, K values for variously shaped flaws in structures can be determined when values of the elastic stress concentration factor are known.

Figure 6 shows the three failure modes treated by fracture mechanics. The first mode is the opening mode, the second is the sliding mode, and the third is a tearing mode. The stress intensity factors associated with these modes are K_I, K_{II} and K_{III}, respectively. Since these K factors are one parameter representations of the stress field at the tip of the crack, it is assumed that they should also be a good theory of failure for materials. Experiments have verified this for average net section stresses below 0.8 of the yield stress. The basic assumption in fracture mechanics is that unstable fracture (where the crack continues to extend with no increase in applied stress) occurs when K reaches a critical value designated K_c, commonly called fracture toughness.

It is important to appreciate the difference between K and K_c. The stress intensity factor K is simply a coefficient in an equation describing the elastic stresses in the vicinity of a crack tip. Fracture toughness K_c is a particular value of K corresponding to the unstable propagation of the crack. K_c is independent of loading conditions and may be considered a material constant and varies with the thickness of the material as shown in Figure 7.

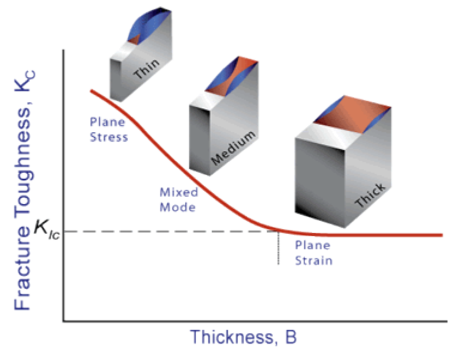


Figure 7: Typical Variation in Fracture Toughness with Plate Thickness

Crack Opening Displacement (COD) and General Yield Fracture Mechanics

Linear elastic fracture mechanics is most applicable to materials in which little local plasticity is associated with fracture. In tough materials where a considerable plastic zone is created ahead of the crack, unstable extension of a crack occurs at a critical value of local displacement near the tip of the crack, crack opening displacement or COD, and assumes that this critical value is the same in actual structures as it is in a test specimen of similar thickness. This approach and that of linear fracture mechanics become similar when the plastic zone is small.

The critical value of COD occurring at fracture is dependent upon the same factors as K_{Ic}; i.e., material, temperature, strain rate, etc. It exhibits a transition with temperature that can be used as a failure criterion or structural design basis for the prevention of plain strain crack propagation. As the plastic zone spreads from the tip of the crack, the COD at the tip of the crack increases.

ENERGY CONSIDERATIONS OF BRITTLE FRACTURE

The sudden onset of unstable crack propagation can also be explained by considering the balance between the elastic energy, δE_e, released and the energy absorbed by the fracture process during unit extension of the crack. The absorbed energy is accounted for by two principal mechanisms; namely, (1) the surface free energy created per increment of crack extension, δS, and (2) the energy of plastic deformation, δW, per increment of crack extension.

$$\delta E_e = \delta S + \delta W$$

For a purely brittle material (glass, for example), $\delta W = 0$ for the condition of crack subject to a tensile stress normal to the plane of the defect. Many materials such as metals fracture with concurrent plastic deformation and it has been observed that the amount of energy required to produce even the small amounts of deformations observed in brittle metallic fractures is of several orders of magnitude greater than the surface free nergy ($\delta W >> \delta S \approx 0$).

EFFECT OF ENVIRONMENT ON FRACTURE TOUGHNESS

Since fracture toughness, K_c is a material property it is affected by environment as are other material properties. Temperature affects all materials; hence, it is a major design concern for all vessels and structures

EFFECT OF TEMPERATURE

Fracture toughness increases with an increase in temperature and this variation must be determines for each type of material.

EFFECT OF RADIATION

The material of nuclear reactor vessels is also subject to irradiation damage. Its effect on fracture toughness is a decrease in this property with an increase in neutron absorption.

EFFECT OF FATIGUE

Fatigue is the prime manner in which crack grows to a critical size; and since fatigue crack growth rate varies as approximately the fourth power of material stress intensity factor, it is of paramount importance.

References:

Theory and Design of Modern Pressure Vessels – John Harvey, *Second Edition*

This page left intentionally blank.

CHECKLIST FOR SHELL-AND-TUBE HEAT EXCHANGERS (API 660)

API 660 specifies requirements and gives recommendations for the mechanical design, material selection, fabrication, inspection, testing, and preparation for shipment of shell-and-tube heat exchangers for the petroleum, petrochemical, and natural gas industries. It is applicable to heaters, condensers, coolers, and reboilers. It is not applicable to vacuum-operated steam surface condensers and feed-water heaters.

The checklist provided in this article indicates requirements for the purchaser to provide information. The requirements have been grouped into classifications that reflect the sections of API 660 where the requirements have been stated.

GENERAL

- The pressure design code shall be specified or agreed by the purchaser. Pressure components shall comply with the pressure design code and the supplemental requirements given in this standard.
- The vendor shall comply with the applicable local regulations specified by the purchaser.
- The purchaser shall specify if either stream has fluid characteristics requiring special considerations (e.g. slurry, entrained particulates, or other certain types of fouling mechanisms).
- The purchaser shall specify if cyclic service design is required. If cyclic service is specified, the purchaser shall specify the type and magnitude of variation in pressure, temperature and flow rate, the time for the variation (hours, weeks, months, etc.) and the number of cycles or frequency for this variation expected during the life of the equipment. The extent and acceptance criteria of any required analysis shall be subject to the agreement of the purchaser. Annex A.2.1 of API 660 provides guidance on cyclic service.
- The purchaser shall specify if the service is designated as sour in accordance with NACE MR0175 (all parts) for oil and gas production facilities and natural gas processing plants or is designated as wet hydrogen sulfide service in accordance with NACE MR0103 for other applications (e.g. petroleum refineries, LNG plants, and chemical plants), in which case all materials in contact with the process fluid shall meet the requirements of the applicable standard to mitigate potential for sulfide stress cracking (SSC). Identification of the complete set of materials, qualification, fabrication, and testing specifications to prevent in-service environmental cracking is the responsibility of the user (purchaser). Annex A.2.2 of API 660 provides guidance on sour or wet hydrogen sulfide service.
- The purchaser shall specify if the shell or tube side is in hydrogen service.
- For single tube pass floating-head and all fixed tubesheet heat exchangers, the purchaser shall specify the data required to determine the need for an expansion joint. This shall include all intended operating conditions defined on the expansion joint datasheet shown in Annex C.

DRAWINGS AND OTHER REQUIRED DATA

<u>OUTLINE DRAWINGS AND OTHER SUPPORTING DATA</u>

- The vendor shall submit flow-induced vibration analysis, if specified by the purchaser. See Annex A.3.2.

<u>INFORMATION REQUIRED AFTER OUTLINE DRAWINGS ARE REVIEWED</u>

- If specified by the purchaser, the vendor shall furnish copies of applicable welding procedure specifications and welding procedure qualifications for review or record.

- The vendor shall submit design calculations for supports, lifting, and pulling devices, if specified by the purchaser.

<u>REPORTS AND RECORDS</u>

- After the heat exchanger is completed the vendor shall furnish the purchaser with the following documents in the format and quantities specified by the purchaser:

  a. "As-built" datasheet

  b. All outline and detail drawings, marked "CERTIFIED AS-BUILT"

  c. Certified record of all impact tests performed

  d. Certified mill test reports for all pressure parts, including tubes (each material test report shall be identified by a part number)

  e. Complete certified bill of materials suitable for obtaining all replacement parts, including quantity, description, material specification, and identification of each part

  f. Temperature charts of all postweld heat treatments

  g. Completed manufacturer's data report in accordance with the pressure design code

  h. Nameplate rubbing or a facsimile

  i. All mechanical design calculations, marked "CERTIFIED AS-BUILT"

  j. Non-destructive examination (NDE) map

  k. All associated NDE reports, including radiographic, magnetic-particle, liquid-penetrant, ultrasonic, hardness, impact, positive material identification (PMI), and any other reports as applicable

  l. Tube-to-tubesheet leak-test results

  m. Hydrostatic test records in the form of a chart or certification

  n. Tube wall reduction records

DESIGN

<u>DESIGN TEMPERATURE</u>

- All heat exchangers shall have two design temperatures for each side, a maximum design temperature and a minimum design metal temperature (MDMT), as specified by the purchaser.

<u>SHELL SUPPORTS</u>

- For all supports the local stresses in the shell shall be analyzed using a method which is specified or agreed with the purchaser. EXAMPLE – WRC BUL 537.

<u>STATIONARY AND FLOATING HEADS</u>

- When specified by the purchaser, all girth flanges, channel covers, and floating-head flanges shall be provided with 1/8 in. future machining allowance on the gasket contact seating surfaces (including pass partition surfaces). The additional thickness shall not be used in the calculation of maximum allowable working pressure. <u>NOTE: This requirement does not apply to clad or weld overlay construction</u>.

<u>TUBE BUNDLE</u>

- When specified by the purchaser, tubesheets shall be provided with 1/8 in. future machining allowance on the gasket contact seating surface (including pass-partition surfaces). The purchaser shall state if this 1/8 in. allowance shall be provided on one or both of the shell side and tube side surfaces of the tubesheet.

The additional thickness shall not be used in the calculation of maximum allowable working pressure. NOTE: This requirement does not apply to clad or weld overlay construction.

- When strength welds are applied for tube-to-tubesheet joints, the degree of expansion and the use of grooves shall be specified or agreed to by the purchaser. See Annex A.4.4 for additional guidance on the selection of tube-to-tubesheet joints.

NOZZLES AND OTHER CONNECTIONS

- Connections NPS 1-1/2 and larger shall be flanged. The purchaser shall specify the required flange design code (e.g. ASME B16.5).
- The purchaser shall specify if nozzles are to be welded to the connecting piping (by others). They shall be beveled and details shall be specified or agreed with the purchaser.
- The projection of flanged connections shall allow through-bolting to be removed from either side of the flange without removing the insulation. For stacked units, this requirement need only be applied to one side of directly coupled connections. The insulation thickness shall be specified by the purchaser.
- The purchaser shall specify if chemical cleaning connections are required. Their nominal size shall be not less than NPS 2.
- Nozzles shall be designed to withstand the simultaneous application of forces and moments in the corroded condition, as defined in Figure 1 and listed in Table 1, unless otherwise specified by the purchaser. Non-piped auxiliary connections, such as vents, drains, and cleaning connections, are excluded from this requirement. The type of analysis applied shall be specified or agreed with the purchaser.

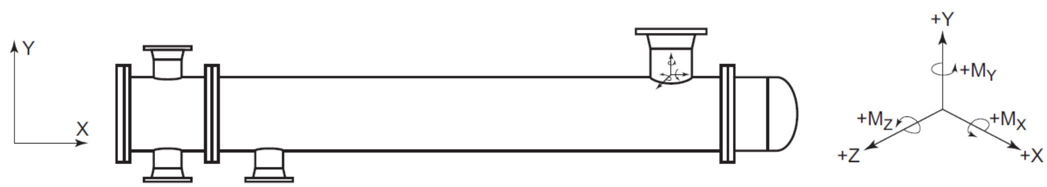


Figure 1: Directions of Moments and Forces on Nozzles

- For nozzle sizes larger than those listed in Table 1, the purchaser shall specify the moments and forces.

Table 1: Nozzle Allowable Forces and Moments at the Nozzle Neck to Shell/Channel Interface

Nominal Diameter (NPS)	Flange Rating	M_X (lbf.ft)	M_Y (lbf.ft)	M_Z (lbf.ft)	F_X (lbf.ft)	F_Y (lbf.ft)	F_Z (lbf.ft)
2	150	200	320	250	370	290	370
	300	250	400	320	450	360	450
	600	350	560	440	630	500	630
	900	440	720	560	820	650	820
	1500	440	720	560	820	650	820
	2500	490	790	630	900	720	900
3	150	430	690	540	530	420	530

Nominal Diameter (NPS)	Flange Rating	M_X (lbf.ft)	M_Y (lbf.ft)	M_Z (lbf.ft)	F_X (lbf.ft)	F_Y (lbf.ft)	F_Z (lbf.ft)
	300	540	860	680	670	530	670
	600	750	1210	950	930	740	930
	900	960	1550	1220	1190	950	1190
	1500	960	1550	1220	1190	950	1190
	2500	1170	1890	1490	1450	1160	1450
4	150	710	1140	900	680	540	680
	300	880	1420	1120	850	680	850
	600	1230	1990	1560	1190	950	1190
	900	1580	2560	2010	1530	1220	1530
	1500	1760	2840	2230	1690	1350	1690
	2500	1930	3120	2460	1870	1490	1870
6	150	1530	2460	1940	1000	800	1000
	300	2670	4310	3380	1750	1400	1750
	600	3430	5540	4350	2240	1790	2240
	900	4190	6760	5320	2740	2190	2740
	1500	4950	7990	6280	3240	2590	3240
	2500	5330	8610	6760	3490	2790	3490
8	150	1530	2460	1940	1000	800	1000
	300	2670	4310	3380	1750	1400	1750
	600	3430	5540	4350	2240	1790	2240
	900	4190	6760	5320	2740	2190	2740
	1500	4950	7990	6280	3240	2590	3240
	2500	5330	8610	6760	3490	2790	3490
10	150	4010	6480	5090	1620	1290	1620
	300	7010	11330	8900	2830	2260	2830
	600	10010	16180	12720	4040	3230	4040
	900	14020	22660	17800	5650	4520	5650
	1500	16020	25890	23340	6450	5160	6450
	2500	17020	27510	21620	6870	5490	6870
12	150	5640	9110	7160	1920	1530	1920
	300	9860	15940	12520	3350	2680	3350
	600	11270	18210	14310	3830	3060	3830
	900	12680	20490	16100	4320	3450	4320

Nominal Diameter (NPS)	Flange Rating	M_X (lbf.ft)	M_Y (lbf.ft)	M_Z (lbf.ft)	F_X (lbf.ft)	F_Y (lbf.ft)	F_Z (lbf.ft)
	1500	15490	25040	19680	5270	4210	5270
	2500	16900	27320	21460	5740	4590	5740
14	150	8490	13720	10780	2630	2100	2630
	300	11890	19210	15100	3680	2940	3680
	600	16980	27440	21560	5250	4200	5250
	900	22070	35680	28030	6830	5460	6830
	1500	30560	49400	38810	9450	7560	9450
	2500	37350	60370	47440	11550	9240	11550
16	150	8870	14340	11270	3200	2560	3200
	300	15520	25090	19720	5600	4480	5600
	600	22170	35840	28160	8000	6400	8000
	900	31040	50180	39430	11200	8960	11200
	1500	35480	57350	45060	12800	10240	12800
	2500	37690	60930	47880	13600	10880	13600
18	150	11230	18150	14260	3600	2880	3600
	300	19650	31760	24950	6300	5040	6300
	600	28060	45360	35640	9000	7200	9000
	900	36480	58970	46340	11700	9360	11700
	1500	44900	72580	57030	14400	11520	14400
	2500	47700	77120	60590	15300	12240	15300
20	150	13860	22400	17600	4000	3200	4000
	300	24250	39200	30800	7000	5600	7000
	600	31180	50400	39600	9000	7200	9000
	900	45040	72800	57200	13000	10400	13000
	1500	51960	84000	66000	15000	12000	15000
	2500	58890	95200	74800	17000	13600	17000
24	150	24950	40320	31680	6000	4800	6000
	300	34920	56450	44360	8400	6720	8400
	600	49890	80640	63360	12000	9600	12000
	900	64850	104840	82370	15600	12480	15600
	1500	89790	145160	114050	21600	17280	21600
	2500	109740	177410	139400	26400	21120	26400

FLANGED EXTERNAL GIRTH JOINTS

- Channel and shell external girth joints shall be of through-bolted construction. Studded-in bolts may be used when specified or approved by the Purchaser.
- Hydraulic bolt tensioning shall be applied for all bolt diameters equal to or greater than 2 in., or in hydrogen service where bolt diameters are equal to or greater than 1-1/2 in.), or when specified by the purchaser. Alternate forms of tightening followed by bolt elongation verification (e.g. hydraulic torquing in combination with ultrasonic extensometer measurement) may be considered in lieu of tensioning, with approval of the purchaser.
- When bolt tensioning is used, the purchaser shall specify any special requirements necessary to allow for adequate clearance for the bolt-tightening device.
- When specified by the purchaser, external girth flanges shall be provided with 3 mm (1/8 in.) future machining allowance on the gasket contact seating surface (including pass-partition surfaces). The additional thickness shall not be used in the calculation of maximum allowable working pressure. NOTE: This requirement does not apply to clad or weld overlay construction.

GIRTH FLANGE JOINTS SUPPLEMENTARY DESIGN REQUIREMENTS

- The joint component approach, as defined in ASME PCC-1, Appendix O, and the requirements contained within this section, shall be applied to one or both sides of the heat exchanger, when specified by the purchaser. Definition of terms and symbology contained within this section are consistent with ASME PCC-1. See A.4.5 for additional guidance.

REQUIREMENTS FOR HYDROGEN SERVICE

- The purchaser shall specify any supplemental requirements for low chrome steels in high temperature or high pressure hydrogen service (e.g. API RP 934-A, API RP 934-C). NOTE: See A.4.7 for information on the potential for leaks resulting from bolting relaxation.

MATERIALS

- Purchaser shall specify materials for all components, including bolting and gaskets
- The maximum allowable carbon equivalent shall be agreed with the purchaser prior to purchase of materials for use in fabrication. Restrictions on other residual elements and micro-alloying elements can also apply depending on the severity of the service. The purchaser shall specify all such restrictions.

FABRICATION

WELDING

- The purchaser shall specify whether weld procedure qualifications for carbon steel in sour or wet hydrogen sulfide service, including tube-to-tubesheet welds, shall include a micro-hardness survey performed on a weld crosssection, including the heat affected zone (HAZ), and transverse to the weld centerline. The micro-hardness testing and acceptance criteria shall be in accordance with NACE SP0472 or NACE MR0175 (all parts), as applicable. Any additional restrictions on residual elements or micro-alloying elements for the qualification test material shall be specified by the purchaser.
- When specified by the purchaser, weld procedure qualifications for duplex stainless steels, including tube-totubesheet welds, shall include a micro-hardness survey performed on a weld cross-section (including HAZ) and transverse to the weld centerline. The micro-hardness testing and acceptance criteria shall be as agreed with the purchaser. NOTE: See API TR 938-C and API RP 582 for guidance on welding of duplex stainless steels.

HEAT TREATMENT

- The purchaser shall specify if heat treatment is required after bending of U-tubes for process reasons.
- For ferritic and martensitic stainless steels, stabilized austenitic stainless steels, duplex stainless steels, copper, copper-nickel, and high nickel alloys (Ni > 30 %), heat treatment of U-tubes shall be applied if cold working can induce susceptibility to stress corrosion. The purchaser shall specify when heat treatment is required in such cases. NOTE: See API TR 938-C for guidance on heat treatment of duplex stainless steel U-bends.
- When specified by the purchaser, the heat treated portion of U-tubes shall receive a de-scaling treatment.
- The purchaser shall specify if postweld heat treatment is required for weld-overlaid channels and bonnets.
- The purchaser shall specify if postweld heat treatment of shell side or tube side components is required for process reasons.

TUBE-TO-TUBESHEET JOINTS

- For shell side clad (or weld overlay) tubesheets, the tube shall be expanded to seal against the cladding material for a minimum distance of 1/4 in. The purchaser shall specify if a groove is required within the shell side cladding.

INSPECTION AND TESTING

QUALITY CONTROL

- The purchaser shall specify whether all carbon steel plate in sour or wet hydrogen sulfide service shall be subjected to an ultrasonic lamination check (e.g. to EN 10160 grade S2E2 or ASME SA-578, acceptance level A supplementary requirement S1).

PRESSURE TESTING

- If specified by the purchaser, tube-to-tubesheet joint integrity shall be tested after final expansion of the tubes by a helium leak test (e.g. per ASME *BPVC, Section V*). See A.7 for additional guidance.
- Any additional requirements for equipment drying or preservation shall be specified by the purchaser.

PREPARATION FOR SHIPMENT

PROTECTION

- The purchaser shall specify if there are requirements for surface preparation and protection (e.g. painting).
- The purchaser shall specify if inert gas (e.g. nitrogen, argon) purge and fill is required. Positive pressure shall be indicated by a pressure gage. Gages shall be suitably protected from damage during transportation. The purchaser shall maintain the positive pressure of the inert gas during storage.

SUPPLEMENTAL REQUIREMENTS

GENERAL

- The purchaser shall specify if the additional requirements in Section 12 (Supplementary Requirements) shall be applied to one or both sides of the heat exchanger. These supplemental requirements should be considered by the purchaser if the cylinder thickness of a heat exchanger component exceeds 2 in. or if the service is considered critical.

References:

API Standard 660: Shell-and-Tube Heat Exchangers, Ninth Edition, March 2015

HOW TO CHANGE BASIC ENGLISH INTO BASIC ENGLISH

At times, it is all right to use informal language – it is acceptable in most everyday situations; however, there are times when you want to create a more powerful impression. At these times, you want to use business English. What is the difference between general English and business English?

Let us look at some easy common examples. These examples should demonstrate that by merely changing the verb in most cases, you can change most conversations to more professional-sounding conversations. First, the conversation is presented using informal language, followed by same conversation using business English:

Informal English	**Business English**
I got your email	I received your email
I need some help.	I require some assistance.
Let's talk about it later.	Let's discuss it later.
How do I get in touch with her?	How do I contact her?
Please make sure you arrive on time.	Please ensure you arrive on time.
Please give her your travel plans.	Please provide her your itinerary.
Please let them know when you will be arriving.	Please inform them of your arrival.
Please tell me why you have made this decision.	Please explain your decision.
Can you talk some more about that subject?	Can you elaborate on that?
How are you going to fix this problem?	How are you going to solve this problem?

5 SUCCESS BEHAVIORS TO STAY POSITIVE AND BE PRODUCTIVE IN SMALL SPACES

Suddenly, a lot of people are working at home. And they're doing it 100 percent of the time.

It's a shock--and while we hate to admit it, this could go on for quite some time.

So, what can you do to increase the odds of being happy and productive while working and living in a confined space? Well, let's latch onto that word: "space."

Because there's a federal agency that's spent a lot of time studying how a certain group of people can remain happy and productive for long periods of time--all while confined to small spaces.

We call that certain group of people "astronauts." And, it's critical for NASA to put them in the best position to succeed--especially over the past 20 years, as we've had astronauts routinely spend six months or more at the International Space Station.

The agency now touts five skills and behaviors that it trains its astronauts to adopt.

I heard about these first from a Twitter post by astronaut Anne McClain, who was on the space station in 2018 and 2019.

Drawing on the work of NASA psychologist Dr. Al Holland and retired astronaut Peggy Whitson, here are the NASA "Expeditionary Behaviors," as summarized by McClain.

Skill 1: Communication

The definition here, according to part of what McClain wrote, is to talk so you are understood, and listen actively so that you understand. That means picking up on non-verbal cues, and looking out for areas where you need to resolve conflict.

It also means sharing information, talking about your intentions, and admitting when you're wrong.

- *For business leaders and teams: Set and accept reasonable expectations about how relationships will work when you're no longer in the office. Then, be prepared to regroup and adapt based on how it's working out.*

Skill 2: Leadership and Followership

Here, we're talking about how quickly a team can adapt to new situations. Trust is key between the group's leader and other team members.

How do you achieve that trust? First, you accept responsibility, adjust your style to the environment, and assign tasks and set goals. Then, there's a lot of emphasis on giving direction, feedback, and encouragement.

- *Make sure that employees have the tools they need to do their jobs while working from home, whether it means equipment from the office, or help setting up a separate place within their homes to do their work effectively.*

Skill 3: Self-Care

Oh, this one is right on the nose. NASA believes that your psychological and physical health, "including hygiene, managing time and personal stuff, getting sleep, and maintaining mood" has a direct impact on astronauts' output.

This means assess your strengths and weaknesses, and how you work within your larger group. Also: "Be social. Seek feedback. Balance work, rest, and personal time," McClain writes. "Be organized."

- *If you're having trouble with this, some of the advice you've probably seen in every basic "working from home" article lately will apply: set up some structure, and make work-life balance a priority.*

Skill 4: Team Care

This is related to Skill #3 of course, but it's more about how each team member's psychological and physical health affects everyone else.

NASA's advice: "Demonstrate patience and respect. Encourage others. Monitor team for signs of stress or fatigue," McClain writes, and "Encourage participation in team activities ... Share the credit; take the blame."

- *One common practice among successful dispersed teams is that often they all get together once or twice a year to build rapport and teamwork. We're just at the start of this experience for a lot of people, but that's something to think about if it lasts for a long time.*

Skill 5: Group Living

This final skill perhaps applies more to how you're getting along with family (or roommates) while working from home, as opposed to your business team. But it's important.

The advice: "Cooperate rather than compete," McClain writes. "Actively cultivate group culture. ... Take accountability, give praise freely. Work to ensure positive team attitude. Keep calm in conflict."

- *Obviously, there's no "going for a walk to clear my head" in space, and limited room for astronauts to truly unplug from the office for any real length of time. So that's an advantage for people who are just working from home--versus working in a 240-foot shell, 254 miles above the planet.*

References:

ASME Boiler and Pressure Vessel Code, Section VIII, Division 1 – 2019 Edition

This page left intentionally blank.

BUILDING A BETTER TOMMORROW

It is becoming less practical for many companies to maintain in-house engineering staff. That is where we come in – whenever you need us, either for one-time projects, or for recurring engineering services. We understand the codes and standards, and can offer a range of services related to pressure vessels, tanks and heat exchangers.

Training & Development
Engineering and Design Services

CoDesign Engineering

Pressure Vessels ● Heat Exchangers ● Storage Tanks

Oil & Gas ● Petrochemical ● Chemical ● Power ● Fertilizer