Introduction to Static Equipment in Oil and Gas Industry

Operations Petrochemicals, Oil and Gas Facebook Group Free Webinar

BAHER ELSHEIKH

JULY 2020

Baher Elsheikh

Mechanical Engineer
Static Equipment Specialist

Career Timeline

- 2002 - 2008 — **Cairo Oil Refining Company**
  Mechanical Design Engineer
- 2008 - 2016 — **Methanex**
  Senior Mechanical Engineer
- 2016 - Present — **Sabic - Safco**
  Senior Mechanical Engineer

Certifications

- **API 580**
  Risk Based Inspection
- **API 571**
  Damage Mechanisms in Fixed Equipment
- **CRE**
  Certified Reliability Engineer
- **CRL**
  Certified Reliability Leader

Publications

- **Thermal Cycling Damage in Reformer Tubes**
  Nitrogen + Syngas 2016 (CRU) – March 2016
- **Effective Reliability and Safety Management of Steam Reformer Tubes**
  NACE Conference – Jubail - 2019
- **Steam Reformer Tubes; Lifecycle and Integrity Management**
  Stainless Steel World Magazine – March, 2020
- **Comprehensive Integrity Management Program for Reformer Tubes**
  Inspectioneering Journal – April, 2020
- **Collar Bolts in Shell and Tube Heat Exchanger**
  Heat Exchanger World Magazine – May, 2020

Baher Elsheikh @ in f YouTube

Ground Rules

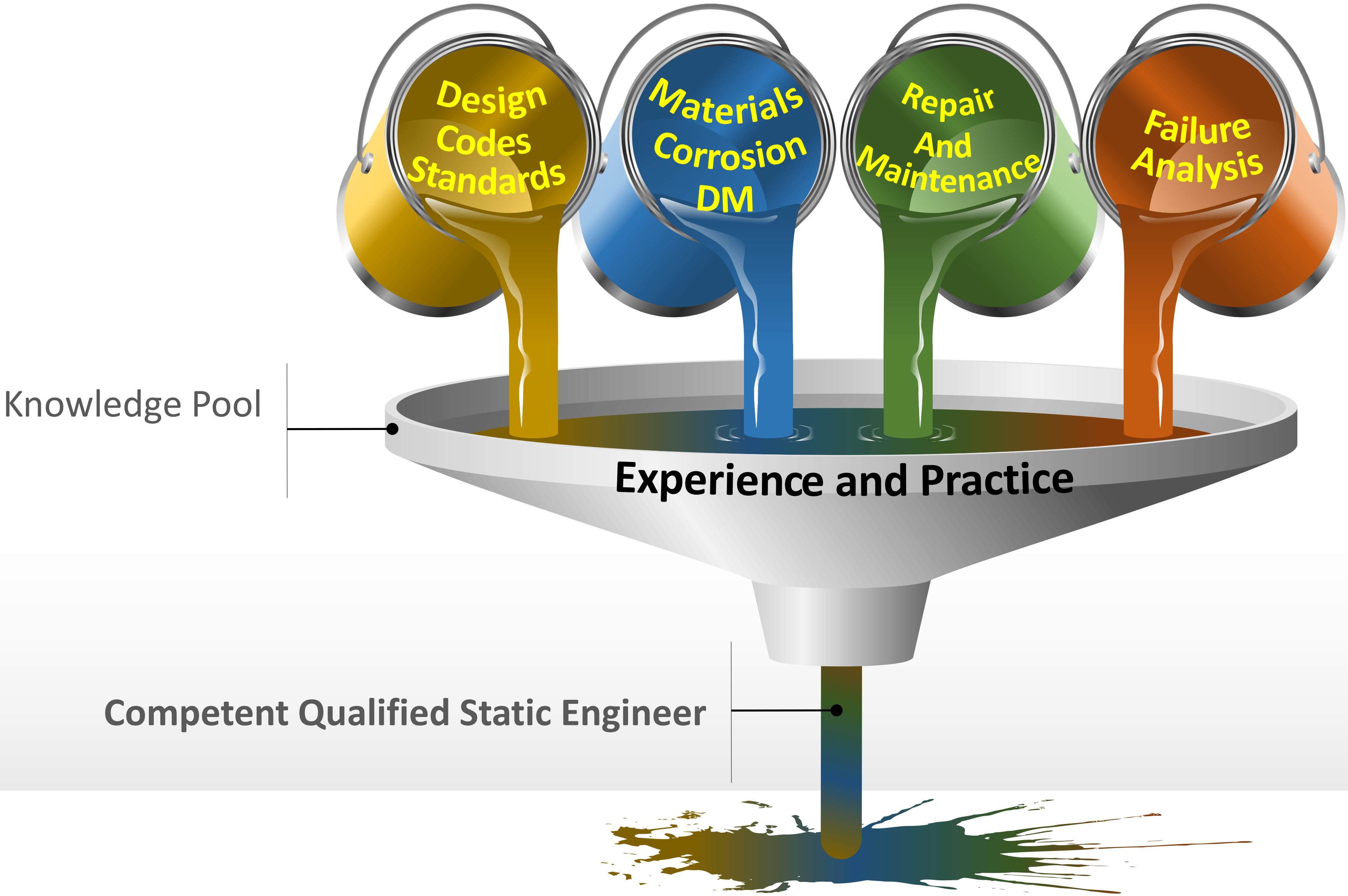
- Mute your device, switch off your camera
- Questions and open discussions at end of the session
- Answer all the questions and get free copy of all references used in the presentation plus copy of presentation

  Q 1 … Q 10 →

- Notice this sign, marked information can be used in case study at end
- We will focus on some parts and others will provided for reference

Contents

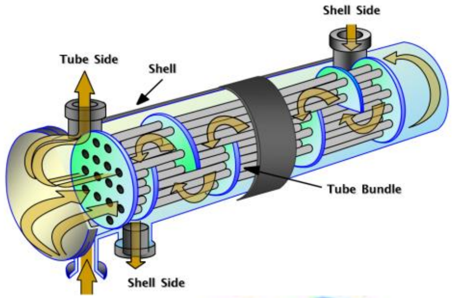
Static Equipment Engineer – Areas of Knowledge



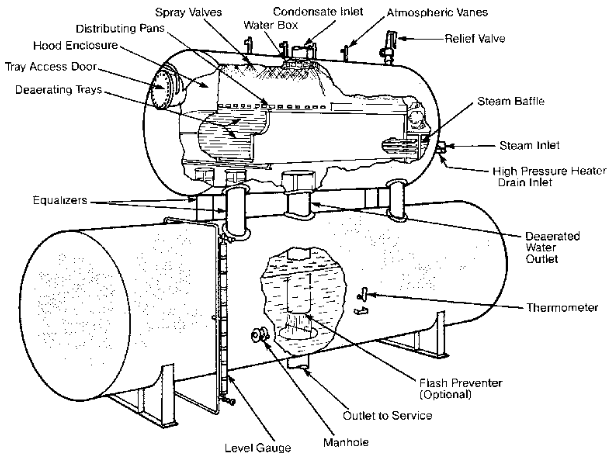
Main Static Equipment



Pressure Vessels

Heat Exchangers

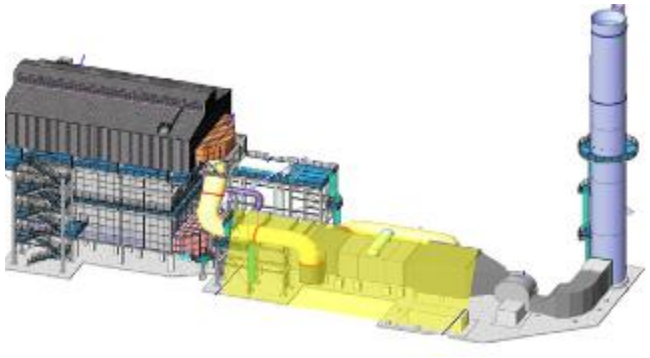


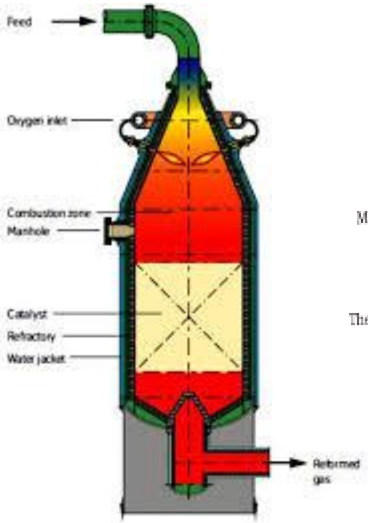
Deaerator

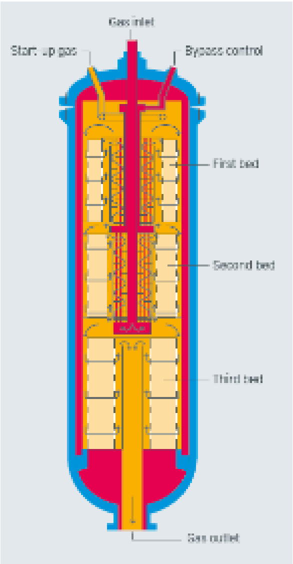
Q 1

How to differentiate between pressure vessel, shell and tube heat Exchanger and Deaerator at site

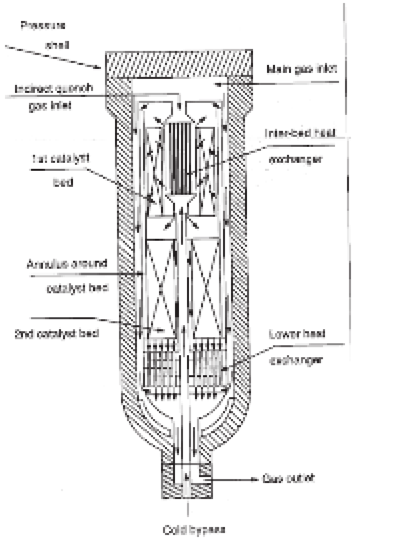
Main Static Equipment

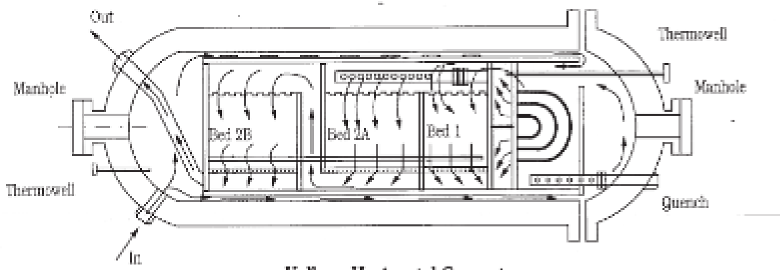




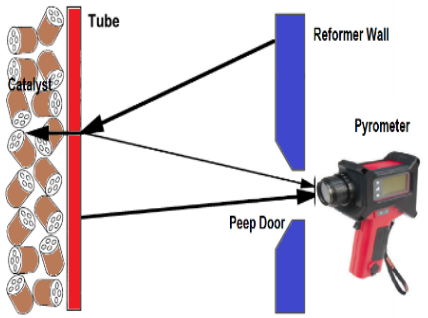


Three bed ammonia converter





Kellogg Horizontal Converter.



Steam Reformer and Fired Heaters

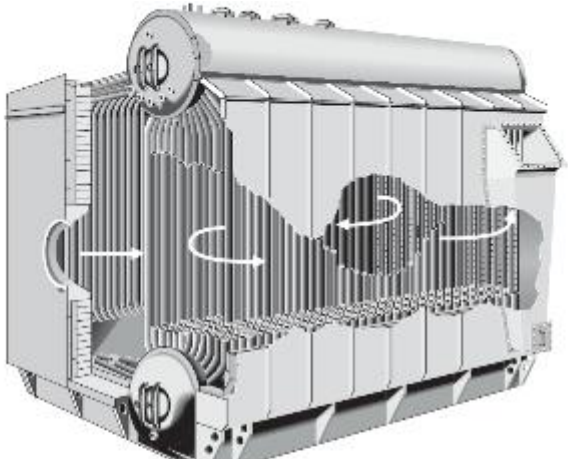
Secondary Reformer

Reactors and Converter

Q 2

Which of the 3 equipment requires frequent temperature monitoring by pyrometer and why?

Main Static Equipment



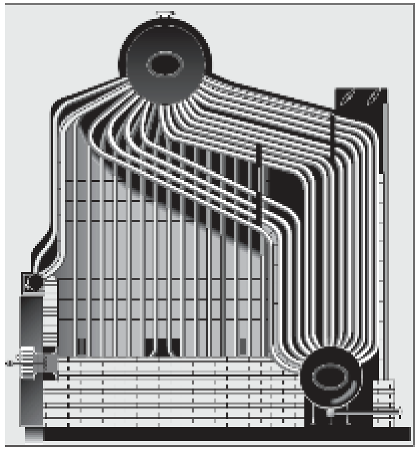
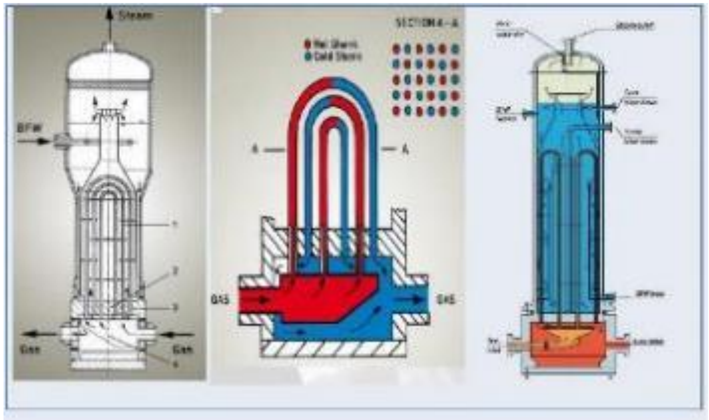
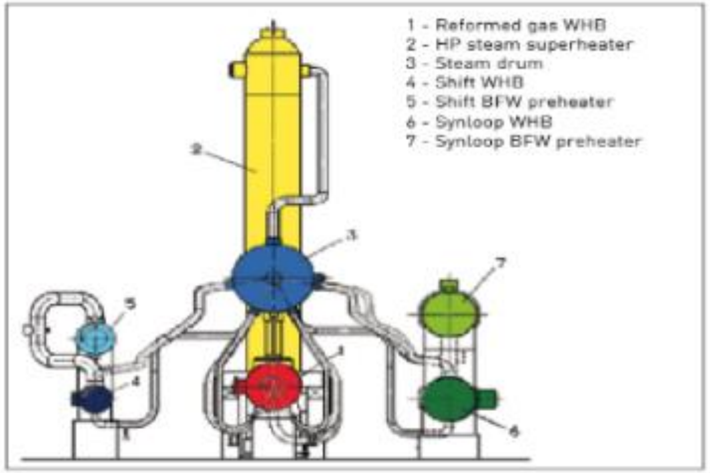


Figure 4—Typical Vertical Oil or Gas-fired Water Tube Boiler

Fired Boiler





Reformed Gas / Waste Heat Boiler

HRSG

Q 3

How RGB differs from Fired Boiler and what are the common aspects

Main Static Equipment

Storage Tanks

Piping Systems

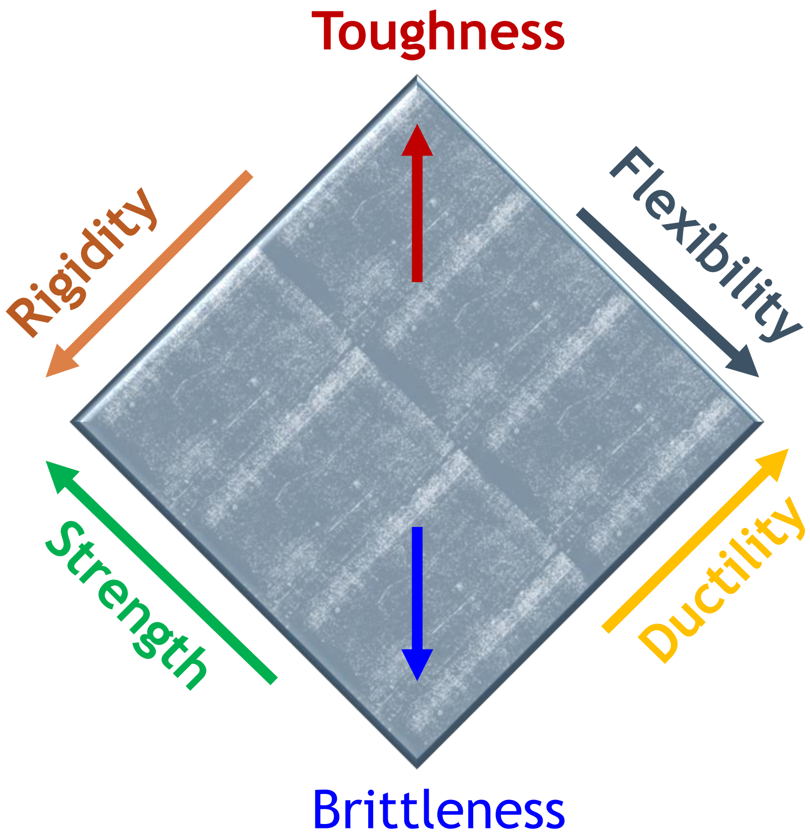
Valves and PRVs

Q 4

What is the main difference between storage tanks and pressure vessels

Materials

Material Selection



Classification of Steels

Composition	Manufacturing Method	Finishing Method	Deoxidation Practice	Microstructure	Required Strength	Heat Treatment
Such as	Such as	such as	such as	such as	As specified in ASTM	Such as
Carbon Steel	**Open hearth**	**Hot Rolling**	**killed**	**Ferritic**	**High strength**	**Annealing**
Low Alloy Steels	**Basic Oxygen Process,**	**Cold Rolling**	**Semikilled**	**Pearlitic**	**Intermediate strength**	**Tempering**
Stainless Steels	**Electric Furnace methods**		**Capped**	**Martensitic**	**Low strength**	**Quenching**
			Rimmed steel			

Source: ASM Handbook, Volume 1, Properties and Selection: Irons, Steels, and High Performance Alloys

Creep Resistance Cr-Mo Low Alloy Steels

Plain Carbon Steel

+Mo for Creep Resistance

Grade 1
1/2 Mo Steels

+Cr & Mo for Creep Resistance

Grade 11 (1Cr-0.5 Mo)
Grade 22 (2.25Cr-1 Mo)

+V for Creep Resistance → **½ to 3% Chrome-Moly-Vanadium Steels 0.5-3Cr;1Mo;0.25 V1**

Micro Alloyed Improved Creep → **Grades 23 & 24 steels micro-alloyed**
2.5Cr–0.2Mo–0.25V–1.5W–B
2.5Cr–1Mo–0.25V–B–Ti

+Cr for Hydrogen And Corrosion Resistance

Grade 5 (5Cr-0.5 Mo)
Grade 9 (9Cr-1 Mo)

+C, Cr, W&V Improved Creep → **Grades X20**
(0.2 C-12Cr-1Mo-0.5W-0.3V)

+Nb, V & N for improved Creep Resistance

Grades 91
(0.1C-9Cr-1Mo-Nb-V-N)

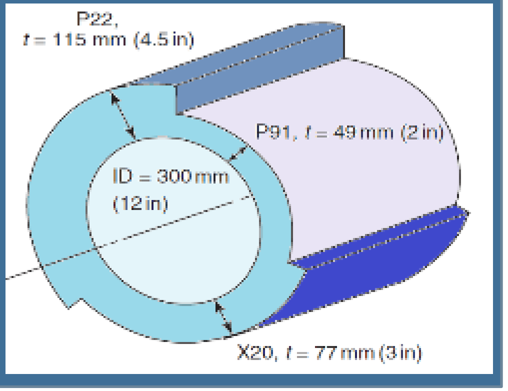
Low C, +Nb, N&Co Better Weldability → **Grades HCM12A/122**
Advanced 12% Cr steels
0.C-11Cr-Nb-V-N(up to 3Co)

+ 1-2% W for even greater Creep Resistance

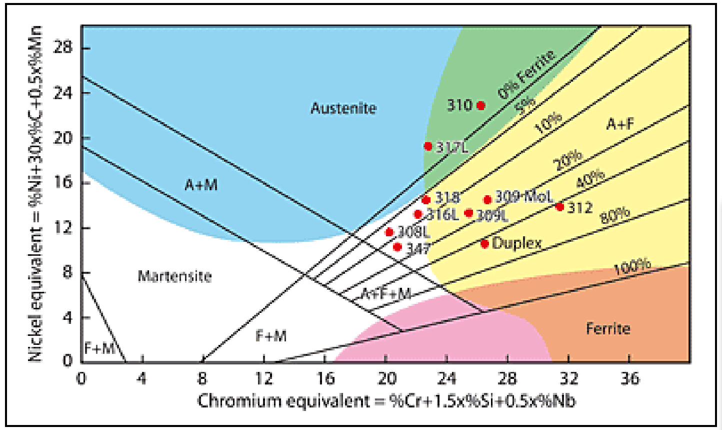
Grade 92 (9Cr-0.5Mo-1.8W)
Grade 911 (9Cr-1Mo-1W)
Tungsten-Bearing (% Cr-Steel

Thickness Required From Differnt Grades of Cr-Mo Steel

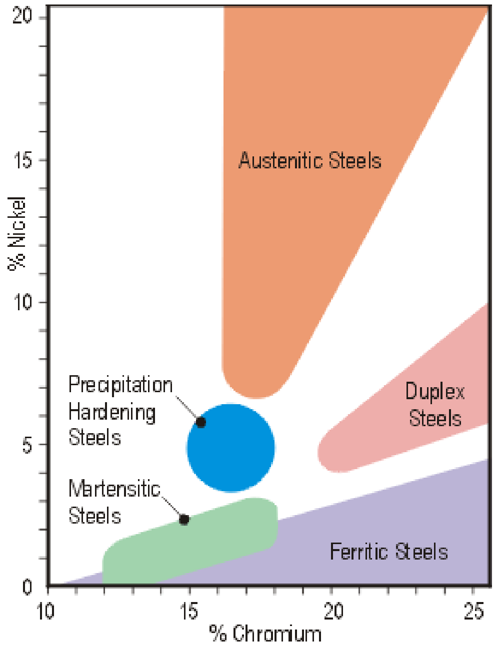
Steam Pipe temperature 600 ˚C, pressure 30MPa



Stainless Steel Families



Shaeffler Diagram (A-austenite; M - Martensite; F - ferrite)

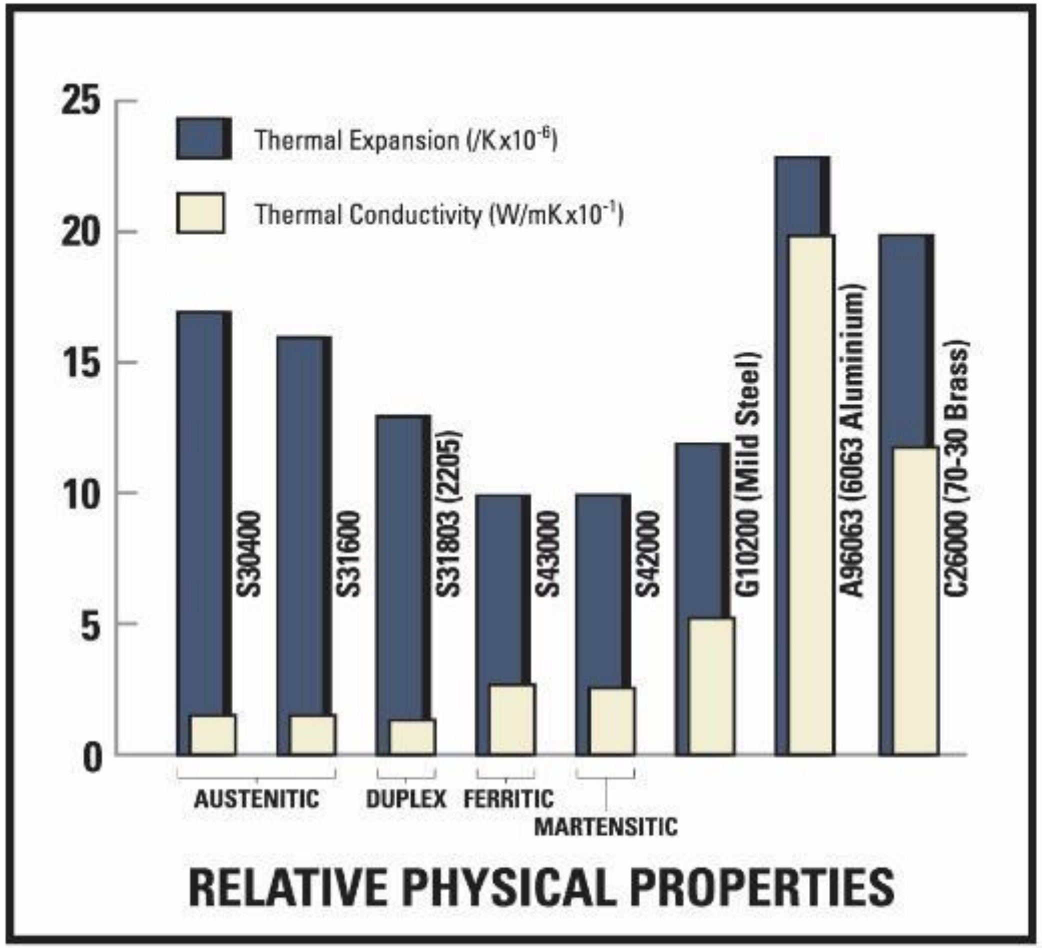


Stainless steel families

Austenitic Stainless Steels	**This group contains at least 16% chromium and 6% nickel (the basic grade 304 is referred to as 18/8**
Ferritic Stainless Steels	**Plain chromium (10.5 to 18%) grades such as Grade 430 and 409**
Duplex Stainless Steels	**Have microstructures comprising a mixture of austenite and ferrite. Duplex ferritic. Examples : 2205 and 2304**
Martensitic Stainless Steels	**Chromium as the major alloying element but with a higher carbon and generally lower chromium content (e.g. 12% in Grade 410 and 416) than the ferritic types**
PH Stainless Steels	**Chromium and nickel containing steels that can develop very high tensile strengths. The most common grade in this group is "17-4 PH"**

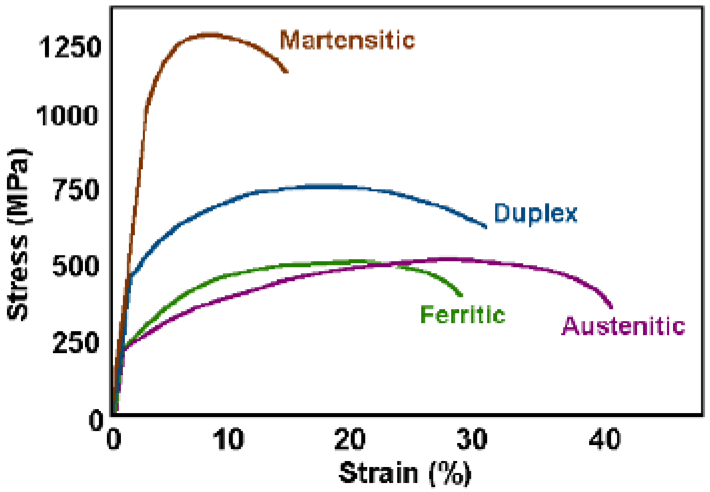
Reative Mechanical and Physical Properties of Stainless Steel

Thermal Expansion and Thermal Conductivity

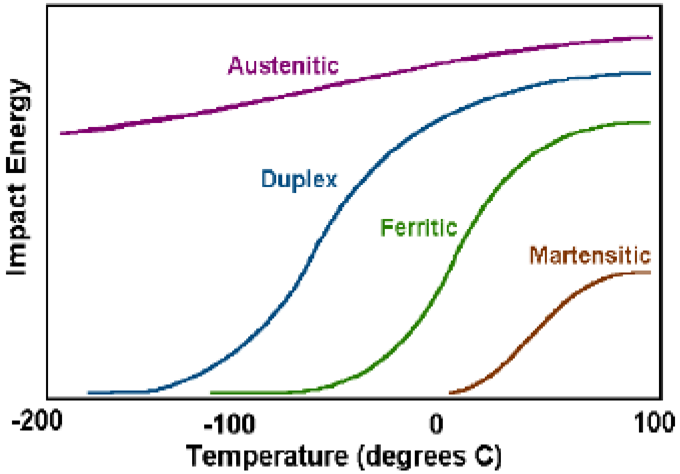


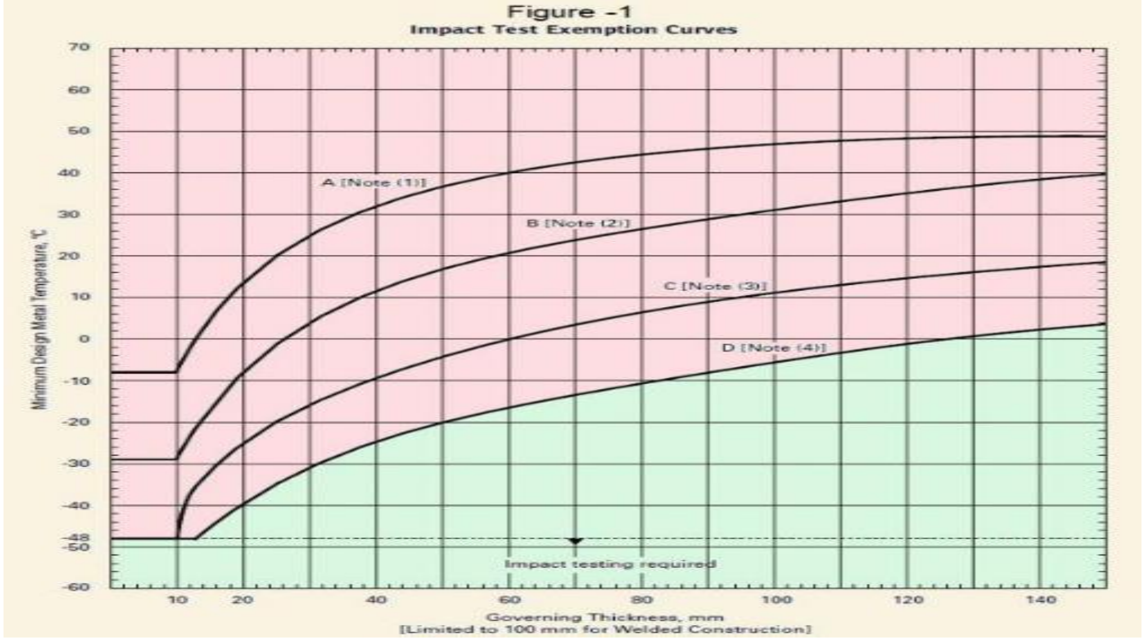
Note: These figures are approximate as there can be a wide variability in quoted results that relate to variations in the actual temperature range and the specific composition.

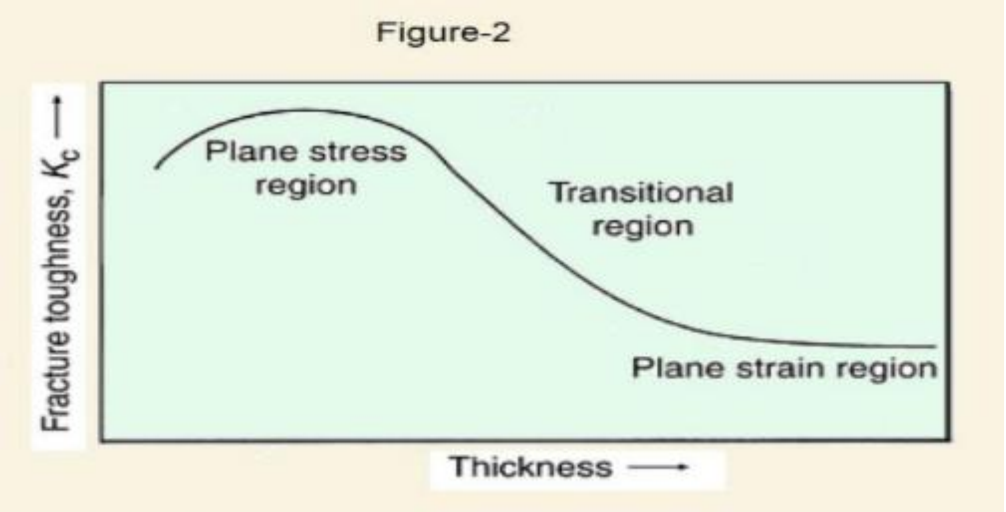
Typical Tensile Properties

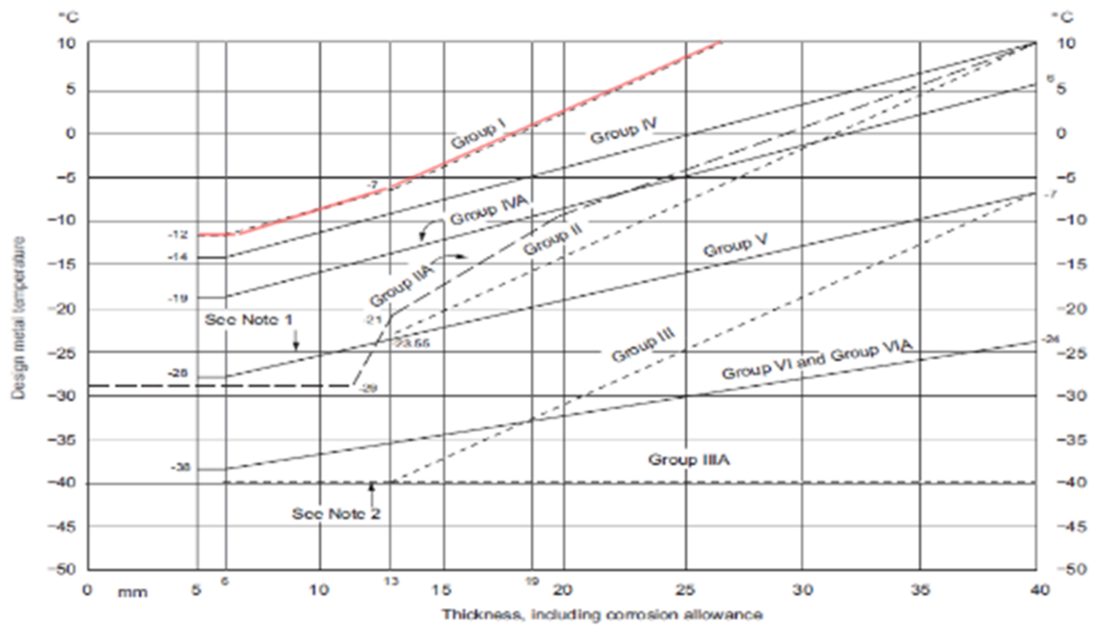


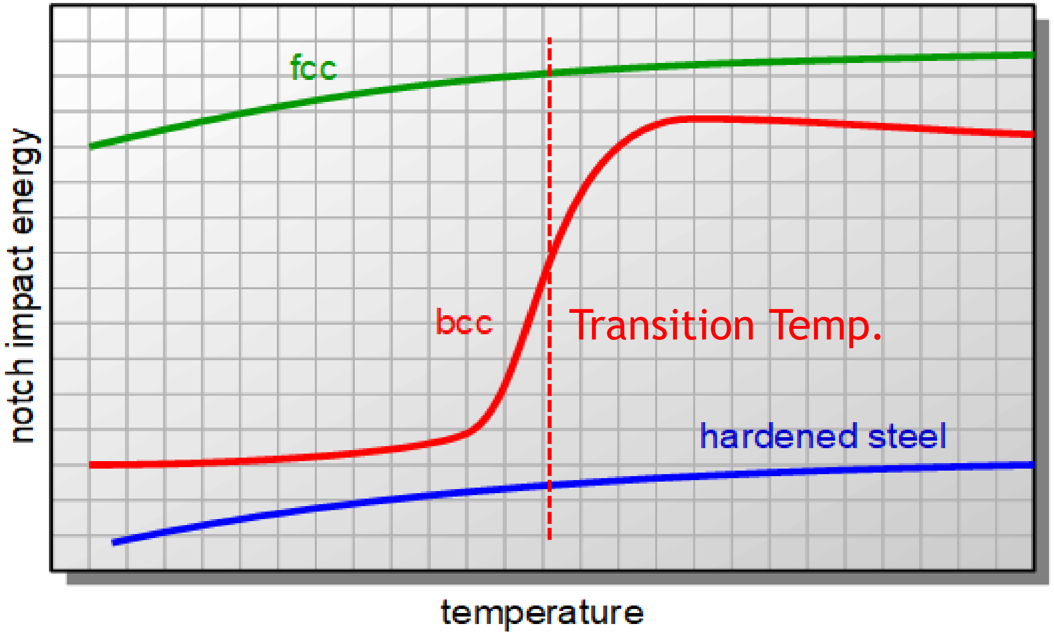
Typical Impact Properties









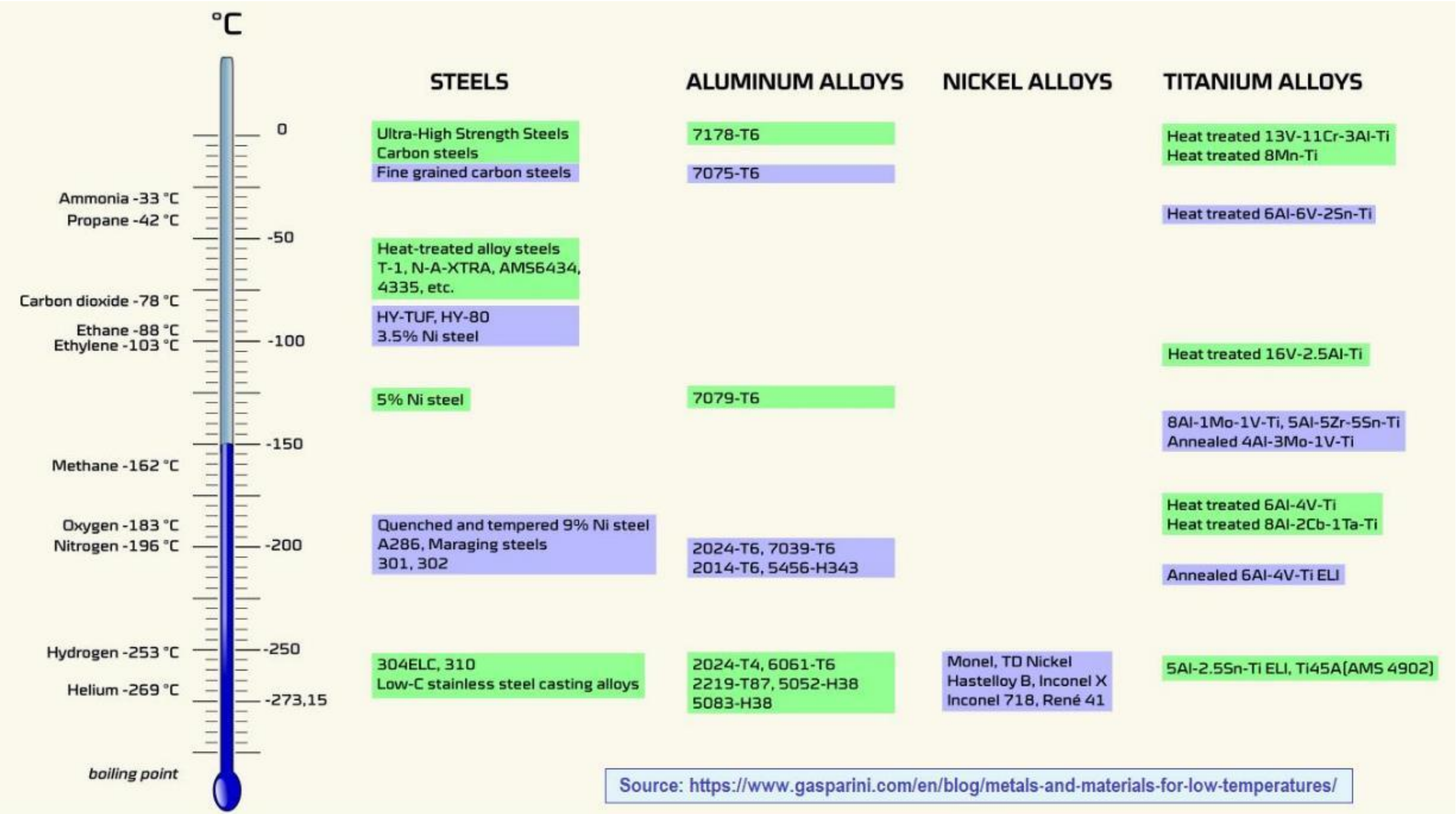


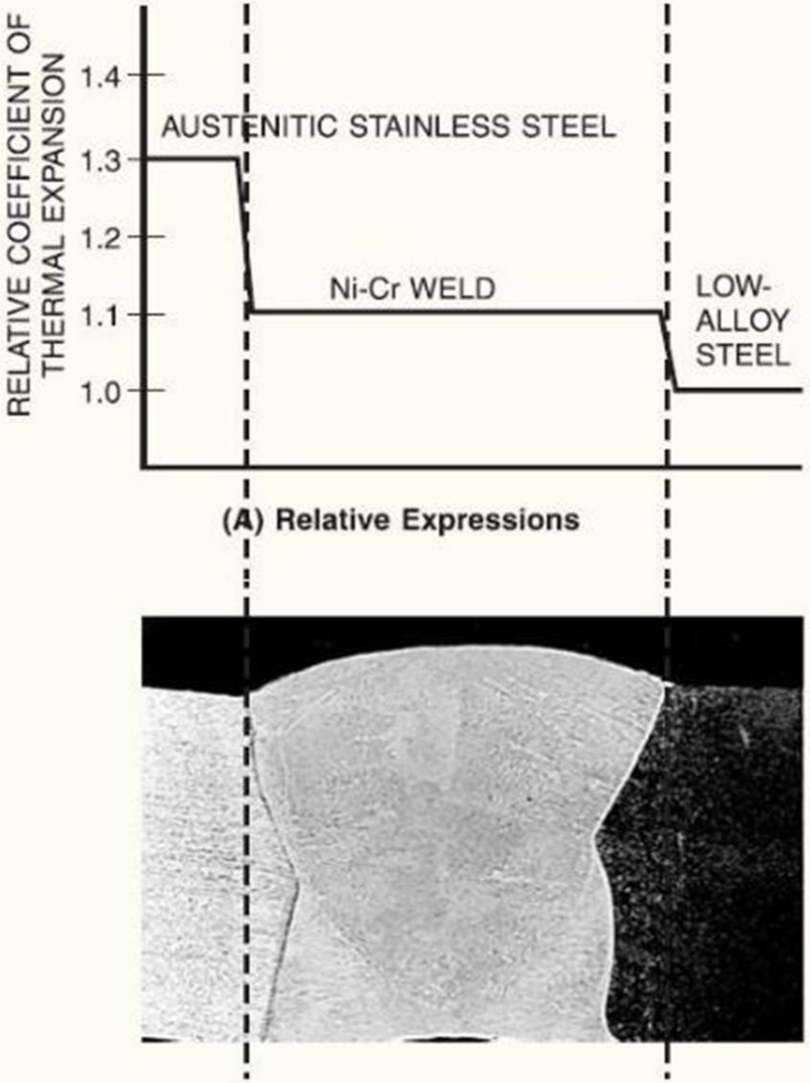
Toughness

Material Thickness and Temperature Effect

References:

- API 579-1 Part 9
- ASM Handbook volume 11 - Failure analysis and prevention
- ASME BPVC Sec. VIII Div.1 - UCS 66
- API 650


°C
STEELS
ALUMINUM ALLOYS
NICKEL ALLOYS
TITANIUM ALLOYS
0
-50
-100
-150
-200
-250
-273,15
Ammonia -33 °C
Propane -42 °C
Carbon dioxide -78 °C
Ethane -88 °C
Ethylene -103 °C
Methane -162 °C
Oxygen -183 °C
Nitrogen -196 °C
Hydrogen -253 °C
Helium -269 °C
boiling point
Ultra-High Strength Steels
Carbon steels
Fine grained carbon steels
Heat-treated alloy steels
T-1, N-A-XTRA, AMS6434, 4335, etc.
HY-TUF, HY-80
3.5% Ni steel
5% Ni steel
Quenched and tempered 9% Ni steel
A286, Maraging steels
301, 302
304ELC, 310
Low-C stainless steel casting alloys
7178-T6
7075-T6
7079-T6
2024-T6, 7039-T6
2014-T6, 5456-H343
2024-T4, 6061-T6
2219-T87, 5052-H38
5083-H38
Monel, TD Nickel
Hastelloy B, Inconel X
Inconel 718, René 41
Heat treated 13V-11Cr-3Al-Ti
Heat treated 8Mn-Ti
Heat treated 6Al-6V-2Sn-Ti
Heat treated 16V-2.5Al-Ti
8Al-1Mo-1V-Ti, 5Al-5Zr-5Sn-Ti
Annealed 4Al-3Mo-1V-Ti
Heat treated 6Al-4V-Ti
Heat treated 8Al-2Cb-1Ta-Ti
Annealed 6Al-4V-Ti ELI
5Al-2.5Sn-Ti ELI, Ti45A(AMS 4902)
Source: https://www.gasparini.com/en/blog/metals-and-materials-for-low-temperatures/



(B) Joint Between Type 304 Stainless Steel (Left) and 2-1/4Cr-1Mo (Right) Welded with ERNiCr-3 Filler Metal

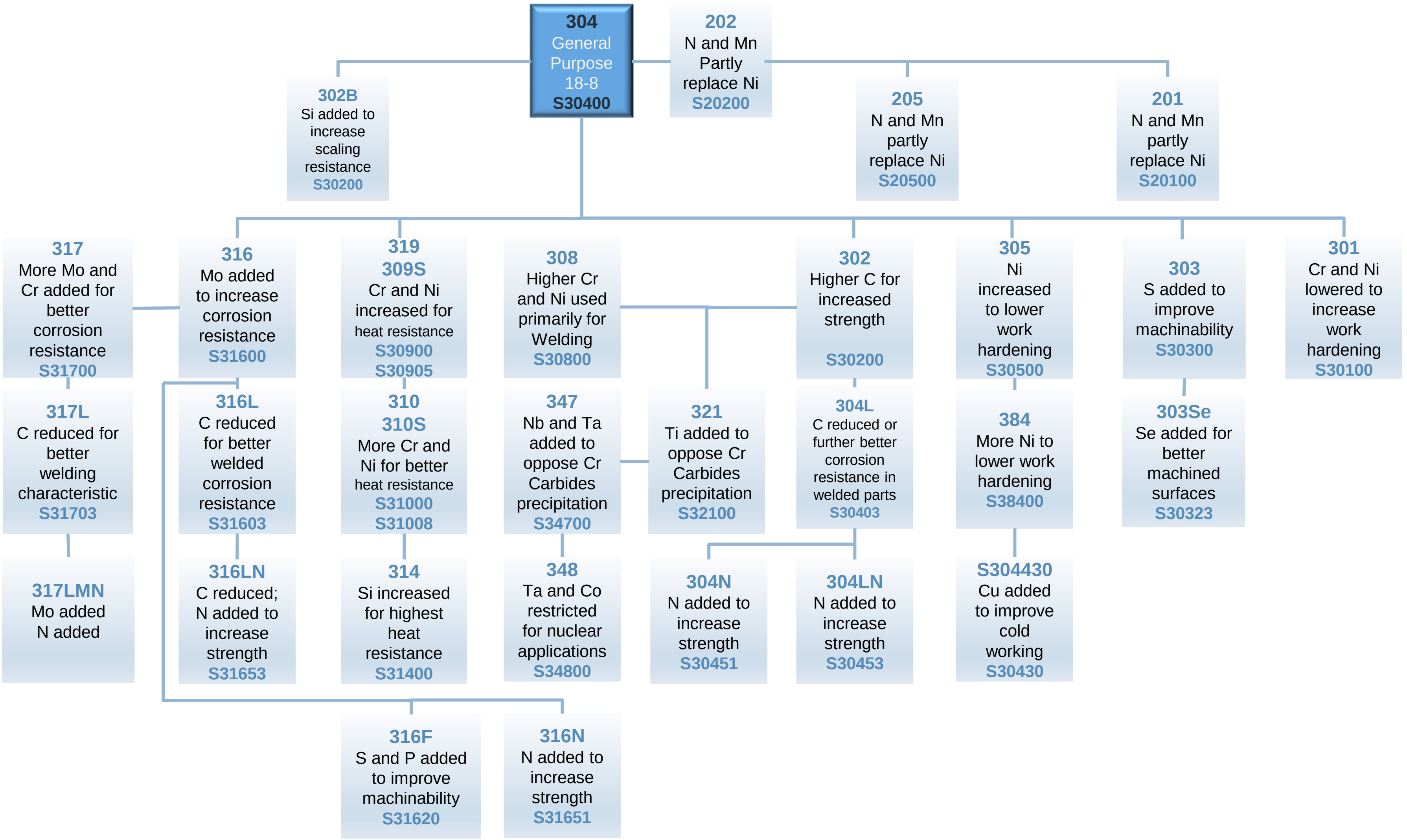
Note: Values shown in (A) represent ratio comparisons to carbon steel (as in Table 6.2), not actual values of properties.

Dissimilar Metal Weld
DMW

References:

AWS – Welding Handbook, Volume 4 Part 1

Austenitic Stainless-Steel



Magnetic X
Ni √
Cr √

- Corrosion Resistance
- good mechanical properties
Suitable for High Temp. Application

- Susceptible to Cl SCC and pitting
- Lower oxidation resistance – prone to oxide spalling

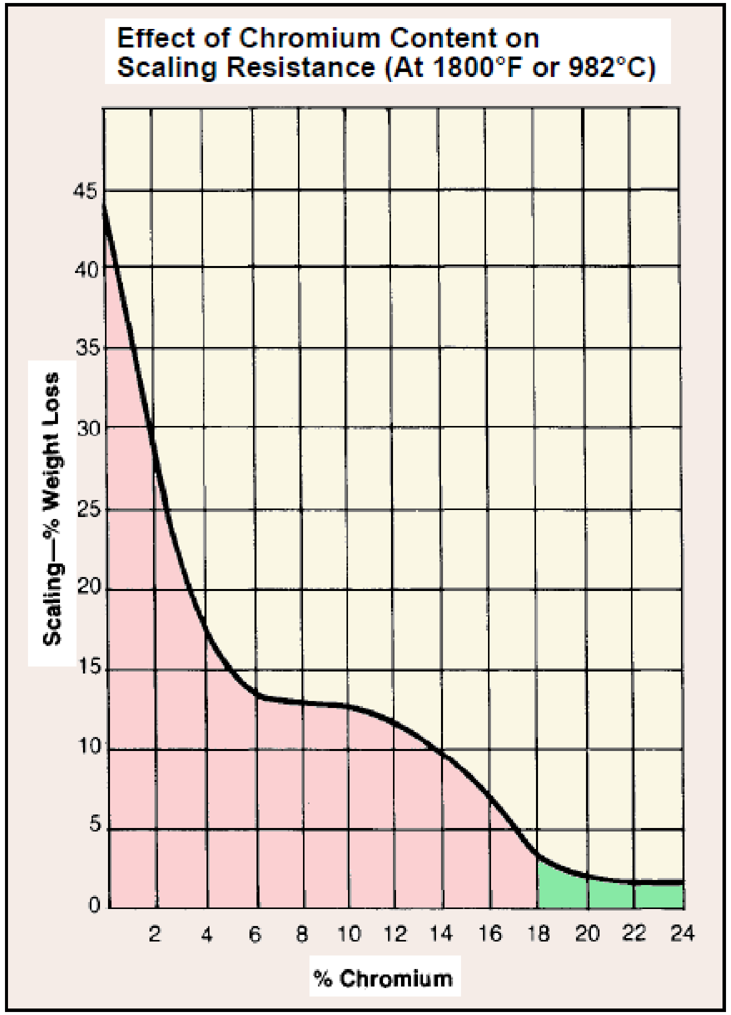
Al: Aluminum	**P:** Phosphorous
C: Carbon	**S:** Sulfur
Cr: Chromium	**Se:** Selenium
Cb: Columbium	**Si:** Silicon
Co: Cobalt	**Ta:** Tantalum
Cu: Copper	**Ti:** Titanium
Mn: Manganese	**V:** Vanadium
Mo: Molybdenum	**W:** Tungsten
N: Nitorgen	
Ni: Nickel	

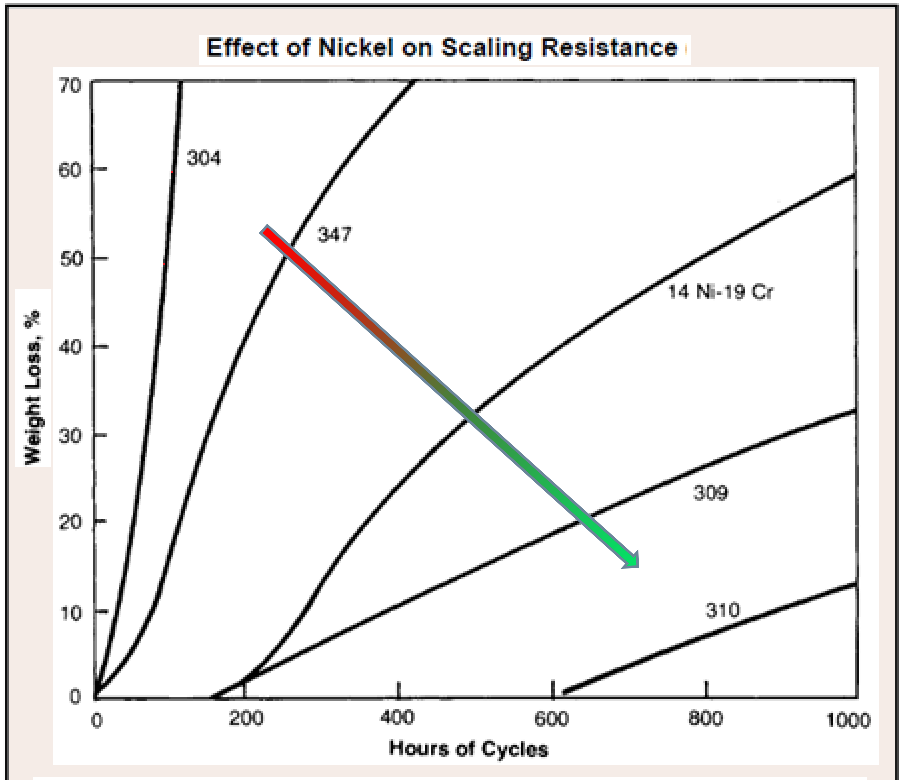
Source: ASM- Stainless Steel for Design Engineers

Austenitic Stainless-Steel Scaling Resistance

Suggested Maximum Service Temperatures in Air (1)

AISI Type	Intermittent Service °C	Intermittent Service °F	Continuous Service °C	Continuous Service °F
201	815	1500	845	1550
202	815	1500	845	1550
301	840	1550	900	1650
302	870	1600	925	1700
304	870	1600	925	1700
308	925	1700	980	1800
309	980	1800	1095	2000
310	1035	1900	1150	2100
316	870	1600	925	1700
317	870	1600	925	1700
321	870	1600	925	1700
330	1035	1900	1150	2100
347	870	1600	925	1700
410	815	1500	705	1300
416	760	1400	675	1250
420	735	1350	620	1150
440	815	1500	760	1400
405	815	1500	705	1300
430	870	1600	815	1500
442	1035	1900	980	1800
446	1175	2150	1095	2000





Scaling resistance of some iron-chromium-nickel alloys in cycling-temperature conditions at 1800°F (982°C). Cycle consisted of 15 min. in the furnace and 5 min. in air. Sheet specimens 0.031 in. (0.787 mm) thick were exposed on both sides.

Q 5

Why the Max. Temp. for intermittent service is less than the allowed for continuous service in Austenitic SS

Source: NiDi- High Temperature Characteristics of Stainless Steels

Ferritic Stainless Steel

430
General Purpose
S43000

- **446** – Cr increased to improve scaling resistance – **S44600**
- **442** – Cr increased to improve scaling resistance – **S44200**
- **444** – C reduced, Mo added to improve corrosion resistance; Ti and Nb added – **S44400**
- **429** – Slightly less Cr for better Weldability – **S42900**
- **439** – C reduced; Ti added to oppose carbide precipitation – **S43035**
- **405** – Lower CR, Al added to prevent hardening when cooled from elevated temperatures – **S40500**
- **409** – Lower Cr; Primarily used for automotive exhaust systems – **S40900**
- **430F** – P and S increased to improve machinability – **S43020**
  - **430F Se** – Se added for better machined surfaces – **S43023**
- **434** – Mo added for improved corrosion resistance in automotive trim – **S43400**
  - **436** – Mo, Nb and Ta added for corrosion and heat resistance – **S43600**

Magnetic √
Ni X
Cr √
-Corrosion Resistance

- Not Suitable for High Temp. Application (subject to 475 embrittlement)

Al: Aluminum	P: Phosphorous
C: Carbon	S: Sulfur
Cr: Chromium	Se: Selenium
Cb: Columbium	Si: Silicon
Co: Cobalt	Ta: Tantalum
Cu: Copper	Ti: Titanium
Mn: Manganese	V: Vanadium
Mo: Molybdenum	W: Tungsten
N: Nitorgen	
Ni: Nickel	

Source: ASM- Alloying, Understanding the Basics

Martensitic Stainless Steel

410
General Purpose
S41000

431
Cr increased and Ni added for better corrosion resistance, good mechanical properties
S43100

414
Ni added for better corrosion resistance
S41400

422
Strength and toughness to 1200^{0}F via addition of Mo, V, W
S41400

403
Select quality for turbines and highly stressed parts
S40300

420
C increased to improve mechanical properties
S42000

420F
P and S increased to improve machinability
S42020

416
P and S increased to improve machinability
S41600

416Se
Se added for better machined surfaces
S41623

440C
C increased for highest hardness; Cr increased for corrosion resistance
S44004

440B
C decreased slightly to improve toughness
S44004

440A
C decreased even more than for 440B to improve toughness
S44002

Magnetic √
Ni X
Cr √
-Corrosion Resistance
- Hardenable

- Hard to weld

Al: Aluminum	**P:** Phosphorous
C: Carbon	**S:** Sulfur
Cr: Chromium	**Se:** Selenium
Cb: Columbium	**Si:** Silicon
Co: Cobalt	**Ta:** Tantalum
Cu: Copper	**Ti:** Titanium
Mn: Manganese	**V:** Vanadium
Mo: Molybdenum	**W:** Tungsten
N: Nitorgen	
Ni: Nickel	

Source: ASM- Alloying, Understanding the Basics

Duplex Stainless Steel

Duplex Stainless Steel
50/50
Austenite / Ferrite

- **Lean DSS** – Lower Ni, no Mo
  - S32101
  - S32202
  - S32304
  - S32003
  - S82011
  - S82441
- **Standard DSS** – Higher Ni, and Mo
  - S31803
  - S2205
- **Super DSS** – 25 Cr and higher Ni, and Mo
  - S32520
  - S32550
  - S32750
  - S32760
  - S82906
- **Hyper DSS** – More Cr, Ni Ni, Mo and N
  - S32707

Magnetic √
Ni √
Cr √

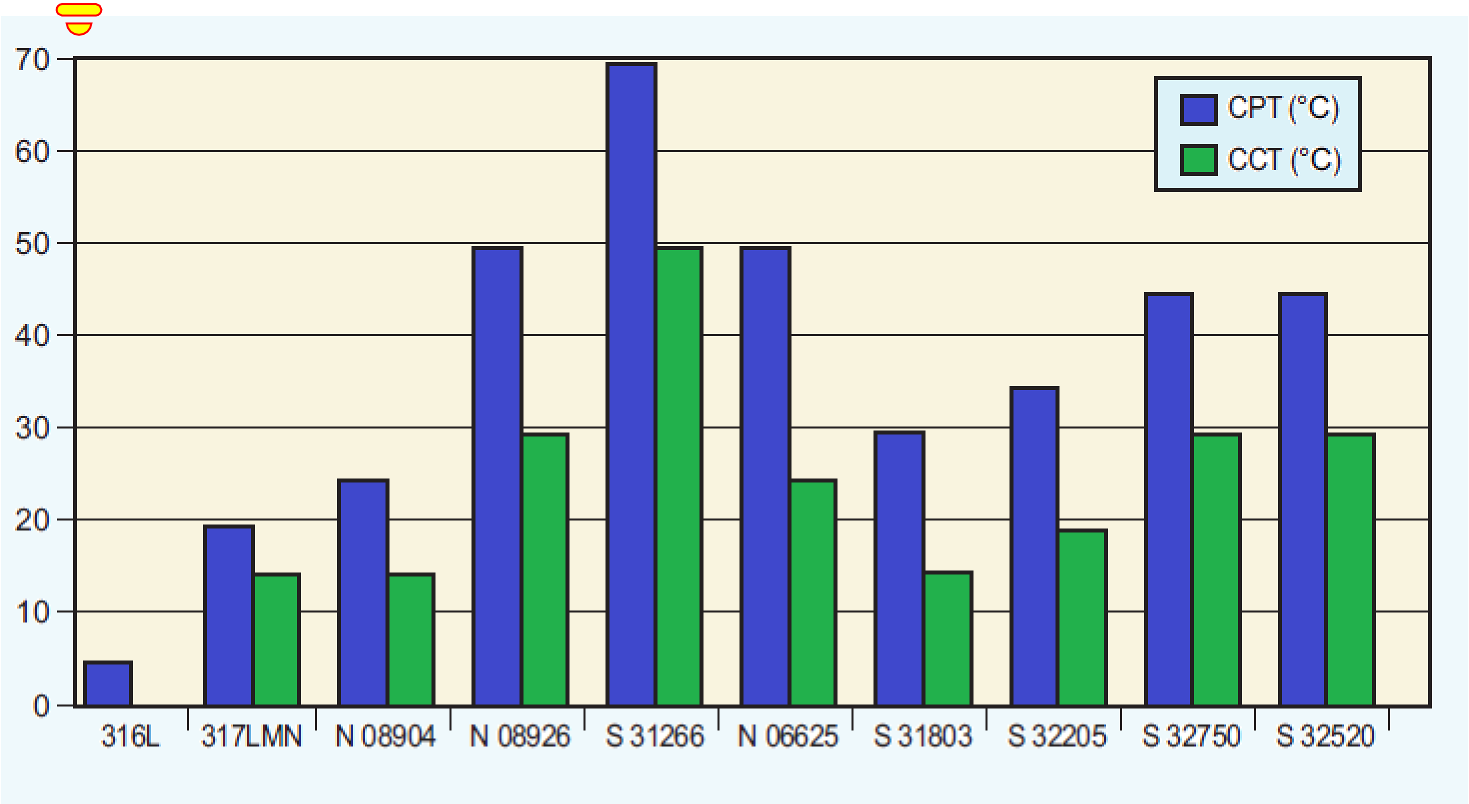
- Corrosion Resistance
- Pitting resistance in Cl service (High PREN)
- High strength

- Not suitable for High T applications (subject to 475 embrittlement)

Al: **Aluminum**	P: **Phosphorous**
C: **Carbon**	S: **Sulfur**
Cr: **Chromium**	Se: **Selenium**
Cb: **Columbium**	Si: **Silicon**
Co: **Cobalt**	Ta: **Tantalum**
Cu: **Copper**	Ti: **Titanium**
Mn: **Manganese**	V: **Vanadium**
Mo: **Molybdenum**	W: **Tungsten**
N: **Nitorgen**	
Ni: **Nickel**	

Source: **API 938C, Use of DSS in Oil Refinery Industry**

Duplex Stainless Steel



PREN = %Cr + 3.3Mo + 16N

Grade	PREN
304L	19
316L	24
2205 S3205	35
2507 S32750	43

Source: API 938C, Use of DSS in Oil Refinery Industry

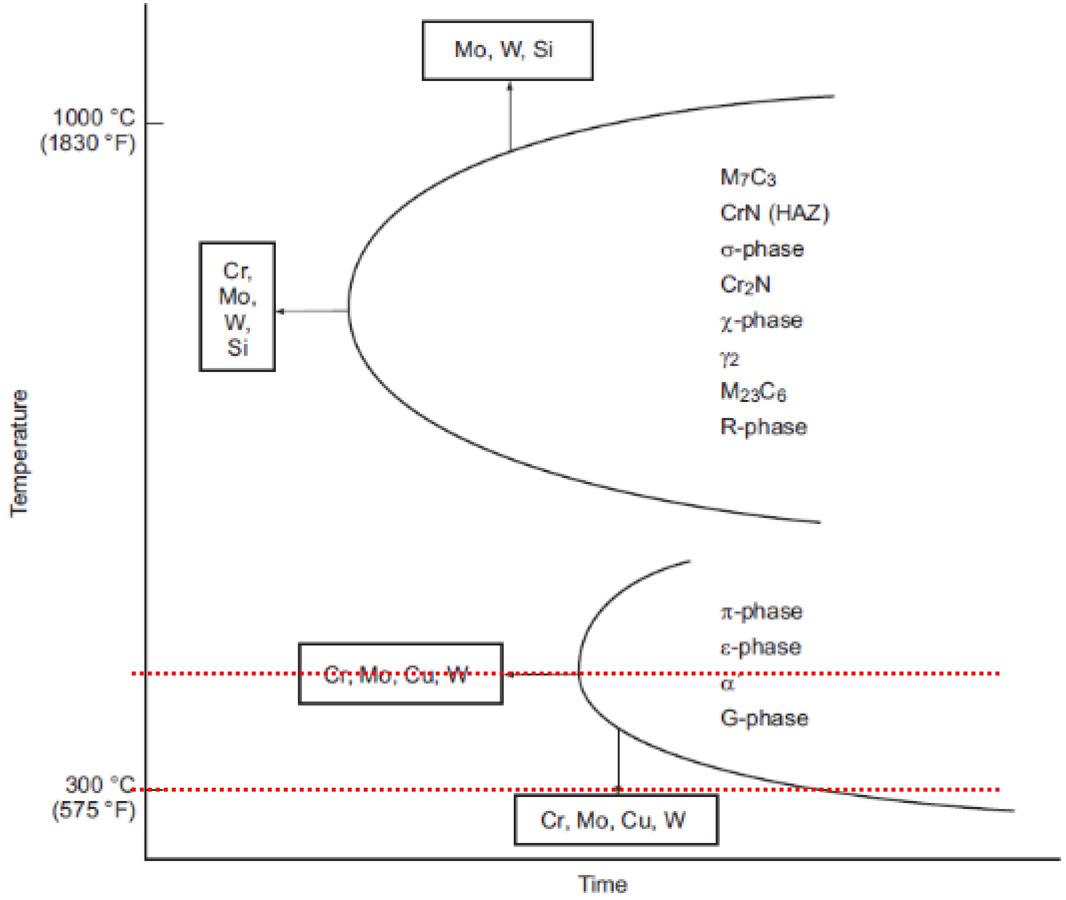
Duplex Stainless Steel

Table 5—ASME Code Maximum Allowable Temperatures

Grade	ASME Section VIII (Div. 1) °C (°F)	ASME B31.3 °C (°F)
S32304	316 (600)	316 (600)
S32101	316 (600) Code Case 2418	NL
S32202	316 (600)	NL
S32003	343 (650) Code Case 2503	343 (650)
S82011	343 (650) Code Case 2735	NL
S82441	316 (600) Code Case 2780	NL
S31803/S33205 (Note 1)	316 (600)	316 (600)
S32550	260 (500)	NL
S32750	316 (600)	316 (600)
S32760	316 (600)	316 (600)
S32906	316 (600)	NL
S32707	260 (500) Code Case 2586	NL

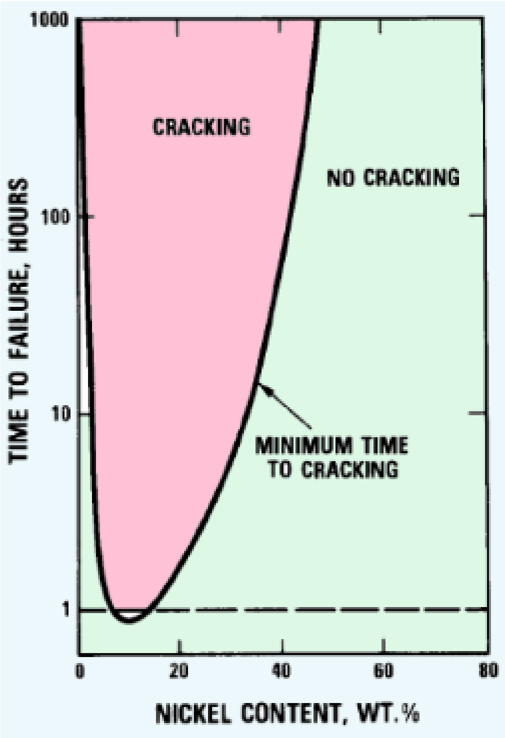
NOTE 1 NL = not listed.

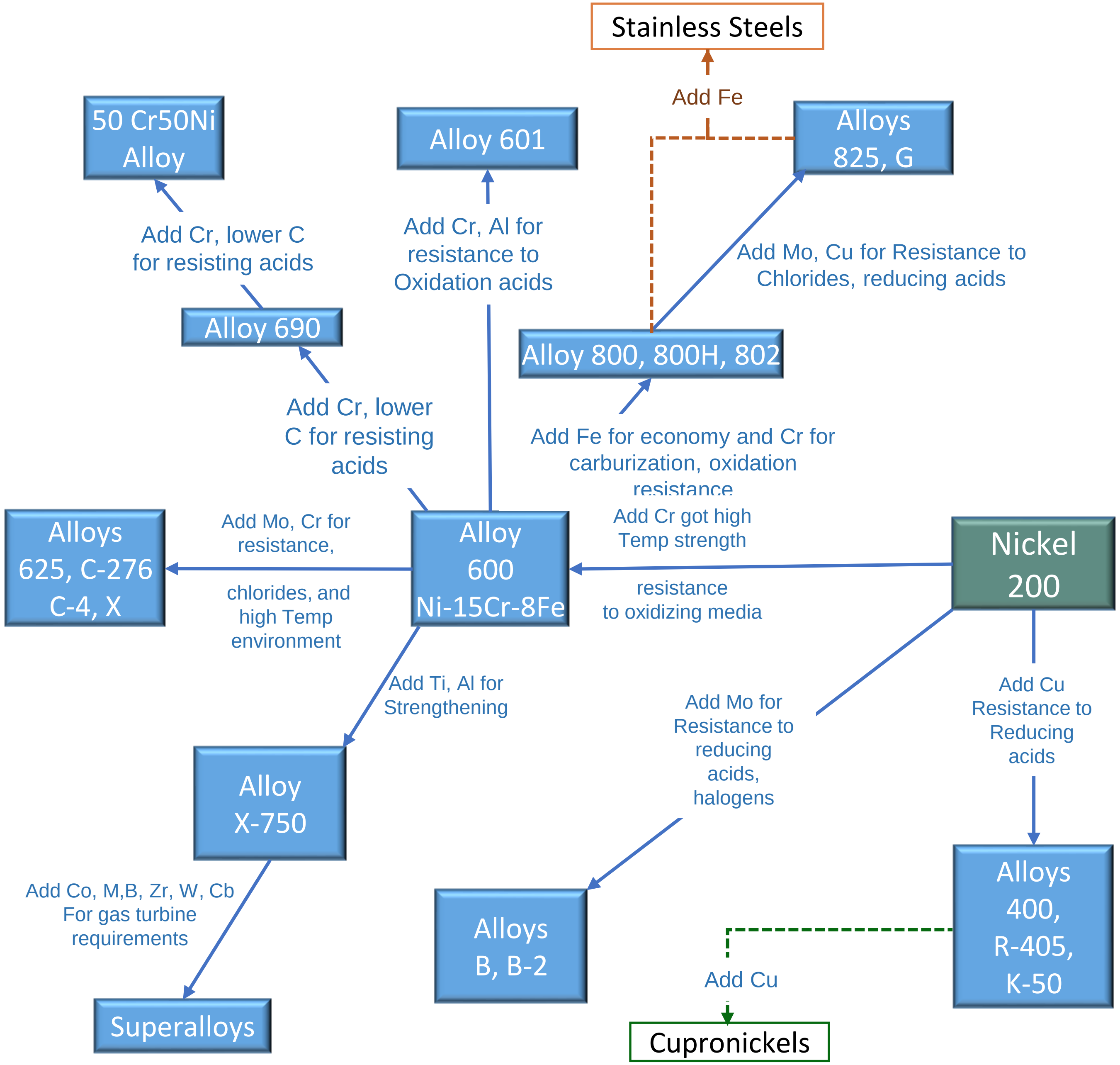
NOTE 2 S32205 can use the design allowables for S31803 if the material is dual-certified.



Source: API 938C, Use of DSS in Oil Refinery Industry

Nickel Alloys





Source: ASM Corrosion of Weldments
ASM Stress Corrosion Cracking

Materials Application – Carbon Steel

Carbon Steel is widely used in oil and gas industry mainly due to its cost, availability and easy fabrication and welding.

Limitations:

Low corrosion resistance in many applications

Very low temperature < -29 C . CS loose toughness

High Temperature: > 425 C . CS low creep strength, high oxidation rate, and susceptibility to carburization

Susceptible to FAC in condensate service

Materials Application – Low Alloy Cr-Mo Steel

Low alloy Chromium Molybdenum (Cr-Mo) Steels are replacing the Carbon steels as a candidate material where:

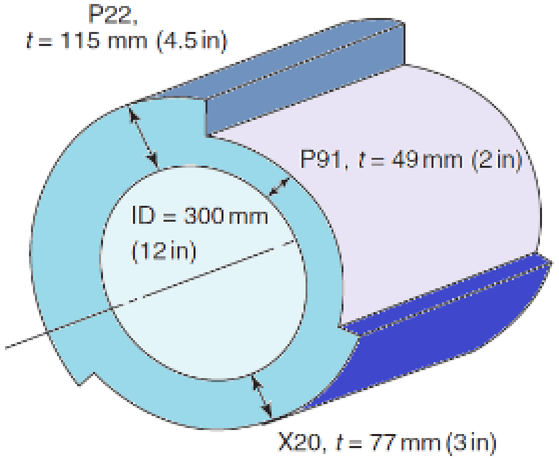
- Temperature is higher than the maximum limits of carbon steels

- In application where Hydrogen is present at relative high temperature and partial pressure to resist High Temperature Hydrogen Attack (HTHA)

Common Grades:

P11 (1.25 Cr- 0.5 Mo)
P22 (2.5 Cr – 0.5 Mo)
P5 (5 Cr- 0.5 Mo)
P91 (9 Cr- 1 Mo)

Note: Cr-Mo steel is usually require application of Post Weld Heat Treatment (PWHT) during fabrication or repair, which sometimes are difficult to apply at site



Steam Pipe temperature 600 °C, pressure 30MPa

Materials Application – Stainless Steel

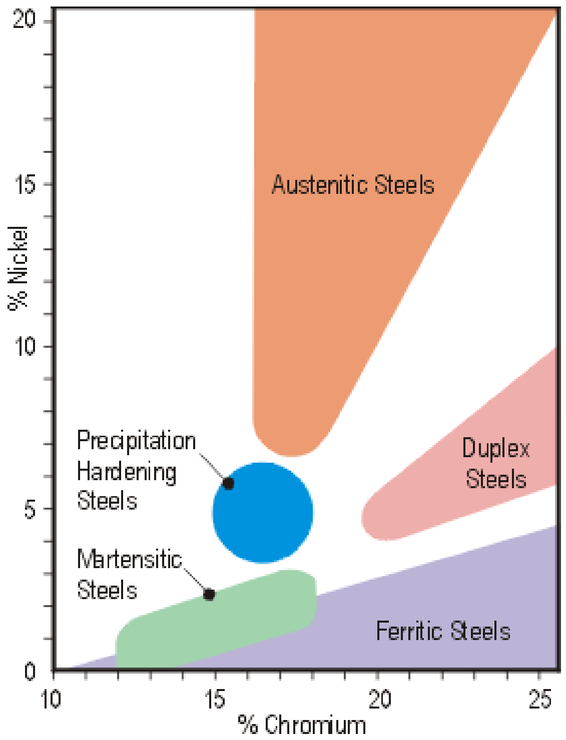
Stainless steels is a material of Cr > 11 % where Cr formed the distinguishing surface oxide layer of the stainless steels.

Austenitic stainless steels is applied widely where:

- Higher Corrosion resistance is required
- Temperature is higher than the maximum limits of Cr-Mo Steels
- Temperature is lower than the lower limit of CS to avoid brittle fracture and toughness loss

A main concern of austenitic SS is the susceptibility to pitting and cracking in Cl services, Where DSS is preferred for this aspect

Duplex stainless steels limited for Temp. <=316 C to avoid 475 embrittlement



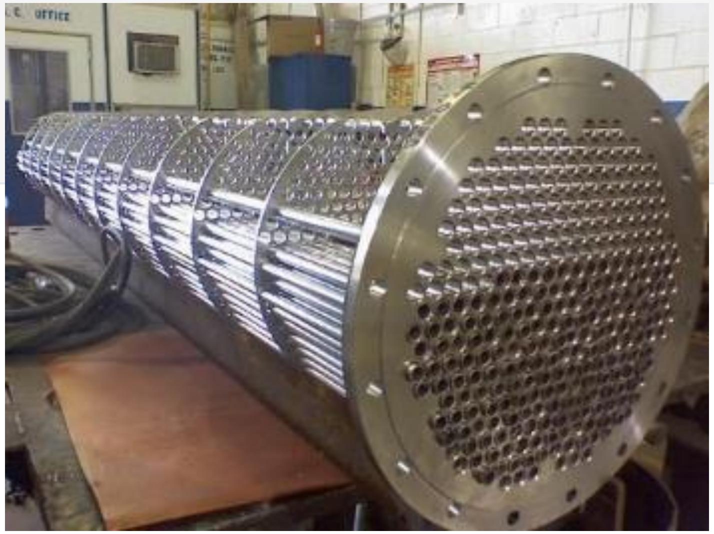
Materials Application – Nickel Based Alloys

Ni Based alloys (Incoloy, Inconel, Monel,…..) are replacing Stainless steels when:

- Higher Corrosion resistance is required
- Temperature is higher than the maximum limits of stainless Steels (oxidation, metal dusting, Nitriding, carburization,..)

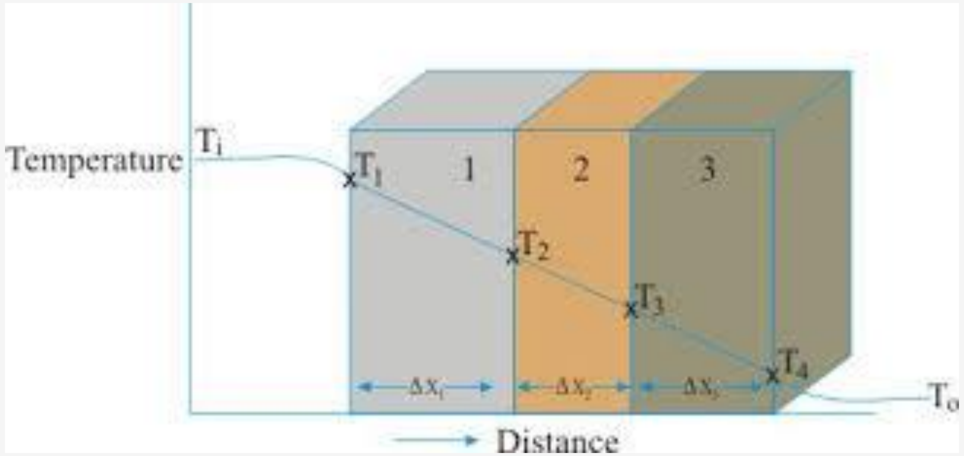
Ni Alloys are of much higher cost compared to stainless steels which limits its application.

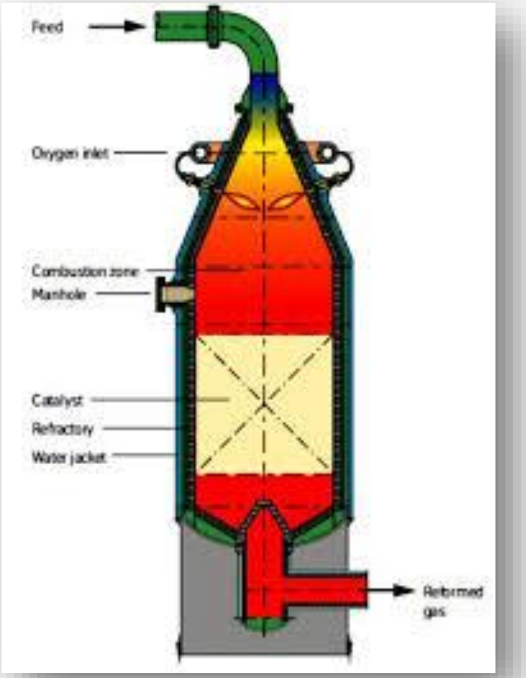
Alloys with Ni >42% is almost immune for chloride SCC. Alloy 825 (42% Ni) is often specified for applications requiring resistance to chloride SCC.



Materials Application – Refractory Lined

Refractory lining is applied where the metals cannot withstand the operating temperature and / or to reduce the cost of the equipment by using lower design temperature and hence lower material grade





Materials Application – Non Metallic Piping and Vessels

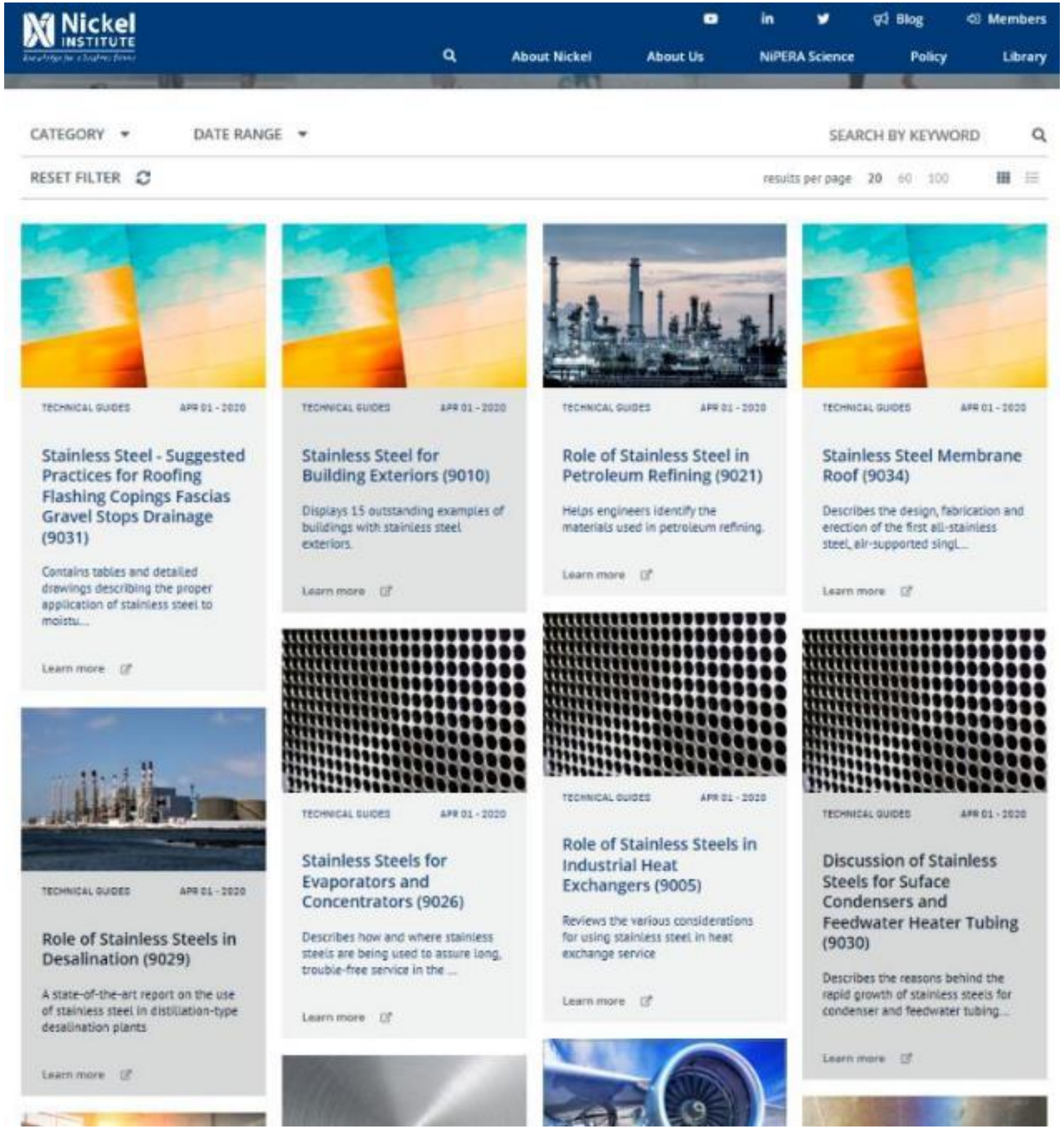
Non metallic materials include wide range of different materials like: FRP, PVC, PE, Cement, lined equipment

Usually applied where corrosion resistance is required

Limited in temperature application

Special precautions (Protection from UV, vent holes for PTFE lined, ……..)

Preferred application for underground piping to have good corrosion resistance without need of Cathodic Protection



Recommended Readings for SS and Ni Alloys

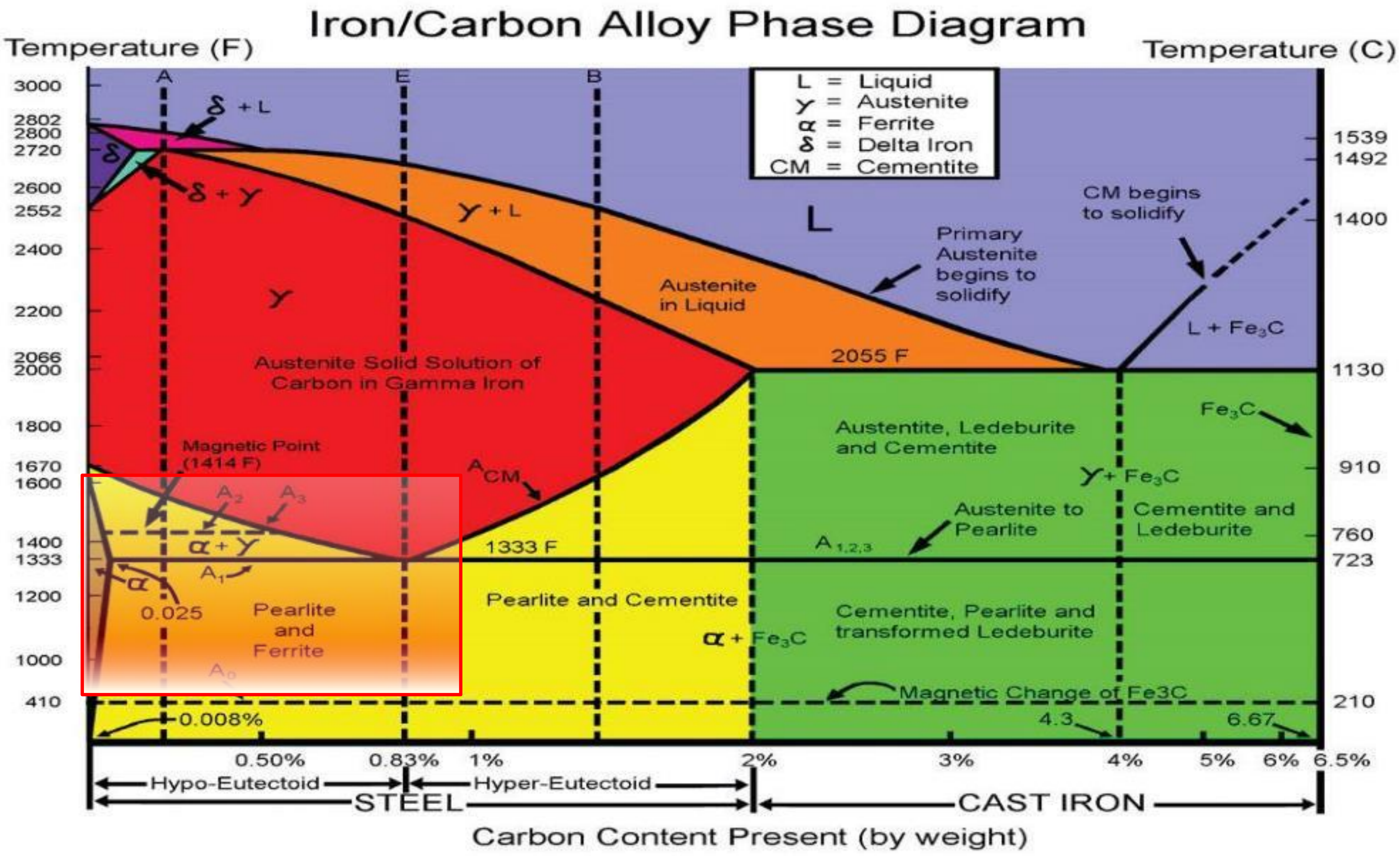
Nickel INSTITUTE

knowledge for a brighter future

https://www.nickelinstitute.org/library

Heat Treatment

Iron-Carbide Phase Diagram



Area of Focus

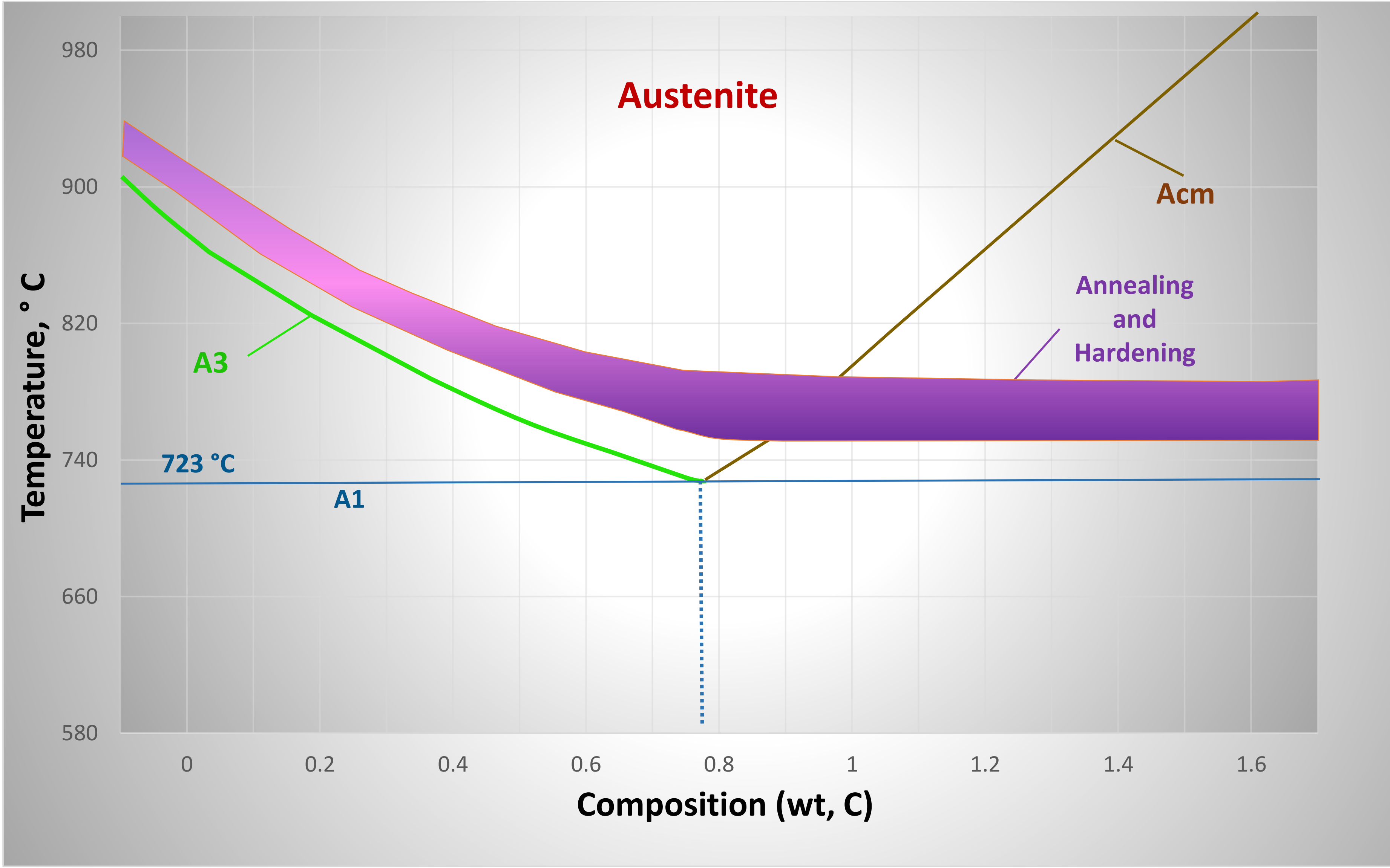
Annealing

Heat treatment with furnace cooling from Austenitizing range

Annealing is used to reduce hardness, obtain a relatively near-stable microstructure, refine grain size, improve machinability, and facilitate cold working.

For Hypoeutectoid steels (C< 0.80%), full annealing consists of heating to 90 to 180 °C A3 temp.

For Hypereutectoid steels (C > 0.80%), heating above the A1 temperature, followed by very slow cooling.



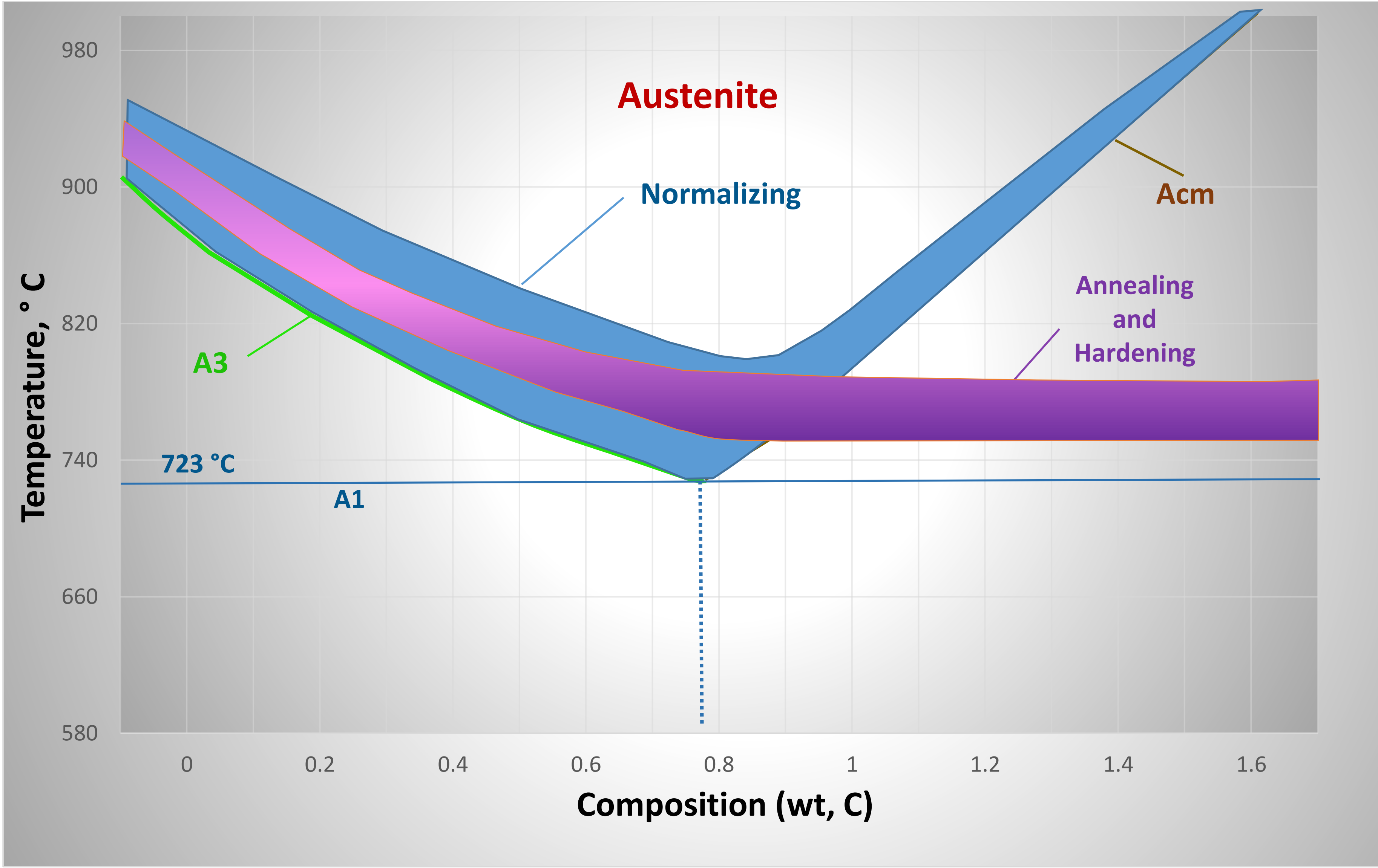
Reference: Heat Treating, Vol 4, ASM Handbook, ASM International

Heat Treatment

Normalizing

Steel is normalized by heating 160 to 200 °C into the austenite-phase field at temperatures somewhat higher than those used by annealing, followed by cooling at a medium rate (Air Cooling for CS).

Steels are normalized to establish a uniform microstructure and refine grain size.
The faster cooling rate results in a much finer microstructure, which is harder and stronger than the coarser microstructure produced by full annealing.

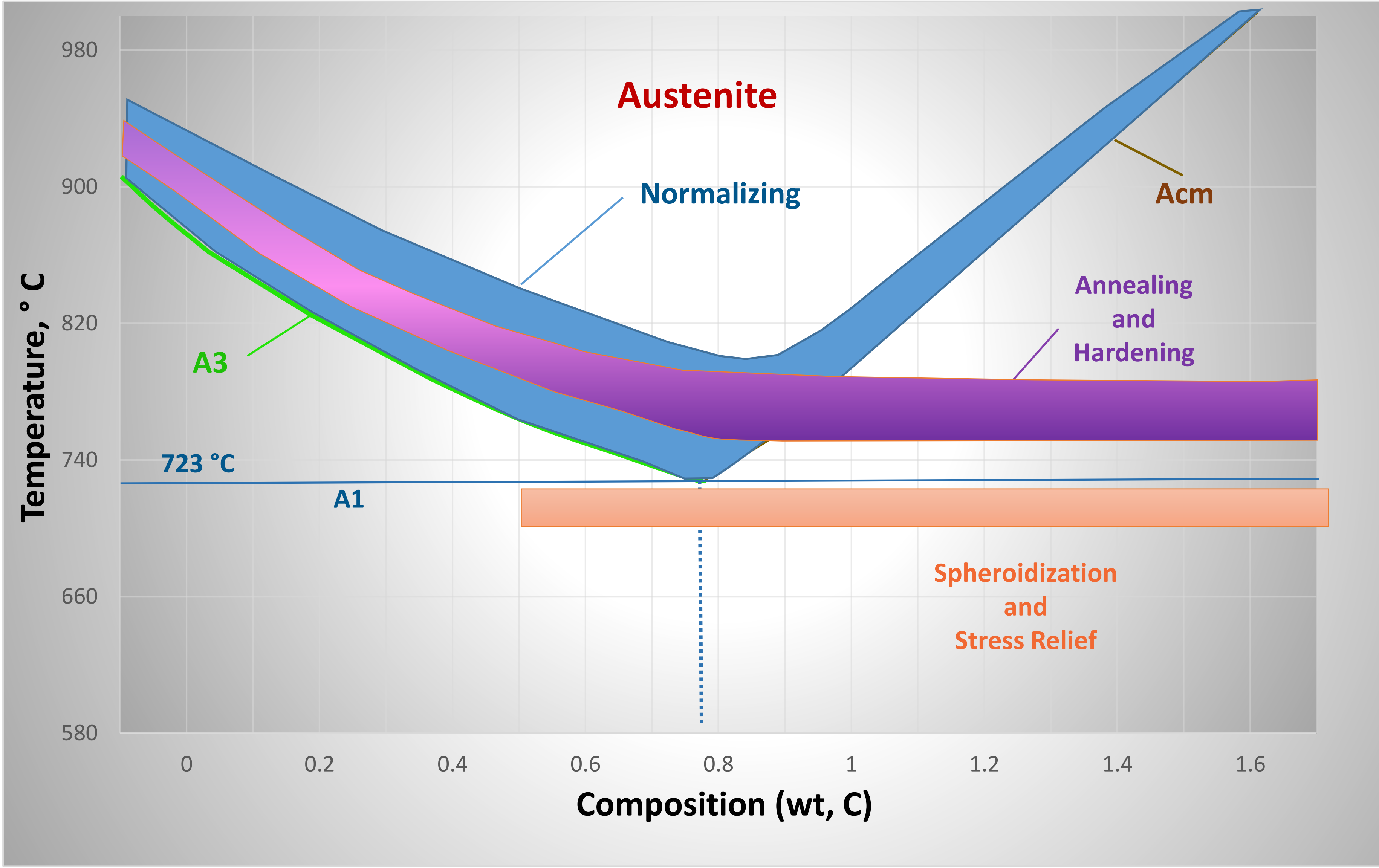


Reference: Heat Treating, Vol 4, ASM Handbook, ASM International

Spheroidizing

To produce a steel in its softest possible condition with minimum hardness and maximum ductility, it can be spheroidized by heating just above or just below the A1 eutectoid temperature and then holding at that temperature for an extended period of time.

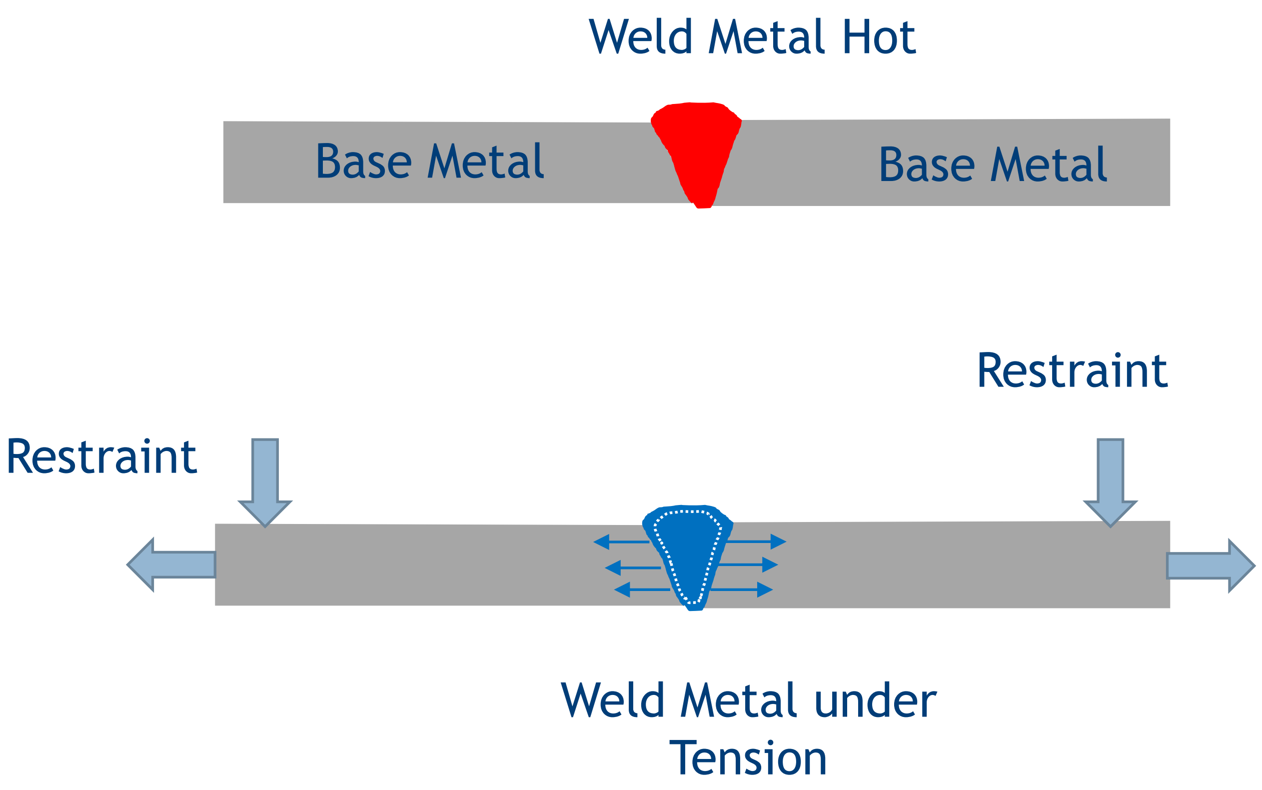
Ref.: Heat Treating Subject Guide - ASM International



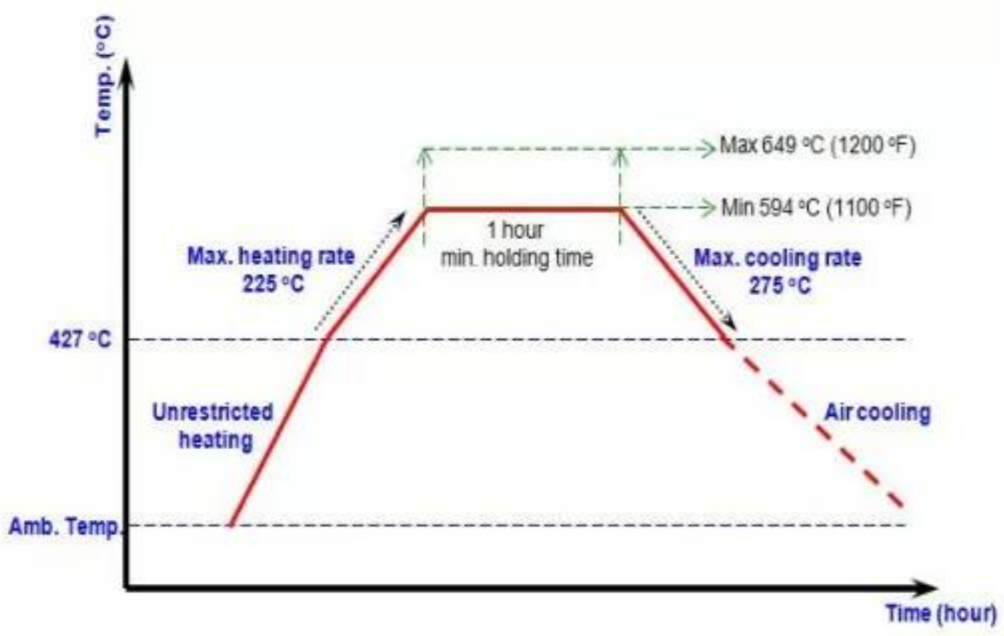
Reference: Heat Treating, Vol 4, ASM Handbook, ASM International

Post Weld Heat Treatment

- When weld is applied it is molten metal and thermally expanded when filling a groove.
- When weld metal cools, it will shrink a lot. Yield Strength is low for much of the cooling range.
- Surrounding metal that was not heated to molten temperatures will constrain or keep the weld from shrinking as it cools.
- Post Weld Heat Treatment is a procedure to reduce residual stress, temper the HAZ, and remove hydrogen from the weld region after a seam weld is made.



- Weld and HAZ heated below the transition temperature for several hours and then gradually allowed to cool.
- Can Global (entire vessel)
- Can be Local (weld seam and surrounding metal



Recommended Readings: WRC 452

Q 6

Think and Answer

What are the main pros and cons of each PWHT technique Global / Local

Corrosion

Corrosion a chemical or electrochemical reaction between a material and its environment that produces a deterioration (change) of the material and its properties

Why do metals corrode?

Most metals are found in nature as ores. The manufacturing process of converting these ores into metals involves the input of energy.

During the corrosion reaction the energy added in manufacturing is released, and the metal is returned to its oxide state.

Metal Ore —Reduction (add Electron)→ Metal —Oxidation (strip electron)→ Corrosion Products

Corrosion Consequence:

1. Downtime
2. Product Loss
3. Efficiency Loss
4. Contamination
5. Overdesign

Corrosion Forms – Classic Fontana & Green Forms

Uniform Corrosion	Corrosion attack that is more or less distributed over the entire exposed surface of a metal.
Galvanic Corrosion	accelerated corrosion of a metal because of contact with a more noble metal in an electrolyte
Intergranular Corrosion	Localized attack at and adjacent to grain boundaries, with relatively little corrosion of the grains, is intergranular corrosion. The alloy disintegrates (grains fall out) and/or loses its strength.
Crevice Corrosion	a localized attack on a metal adjacent to a crevice between two joining surfaces (two metals or metal-nonmetal crevices)
Pitting Corrosion	a localized phenomenon confined to smaller areas. Pitting corrosion are normally found on passive metals and alloys
Selective Leaching	Removal of one element from a solid alloy by corrosion processes Examples are dezincification in Brass, dealuminification
Erosion Corrosion	deterioration of metals and alloys due to relative movement between metal surfaces and corrosive fluids. Depending on the rate of this movement, abrasion takes place.
Stress Corrosion Cracking	(SCC) refers to failure under simultaneous presence of a corrosive medium and a tensile stress.

Uniform Corrosion

Uniform Corrosion is also called general corrosion. The surface effect produced by most direct chemical attacks (e.g., as by an acid) is a uniform etching of the metal

Control

- Selection of a more corrosion resistant alloy (i.e. higher alloy content or more inert alloy)
- Utilize coatings to act as a barrier between metal and environment.
- Modify the environment or add chemical inhibitors to reduce corrosion rate.
- Apply cathodic protection.
- Replace with corrosion resistant non-metallic material.

Reference: Inspector Knowledge – Corrosion Basics, By Mok Check Min

Galvanic Corrosion

Galvanic Corrosion is an electrochemical action of two dissimilar metals in the presence of an electrolyte and an electron conductive path.

It occurs when dissimilar metals are in contact.

Control

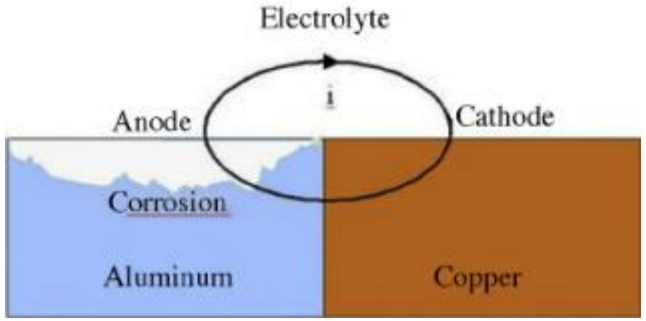
- Use of galvanically compatible materials
- Avoid unfavorable area effects of a small anode and large cathode
- Use of electrical insulation between dissimilar materials

Galvanic Series Chart

	Active	Magnesium
Anode (-)	(most susceptible to	Zinc
	corrosive attack)	Galvanized Steel
		Aluminum
		Mild Steel
		Cast Iron
		Lead
		Brass
		Copper
		Bronze
		Monel
		Nickel
		Stainless Steel 304
		Stainless Steel 316
		Silver
		Titanium
	Noble	Gold
Cathode (+)	(least susceptible to	Graphite
	corrosive attack)	Platinum

Electrical current/movement of ions

Direction of attack



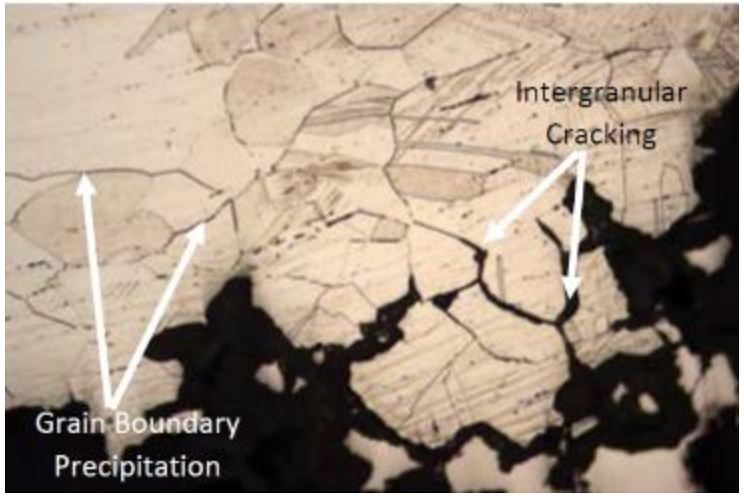
Intergranular Corrosion

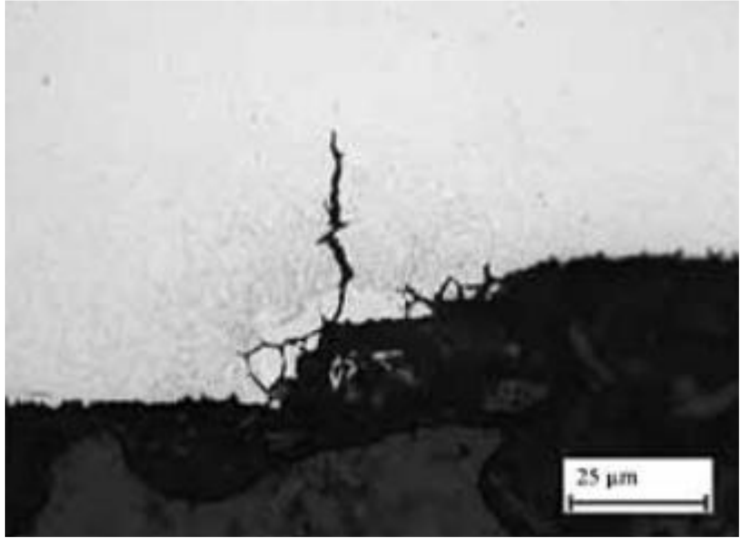
Intergranular corrosion is an attack on or adjacent to the grain boundaries of a metal or alloy. A highly magnified cross section of most commercial alloys will show its granular structure.

This structure consists of quantities of individual grains, and each of these tiny grains has a clearly defined boundary that chemically differs from the metal within the grain center.

Control

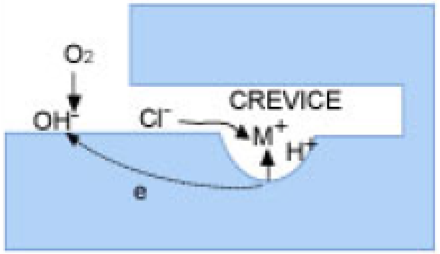
- Heat treatment of alloy to remove phases from grain boundary regions which reduce corrosion resistance (i.e. solution annealing).
- Use modified alloys which have eliminated such grain boundary phases through stabilizing elements or reduced levels of impurities

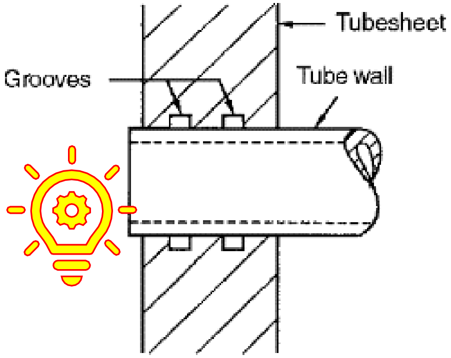




Crevice Corrosion

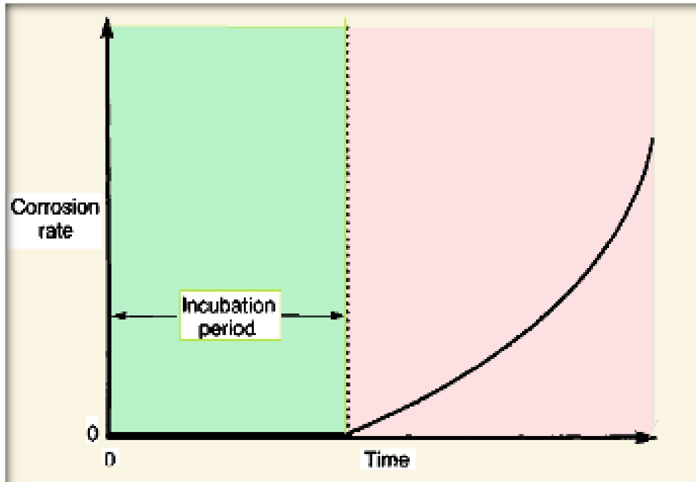
Crevice Corrosion is an intense localized corrosion frequently occurs within crevices and other shielded areas on metal surfaces exposed to corrosives. This type of attack is usually associated with small volumes of stagnant solution caused by holes, gasket surfaces, lap joints, surface deposits, and crevices under bolt and rivet heads





Control

- Redesign of equipment to eliminate crevices.
- Close crevices with non-absorbent materials or incorporate a barrier to prevent of moisture penetration into crevice.
- Prevent or remove builds-up of scale or solids on surface.
- Use of one-piece or welded construction versus bolting or riveting.
- Select more corrosion resistant or inert alloy

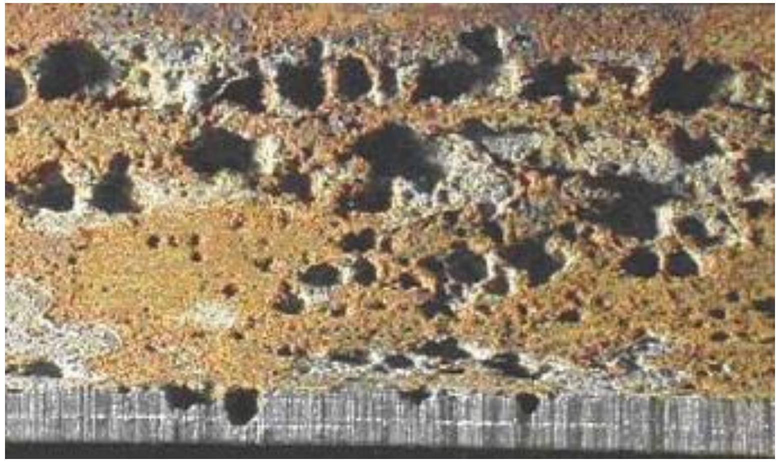


Schematic representation of corrosion rate as a function of time in a crevice in stainless steel exposed to chloride-containing water. The time before corrosion initiation is called the incubation period.

Reference: NALCO Guide to Cooling Water System Failure Analysis

Pitting Corrosion

Pitting is a form of extremely localized attack that results in holes in the metal. These holes may be small or large in diameter, but in most cases they are relatively small. Pits are sometimes isolated or so close together that they look like a rough surface.



For stainless steels, pitting resistance equivalent number (PREN) is equal to:

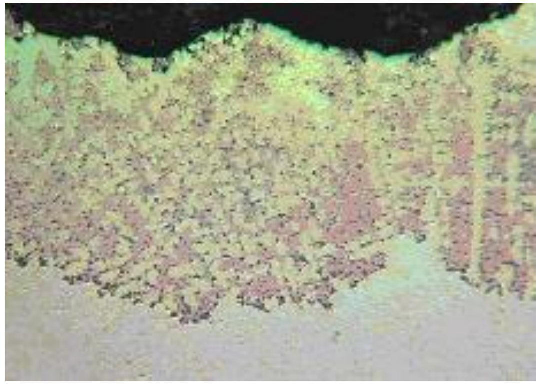
$$PREN = Cr + 3.3\,(Mo + \underline{0.5\,W}) + 16N$$

Control

- Choose the material most appropriate for the service conditions
- Avoid stagnant zones and deposits
- Reduce the aggressivity of the medium (using inhibitors)
- Maintain the protective film of the material
- Use cathodic protection.

Selective Leaching

Selective Leaching is the removal of one element from a solid alloy by corrosion processes. The most common example is the selective removal of zinc in brass alloys (dezincification). Similar processes occur in other alloy systems in which aluminum; iron, cobalt, chromium, and other elements are removed

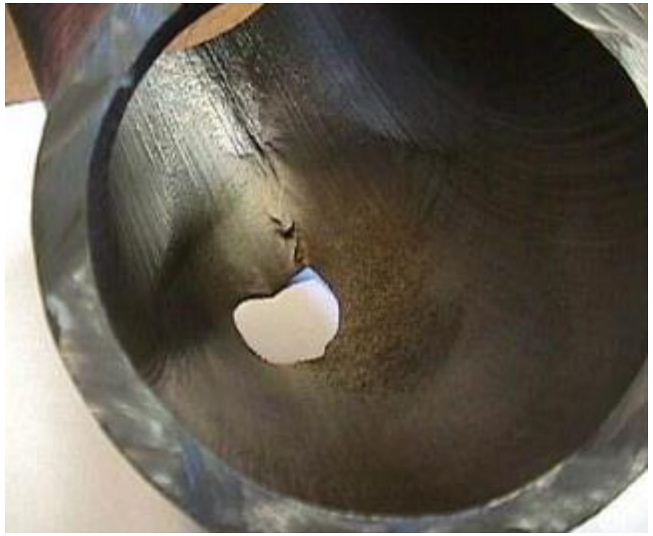


Control

- Select “inhibited” versions of copper alloys.
- Use alternative materials that are not susceptible to dealloying in the environment(s)
- Reduce severity of environment through environmental control or addition of effective chemical inhibitors
- Cathodic protection
- Use of coating to act as a barrier between the environment and the alloy

Erosion-Corrosion

Erosion-corrosion is a description for the damage that occurs when particle erosion and/or high flow velocity contributes to corrosion by removing protective films or scales or otherwise accelerating the corrosion rate.

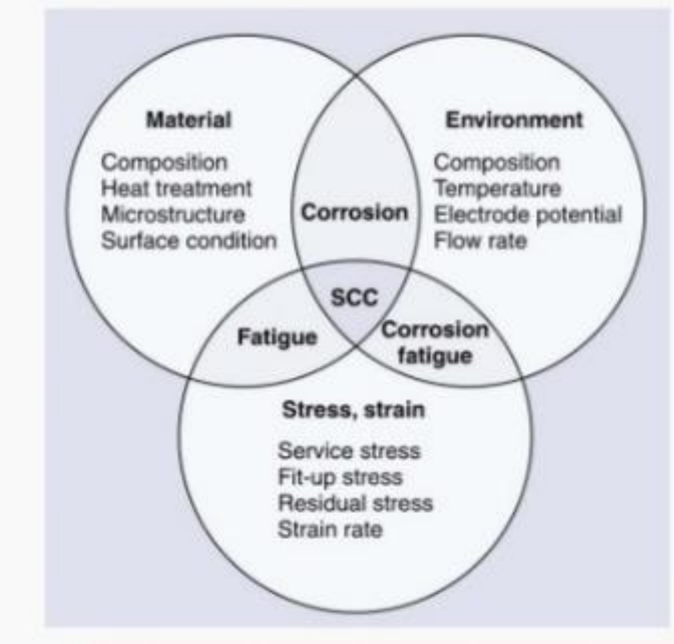


Control

- Changes in shape, geometry, and materials can help mitigate erosion and erosion-corrosion. Examples include increasing the pipe diameter to reduce velocity
- Improved resistance to mechanical erosion is usually achieved by increasing component hardness
- Heat exchangers utilize impingement plates and occasionally tube ferrules
- Ensure proper operation to avoid water droplets in the steam system.
- Use abrasion resistance coating

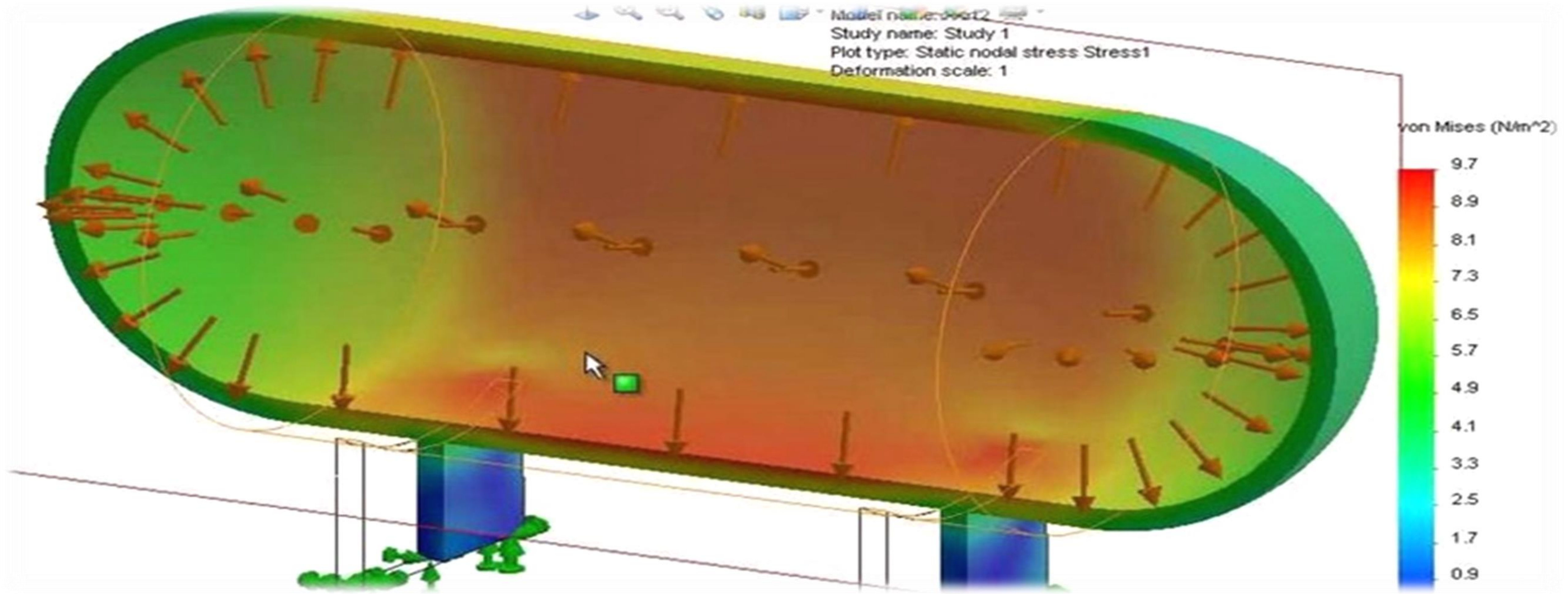
SCC is Cracking caused by the simultaneous presence of tensile stress and a specific corrosive medium. Usually lead to unexpected sudden failure.

Examples: (Chloride SCC, Carbonate SCC, Caustic SCC, Ethanol SCC, HF SCC and Polythionic acid SCC)



Control

- Use resistant material
- Properly apply coating if applicable
- Residual stress release application when applicable
- Design to avoid stagnant conditions of species causing SCC
- Proper application of NDE and inspection techniques for early detection of cracks



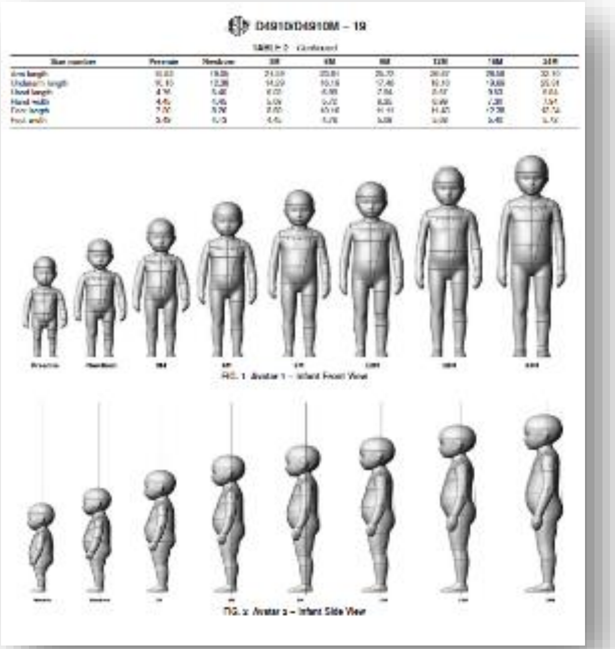
Stresses in Pressure Vessels

Design Codes and Standards

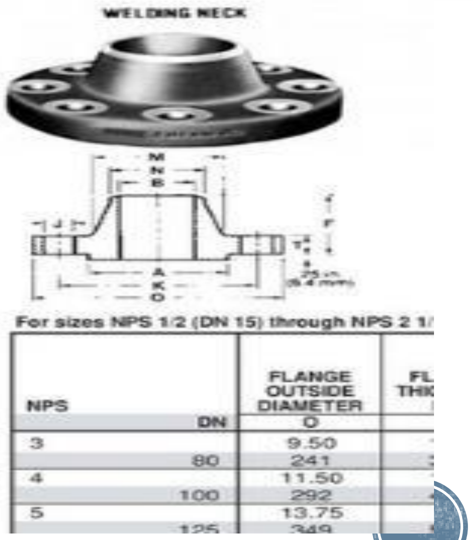
Codes: Examples: ASME BPVC, API 650

Regulations: Federal Laws

Standards:
Example ASME B16.5 (standard flanges dimensions).



Specifications: Company specifications; shell, Aramco, BP,…



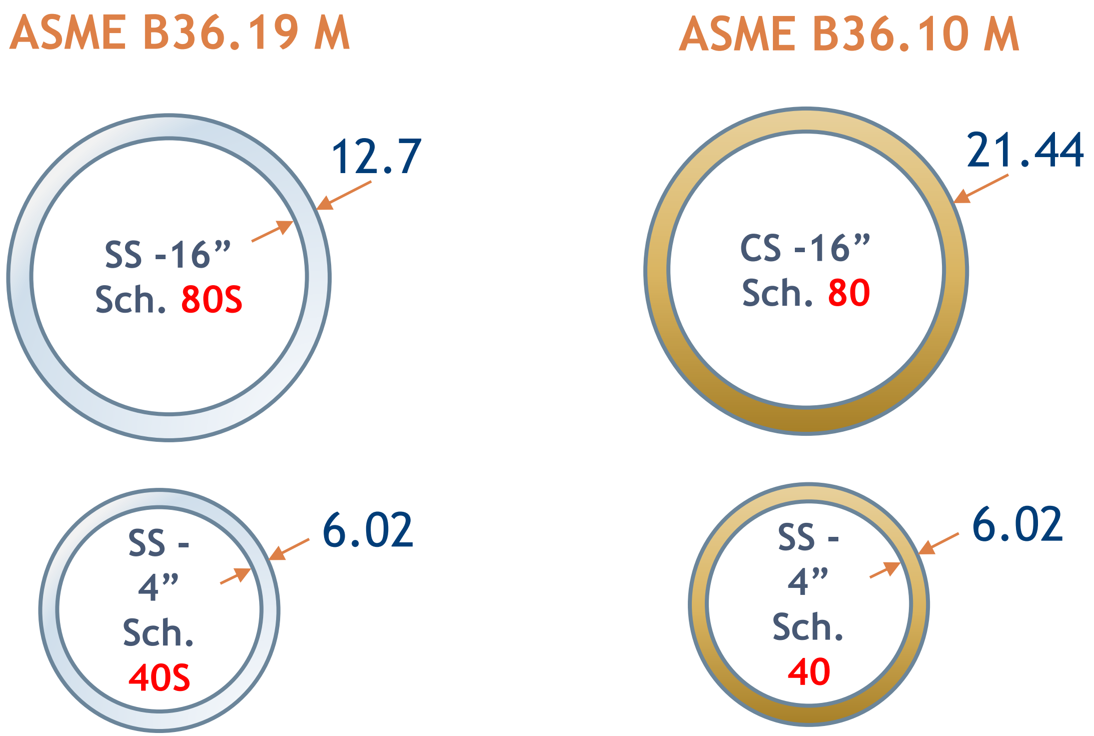
Recommended Practices: Guidelines

Process Industry Practices (PIP)

Careful Use of Standards

Pipe dimensions and wall thickness of steel pipes covered under ASME B36.10M and stainless steel pipes under ASME B36.19M

Make sure you have identified the correct pipe schedule



ASME B16.5-2017
(Revision of ASME B16.5-2013)

Welded neck flange

Careful Use of Standards

- **Specifying Standard Flange per ASME B16.5**
- Standard: ASME B16.5
- Type: WN/SW / SO / Thr. /Blind / Lap
- Class / Rating: 150# / 300# / 600# ....
- Facing: Raised Face, Flat Face, Ring Joint
- Material: CS ASTM A105, ……..
- Schedule/Hub thk.: in case of WN Flange

Table SW-2.5-2 Maximum Bore of ASME B16.5 Flanges for Use With Spiral-Wound Gaskets

Flange Size (NPS)	Maximum Bore by Pressure Class: 75	150	300	400	600	900 [Note (1)]	1500 [Note (1)]	2500 [Note (1)]
½, ¾, 1	No flanges	WN flange only [Note (2)]	WN flange only [Note (2)]	No flanges Use Class 600	WN flange only [Note (2)]	No flanges Use Class 1500	WN flange only [Note (2)]	WN flange only [Note (2)]
1¼, 1½	No flanges	SO flange [Note (3)] WN flange [Note (2)]	SO flange [Note (3)] WN flange [Note (2)]	No flanges Use Class 600	SO flange [Note (3)] WN flange [Note (2)]	No flanges Use Class 1500	WN flange only [Note (2)]	WN flange only [Note (2)]
2, 2½	No flanges	SO flange [Note (3)] WN flange, any bore	SO flange [Note (3)] WN flange, any bore	No flanges Use Class 600	SO flange [Note (3)] WN flange, any bore	No flanges Use Class 1500	WN flange only [Note (2)]	WN flange only [Note (2)]
3	No flanges	SO flange WN flange, any bore	SO flange WN flange, any bore	No flanges Use Class 600	SO flange [Note (3)] WN flange, any bore	WN flange with Schedule 10S bore described in ASME B36.19M [includes nozzle [Note (4)] but excludes SO flange]	WN flange with SW bore [includes nozzle [Note (4)] but excludes SO flange]	WN flange with SW bore [includes nozzle [Note (4)] but excludes SO flange]
4, 6	No flanges	SO flange WN flange, any bore	SO flange WN flange, any bore	WN flange with Schedule 10S bore described in ASME B36.19M [includes nozzle [Note (4)] but excludes SO flange]	WN flange with Schedule 10S bore described in ASME B36.19M [includes nozzle [Note (4)] but excludes SO flange]	WN flange with Schedule 10S bore described in ASME B36.19M [includes nozzle [Note (4)] but excludes SO flange]	WN flange with SW bore [includes nozzle [Note (4)] but excludes SO flange]	WN flange with SW bore [includes nozzle [Note (4)] but excludes SO flange]
8, 10, 12	No flanges	SO flange WN flange, any bore	SO flange WN flange, any bore	WN flange with Schedule 10S bore described in ASME B36.19M [includes nozzle [Note (4)] but excludes SO flange]	WN flange with Schedule 10S bore described in ASME B36.19M [includes nozzle [Note (4)] but excludes SO flange]	WN flange with Schedule 80 bore [excludes nozzle [Note (4)] and SO flange] [Note (5)]	WN flange with Schedule 80 bore [excludes nozzle [Note (4)] and SO flange] [Note (5)]	WN flange with Schedule 80 bore [excludes nozzle [Note (4)] and SO flange] [Note (5)]
14, 16, 18, 20, 24	No flanges	SO flange WN flange, any bore	SO flange WN flange, any bore	WN flange with Schedule 10S bore described in ASME B36.19M [excludes nozzle [Note (4)] and SO flange] [Note (5)]	WN flange with Schedule 10S bore described in ASME B36.19M [excludes nozzle [Note (4)] and SO flange] [Note (5)]	WN flange with Schedule 80 bore [excludes nozzle [Note (4)] and SO flange] [Note (5)]	WN flange with Schedule 80 bore [excludes nozzle [Note (4)] and SO flange] [Note (5)]	No flanges

GENERAL NOTES:
(a) This Table shows the maximum bore of flanges for which the spiral-wound gasket dimensions shown in Table SW-2.1-1 are recommended, considering the tolerances involved, possible eccentric installation, and the possibility that the gasket may extend into the assembled flange bore.
(b) For maximum permissible flange bores for nonmandatory inner rings, see Table SW-2.5-1.
(c) Abbreviations: SO = slip on and threaded, WN = welding neck, and SW = standard wall.

NOTES:
(1) Refer to para. SW-2.5 for required use of inner rings. These inner rings may extend into the pipe bore a maximum of 1.5 mm (0.06 in.) under the worst combination of maximum bore, eccentric installation, and additive tolerances.
(2) In these sizes, the gasket is suitable for a welding neck flange with a standard wall bore, if the gasket and flanges are assembled concentrically. This also applies to a nozzle. It is the user's responsibility to determine if the gasket is satisfactory for a flange of any larger bore.
(3) Gaskets in these sizes are suitable for slip-on flanges only if the gaskets and flanges are assembled concentrically.
(4) A nozzle is a long welding neck; the bore equals the flange NPS.
(5) An NPS 24 gasket is suitable for nozzles.

Careful Use of Standards

- Maximum size of 2500 class is NPS 12. There is no 2500 flange of NPS 14 and larger
- Smallest size of class 400 is NPS 4. There is no class 400 of NPS 3.5 and smaller.
- Smallest size of class 900 flanges is NPS 3. There is no class 900 flanges of NPS 2.5 and smaller.

ASME BPVC

SEC. I	Power Boilers
Sec II	Materials
Sec III	Rules for Construction of Nuclear Facility Components
Sec IV	Rules for Construction of Heating Boilers
Sec V	Nondestructive Examination
Sec VI	Rules for the Care and Operation of Heating Boilers
Sec VII	Guidelines for the Care of Power Boilers
Sec VIII	Rules for Construction of Pressure Vessels
Sec IX	Welding, Brazing, and Fusing Qualifications
Sec X	Fiber-Reinforced Plastic Pressure Vessels
Sec XI	Inservice Inspection of Nuclear Power Plant Components
Sec XII	Construction and Continued Service of Transport Tanks

ASME B 31 CODES FOR PRESSURE PIPING

ASME B31 CODES

B 31.1	Power Piping
B 31.3	Process Piping
B 31.4	Pipeline Transportation systems for liquids and Slurries
B31.5	Refrigeration Piping
B 31.8	Gas Transmission and Distribution Piping
B31.9	Building Service Piping
B31.12	Hydrogen Piping and Pipelines

AN INTERNATIONAL PIPING CODE®

The American Society of Mechanical Engineers

API Design and construction Codes and Standards

API Std 650: Welded Tanks for Oil Storage [P <= 2.5 Psi]

API 620: Design and Construction of Large, Welded, Low-pressure Storage Tanks [P<= 15 psi]

API Std 660: Shell-and-Tube Heat Exchangers

API Std 661: Air-cooled Heat Exchangers

API Std 662: Plate Heat Exchangers

API Std 530: Calculation of Heater-tube Thickness

API Std 976: Refractory Installation Quality Control

Post Construction, Inspection and Repair Codes

National Board Inspection Code

ASME PCC-2–2018

ASME PCC 2 – Repair of Pressure Equipment and Piping

ASME PCC-1–2019

Guidelines for Pressure Boundary Bolted Flange joint Assembly

API 571 For Damage Mechanisms in Fixed Equipment

Inspection codes: API 510, 570, 653, 573, …….

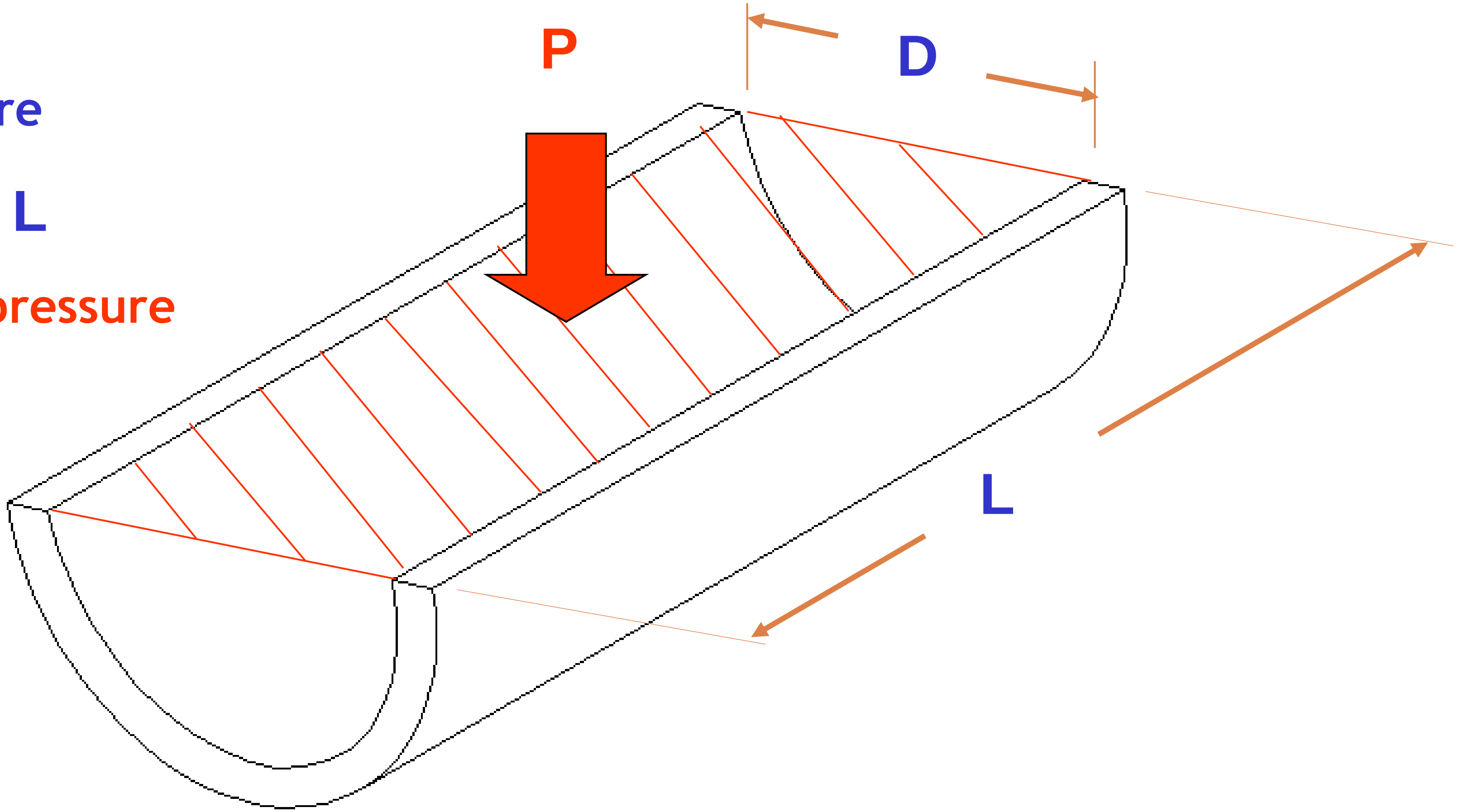
Internal Pressure stresses on cylindrical shell

Consider the forces acting on the Shell from Pressure

From pressure

Area = D x L

Here is the pressure

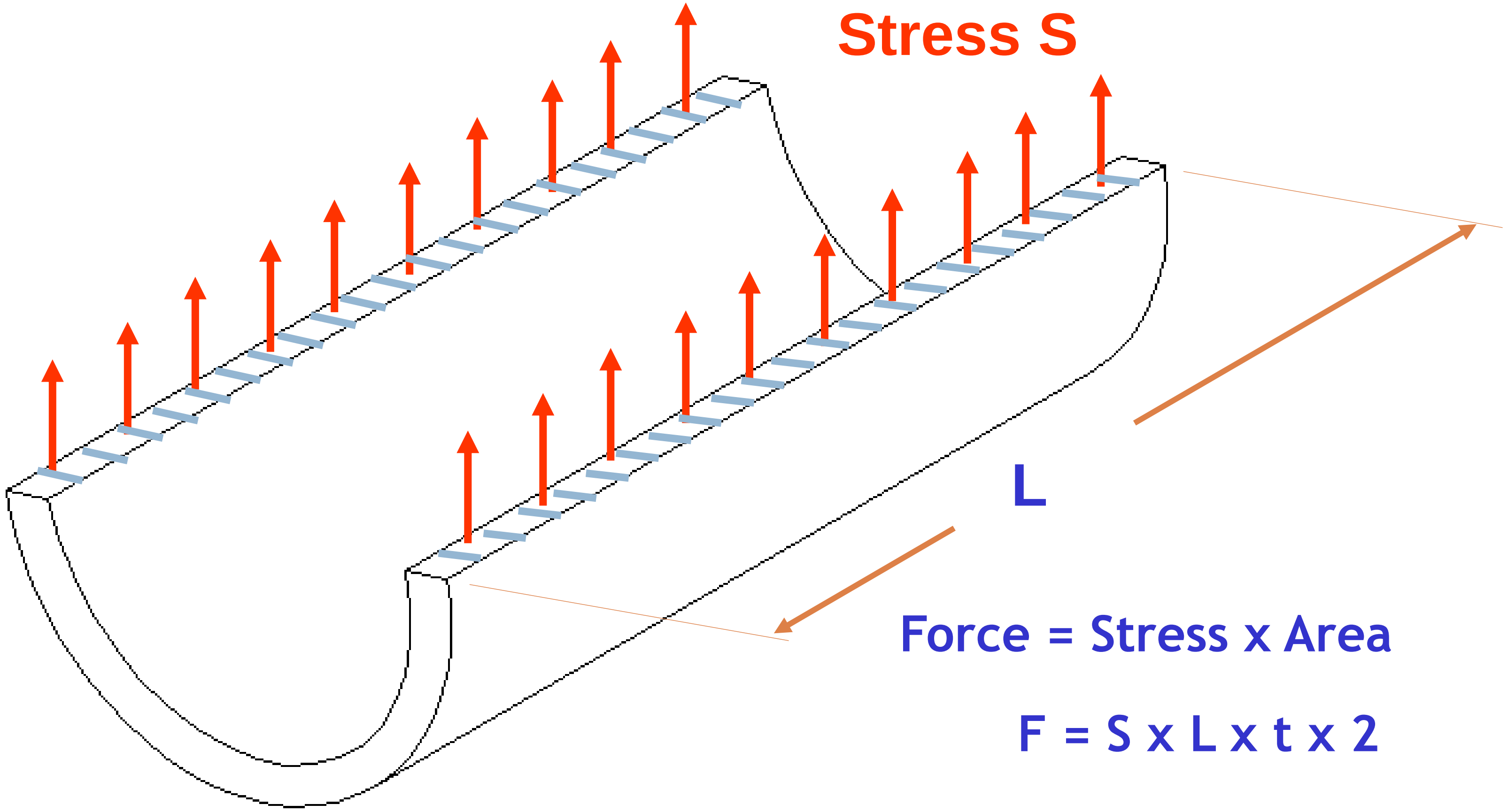


Internal Pressure stresses on cylindrical shell

This is resisted by the internal stress

Area = 2 x t x L

Stress S



Force = Stress x Area

F = S x L x t x 2

= 2SLt

Internal Pressure stresses on cylindrical shell

For equilibrium - Forces must be Equal

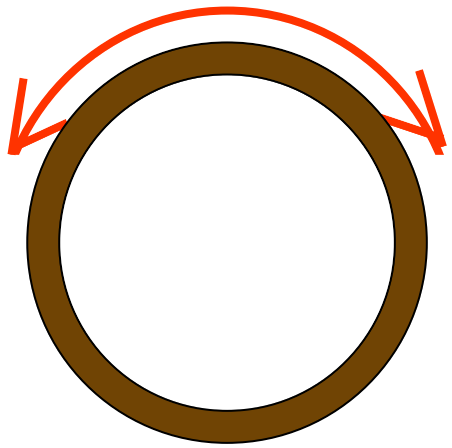
From pressure : $F = PDL$

From internal stress: $F = 2SLt$

Equating therefore : $PDL = 2SLt$

Finally : $Sh = \frac{PD}{2t}$

This is known as the HOOP STRESS Sh



Internal Pressure stresses on cylindrical shell

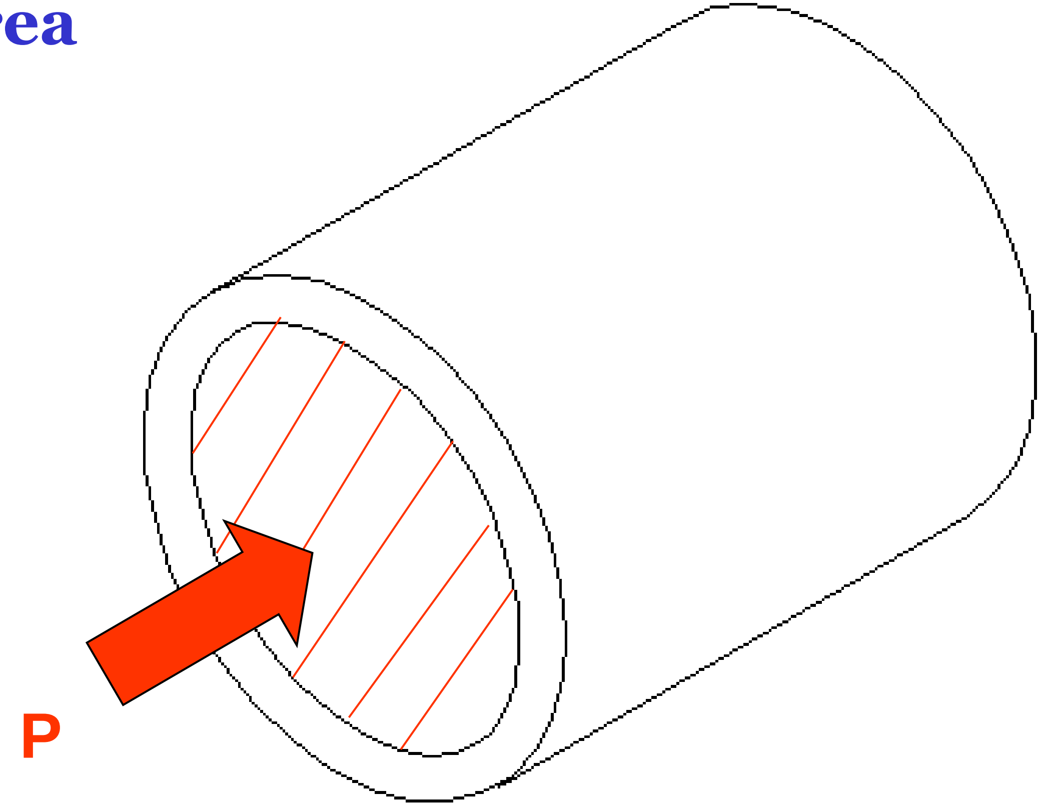
Consider now the Axial or Longitudinal Stress

Force = Pressure x Area

$$\text{Area} = \frac{\pi . D^2}{4}$$

Pressure

$$F = \frac{P.\pi . D^2}{4}$$



Internal Pressure stresses on cylindrical shell

Consider now the Axial or Longitudinal Stress

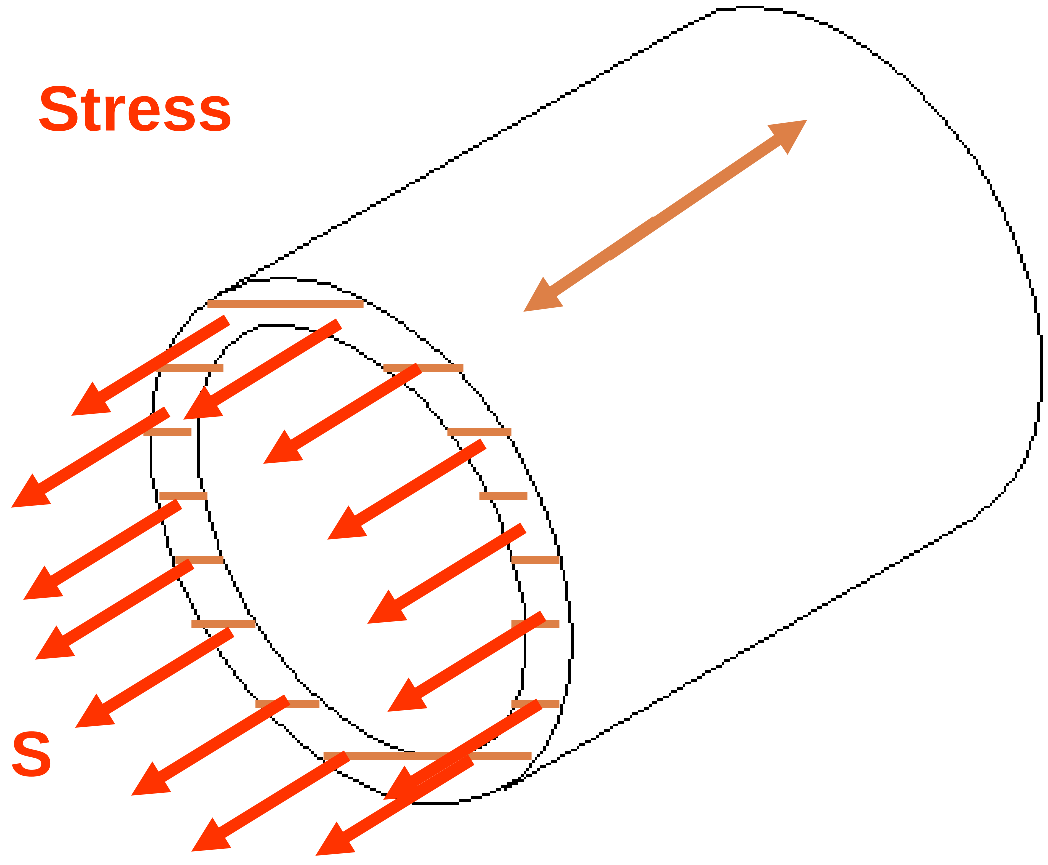
Force = Stress x Area

Area = $\pi.D.t$ (approx)

F = $S.\pi.D.t$

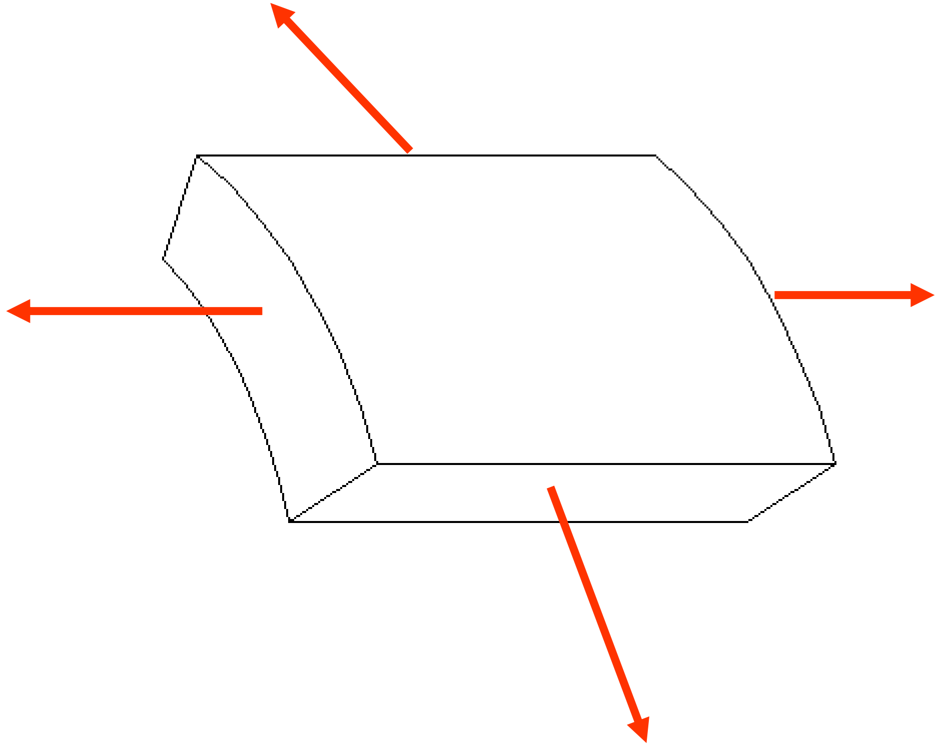
Equate F = $S.\pi.D.t = \frac{P.\pi.D^2}{4}$

Thus $SL = \frac{P.D}{4t}$



This is kown as the Axial or Longitudinal Stress

Internal Pressure stresses on cylindrical shell



$$SL = \frac{P.D}{4t}$$

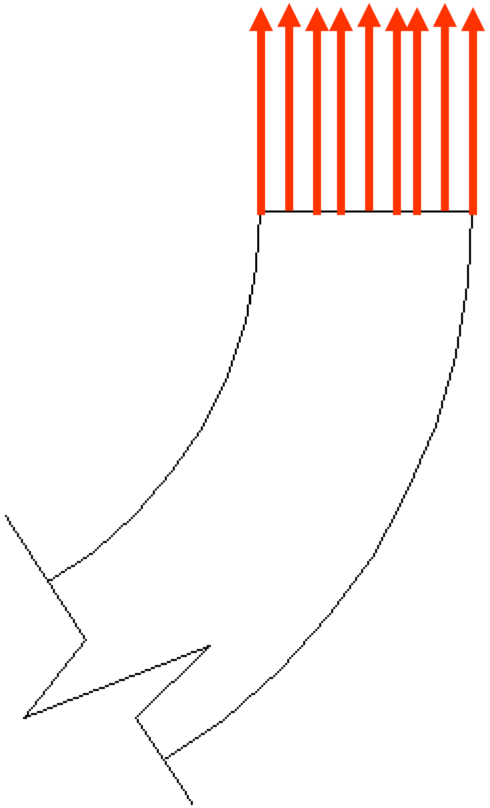
$$Sh = \frac{PD}{2t}$$

Sh is twice SL

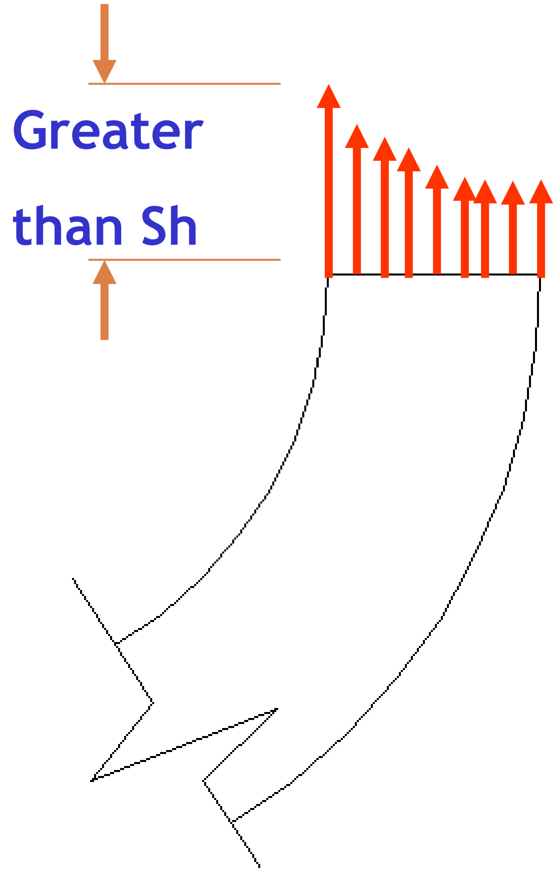
Internal Pressure stresses on cylindrical shell

We have assumed the stress is like this:

$$Sh = \frac{PD}{2t}$$



In reality it is like this:



Internal Pressure stresses on cylindrical shell

This is the formula per UG-27 in the code:

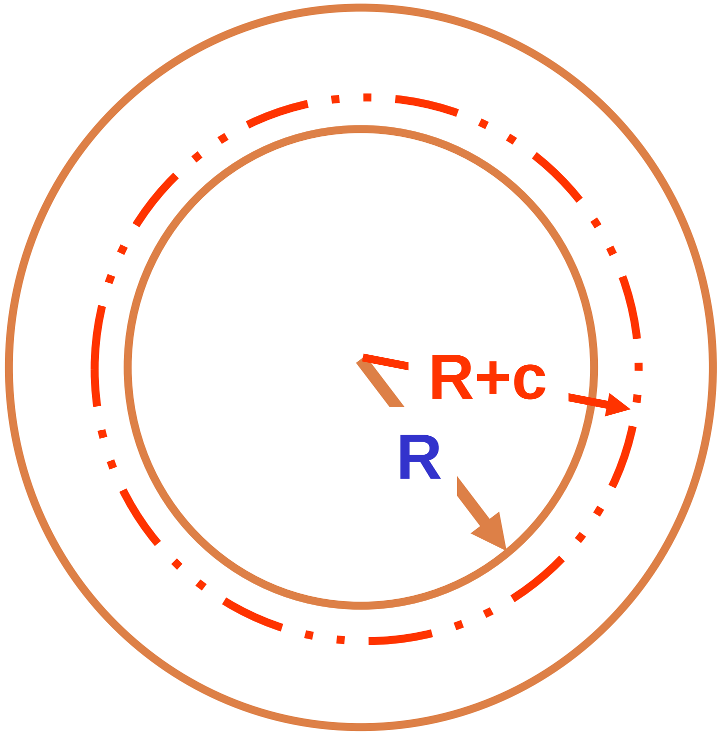
$$t = \frac{P.R}{S.E - 0.6.P}$$

P = Pressure psi

R = Radius inches

S = Design Stress psi

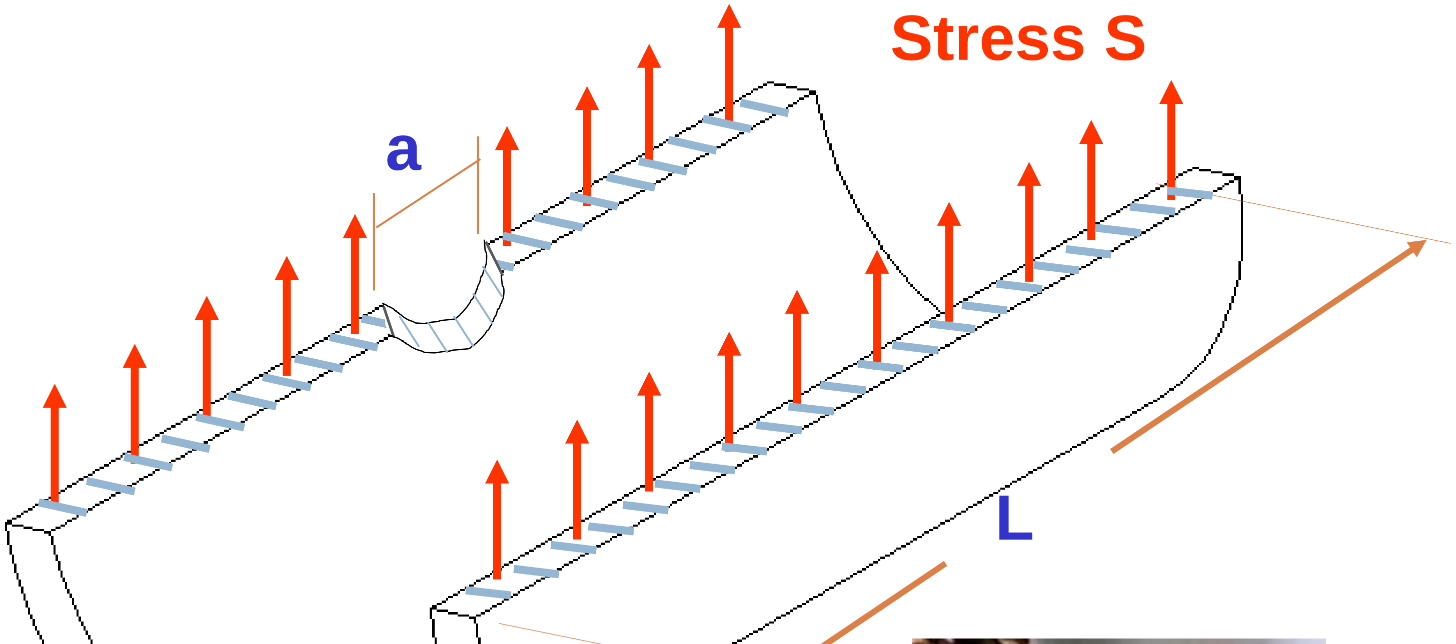
E = Welded Joint Efficiency

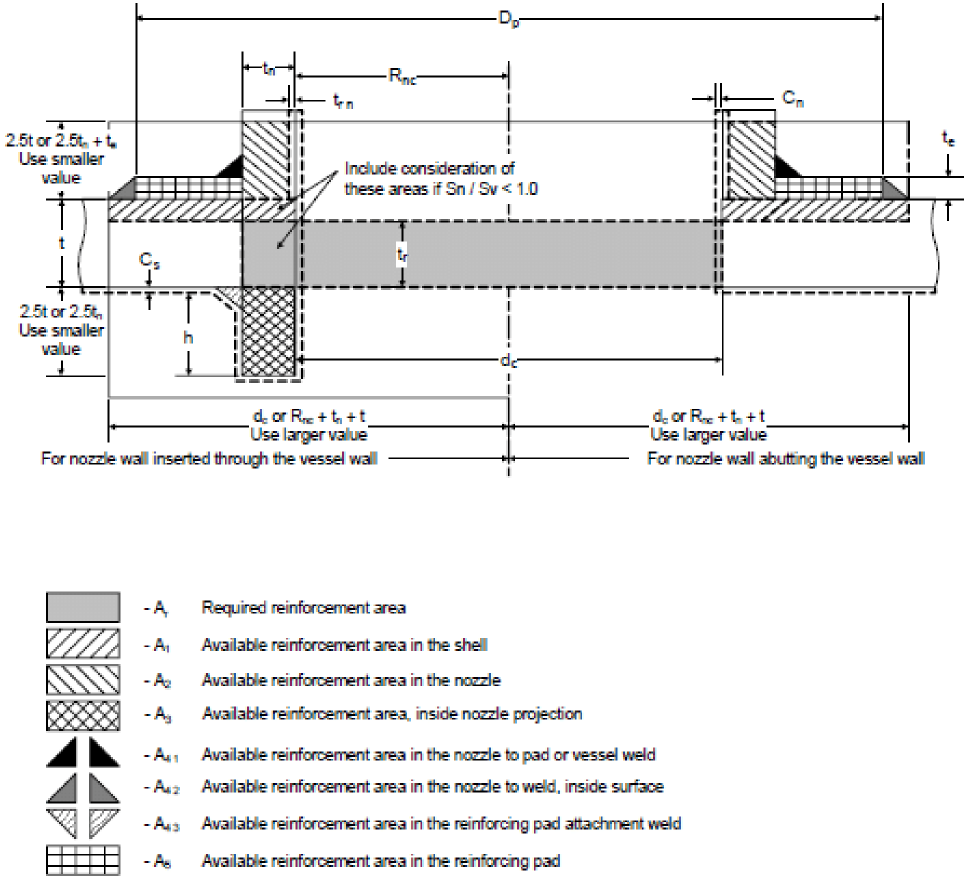


Calculations are done the CORRODED condition

Internal Pressure stresses on cylindrical shell – Shell Openings

$$Area = 2 \times t \times L - a \times t$$

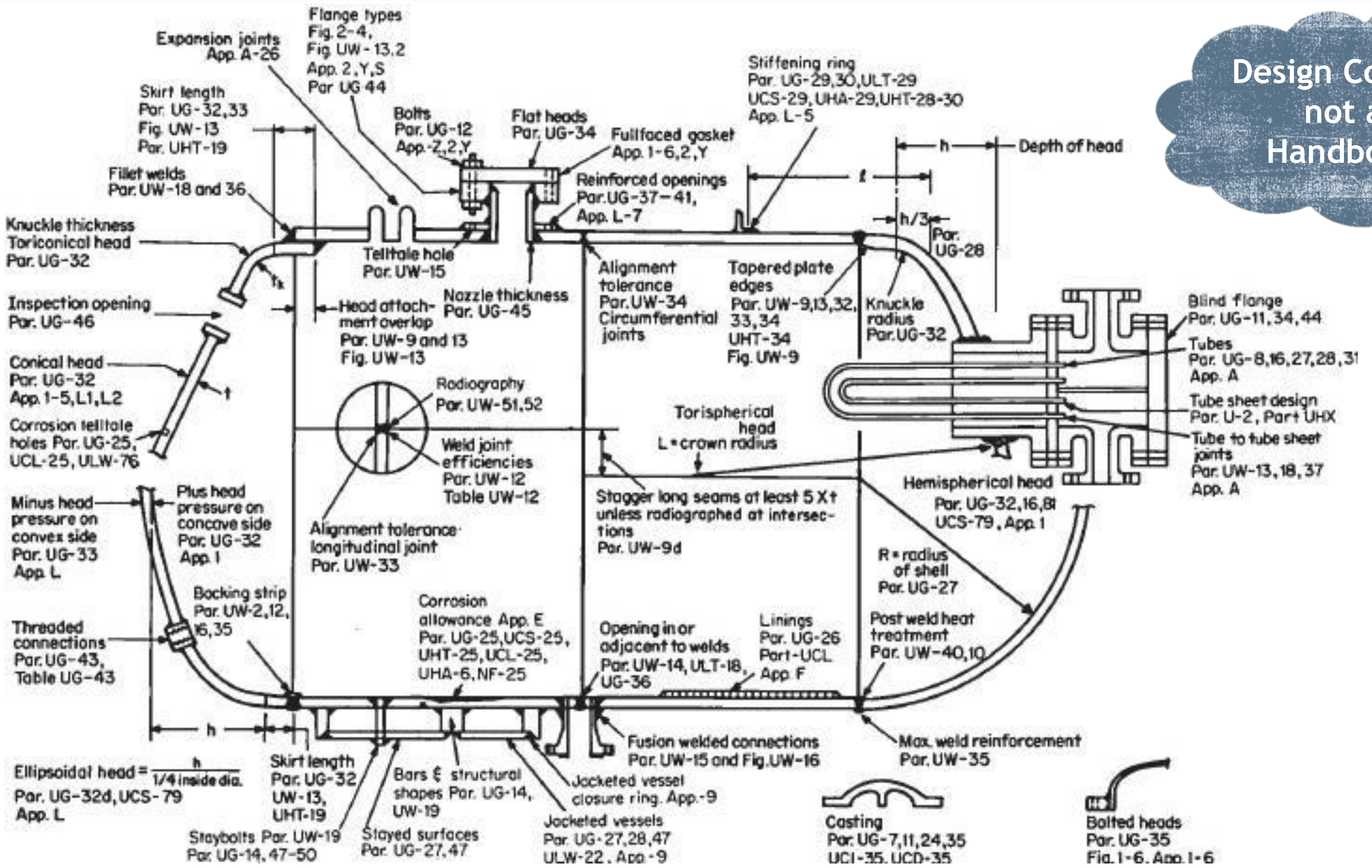




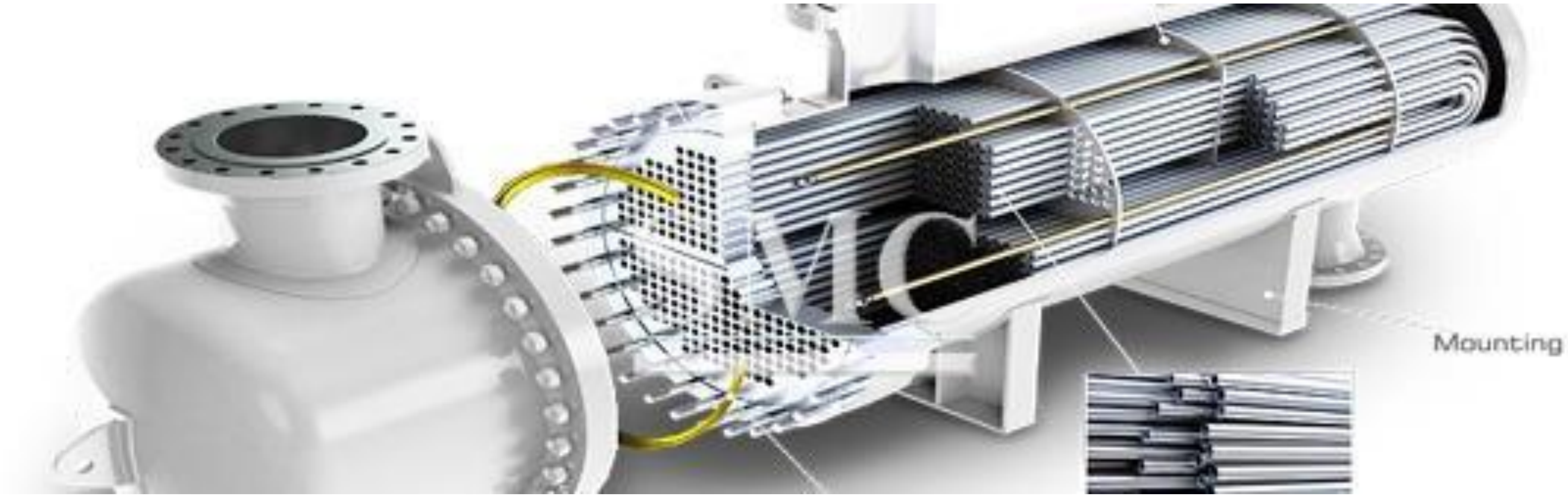
Area Replacement Calculations

ASME BPVC Sec. VIII div. 1 – UG 37

Internal Pressure stresses on cylindrical shell



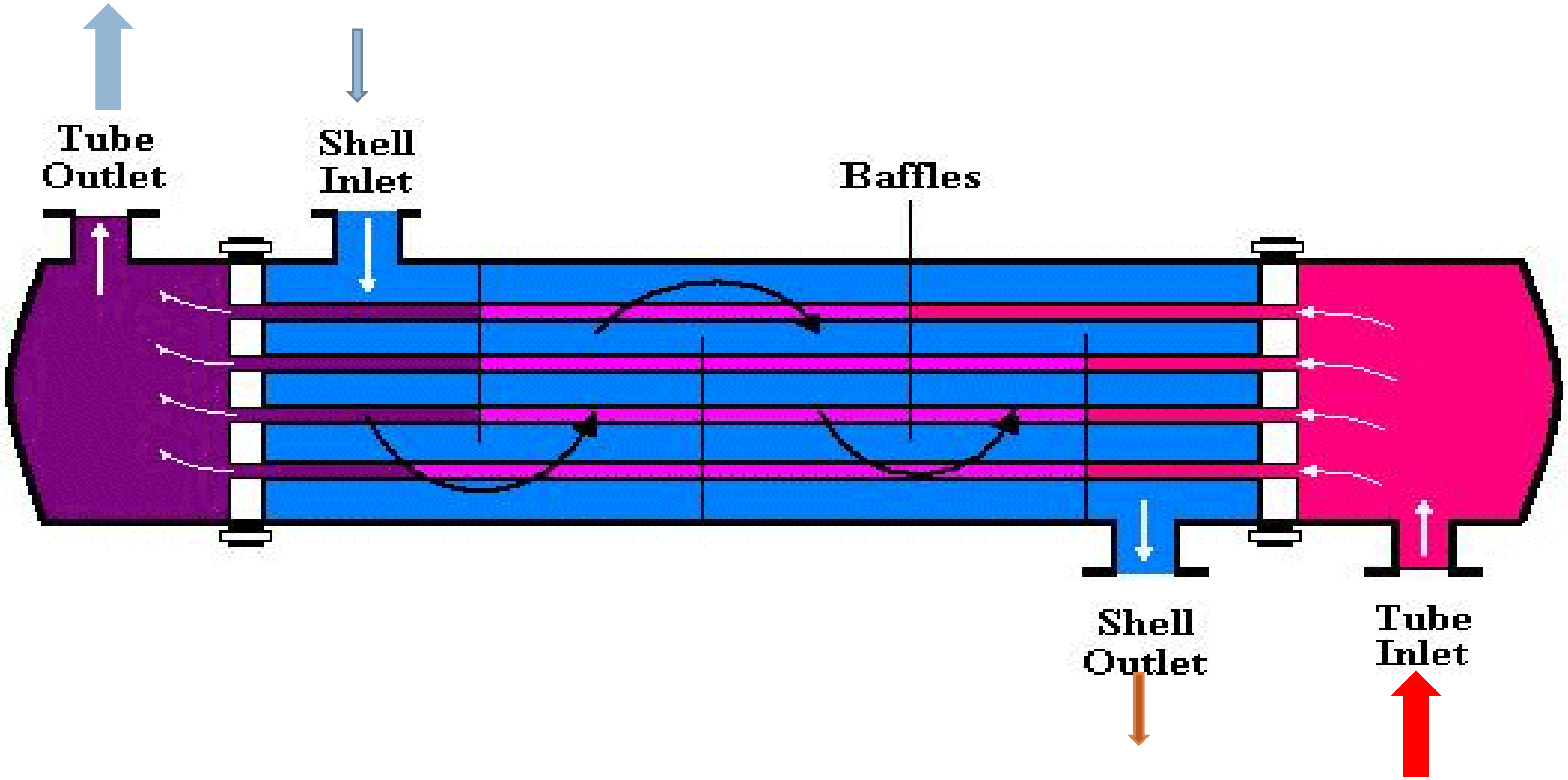
Design Code is not a Handbook



Shell and Tube Heat Exchangers

How it works

Shell and tube heat exchangers are one of the most common equipment found in all plants



Function and Classification

Heat Exchanger: Both sides single phase and process stream

Cooler: One stream process fluid and the other cooling media (water / air)

Heater: One stream process fluid and the other heating utility (steam)

Condenser: One stream condensing vapor and the other cooling media (water / air)

Reboiler: One stream bottom stream from distillation column and the other a hot utility of process stream

Design Codes and Standards Used for Design of S&T Exchangers

Codes

ASME BPVC – TEMA

Standards

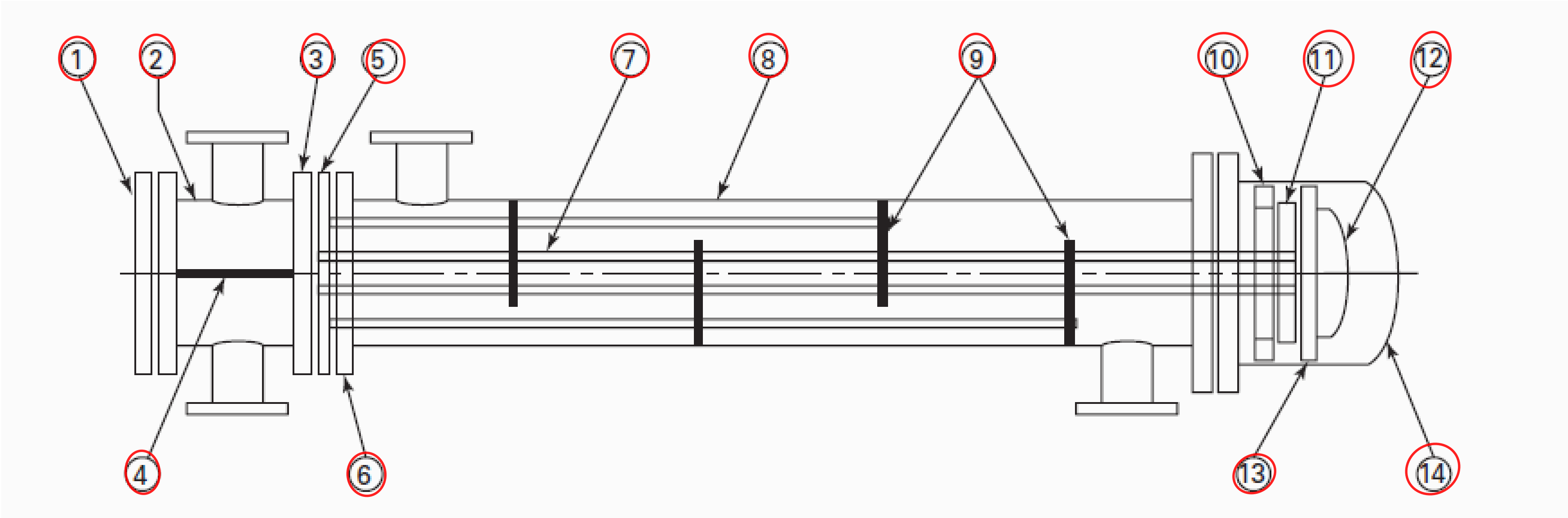
API 660 – HEI – PIP VESST001 - ASME B16.5 – ASME B36.10M – ASME B16.9 – ASME B16.11

Specifications

Contractor or Owner specifications

Process Industry Practices (PIP)

Main Components

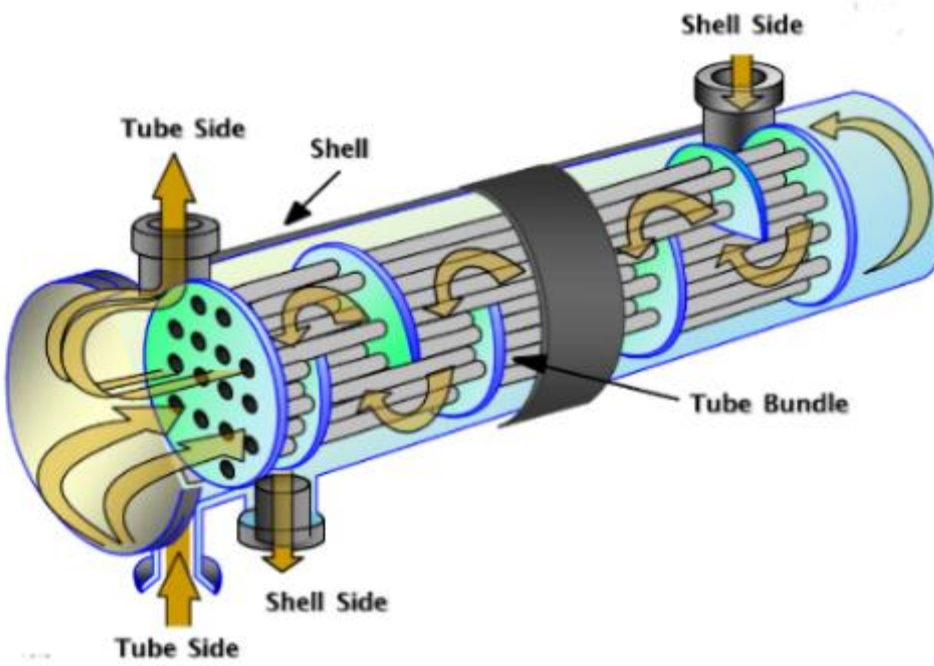


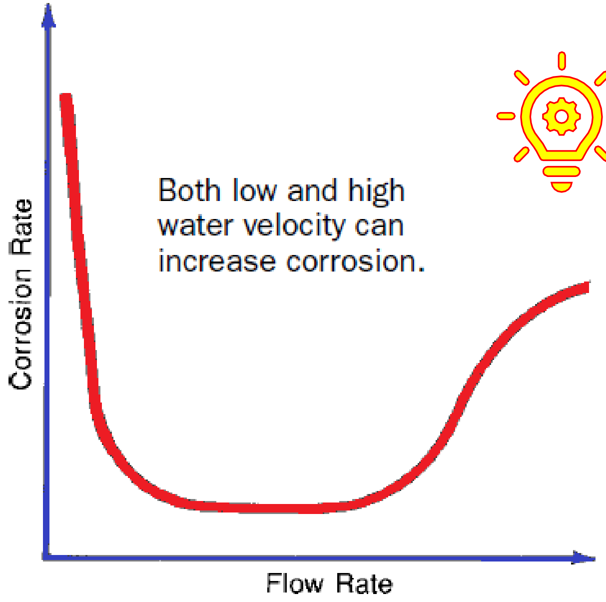
1- Channel Cover
2- Channel
3- Channel Flange
4- Pass Partition
5- Stationary Tubesheet
6- Shell Flange
7- Tube

8- Shell
9- Baffles
10- Floating Head backing Device
11- Floating Tubesheet
12- Floating Head
13- Floating Head Flange
14 –Shell Cover

Fluid Allocation

- Fluids to be passed in shell side :
  - Fluids of which pressure drop should be low.
  - Highly viscous fluids
  - Fluids which exhibit a low heat transfer rate
  - Fluids which undergo the phase change
- Fluids to be passed in Tube side :
  - Dirty Fluids
  - Fluids at higher pressure
  - Corrosive Fluids
  - Fluids which contain solids
  - Cooling water

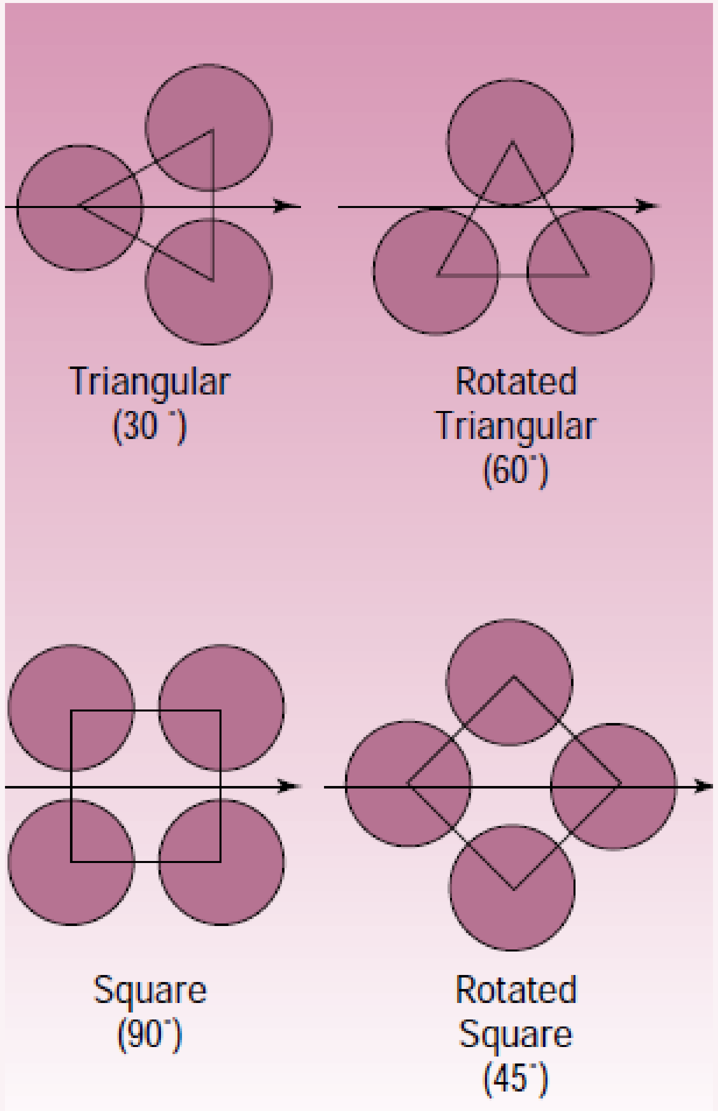




Tube Pattern

- Triangular pitch (30 deg) is better for heat transfer and surface area per unit length (greater tube density)

- Square pitch is needed for mechanical cleaning



Baffle Design

To promote ideal shellside flow, baffle design must balance the baffle cut and baffle spacing geometry. This encourages the fluid to fully enter the baffle space and direct the majority of the ow stream around each baffle

Window velocity is affected by baffle cut, and crossflow velocity is affected by baffle spacing. Using a rule of thumb, the window and crossflow velocities of the shellside flow should be roughly equal to achieve ideal ow

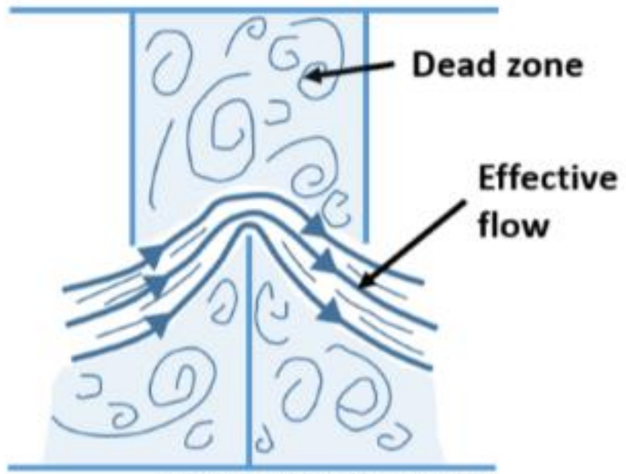


Figure 1. Example of non-ideal flow pattern

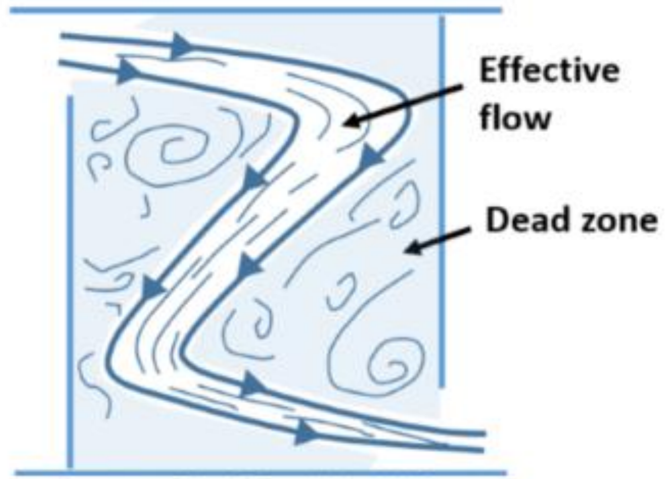


Figure 2. Example of non-ideal flow pattern

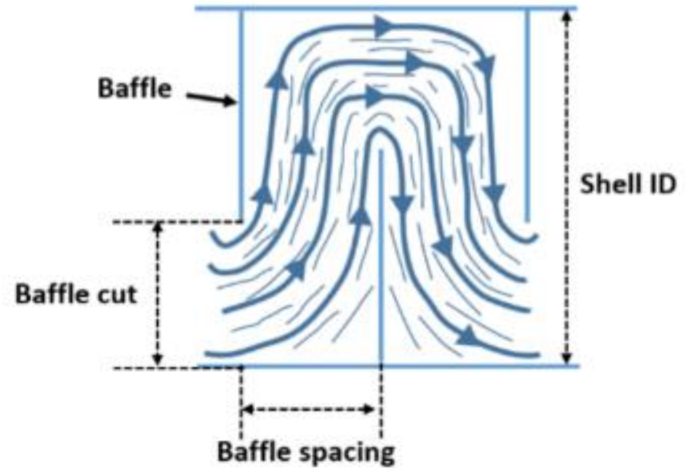
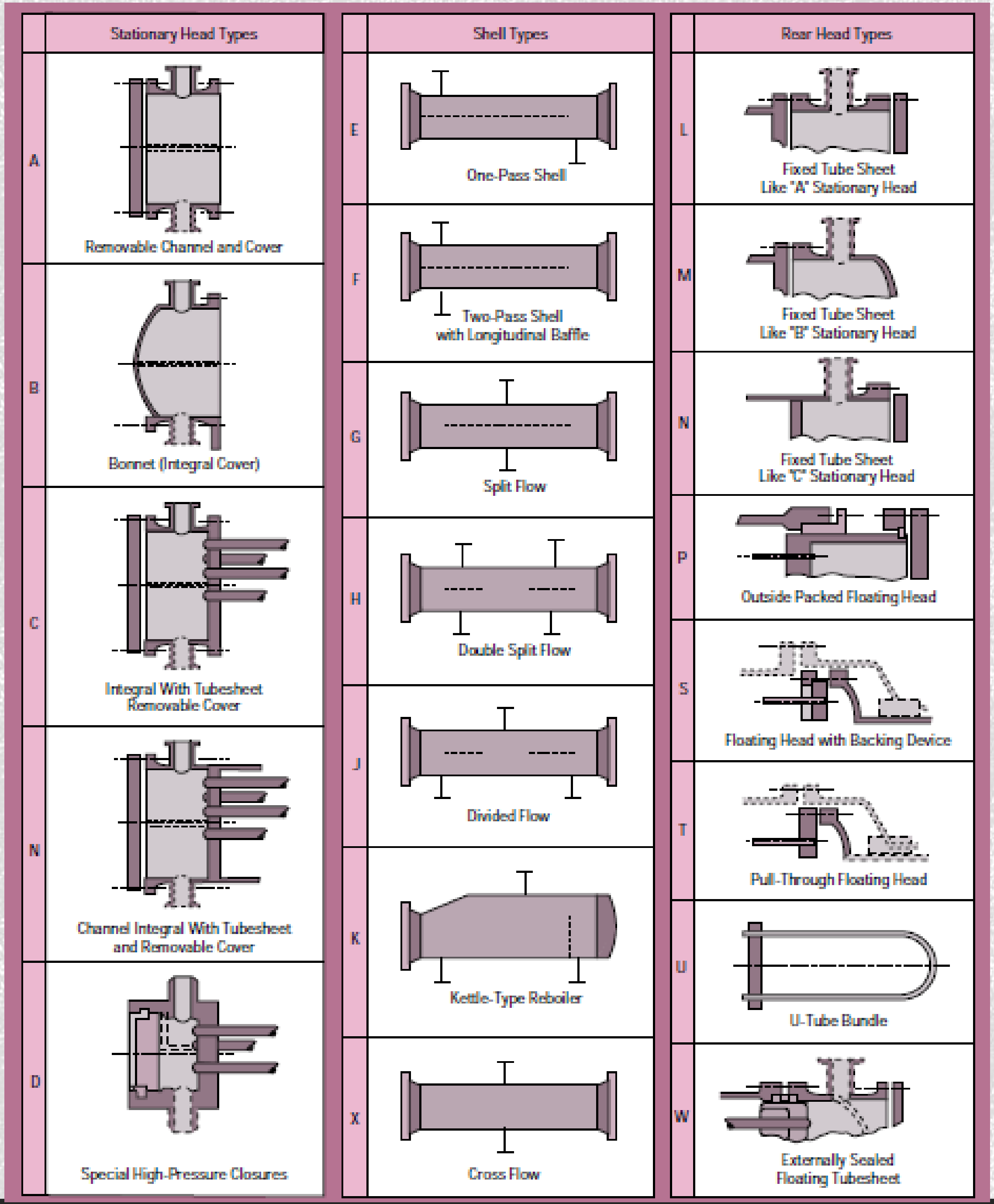
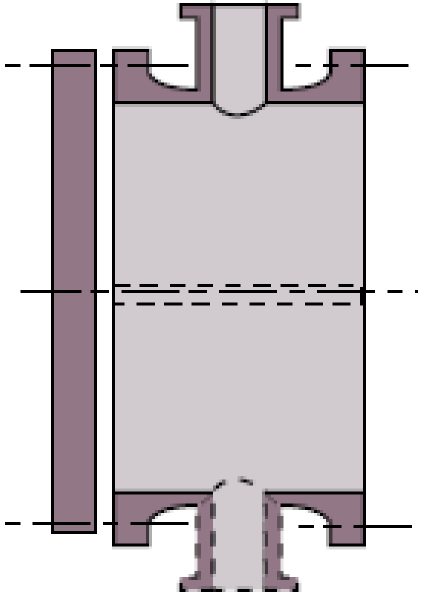


Figure 3. Example of ideal flow pattern

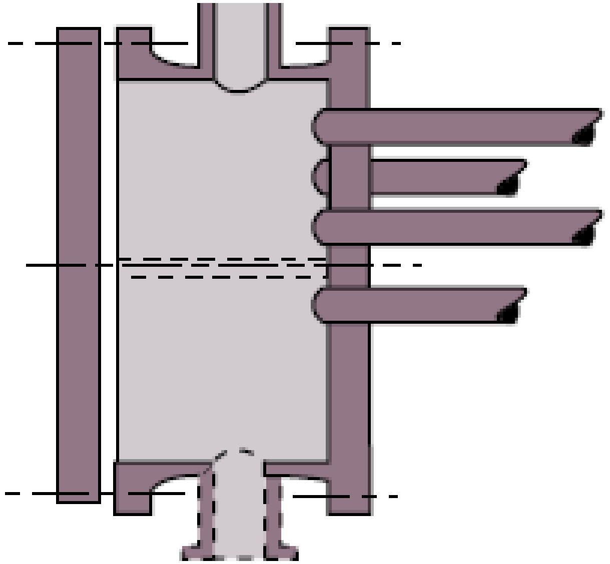

Stationary Head Types
A
Removable Channel and Cover
B
Bonnet (Integral Cover)
C
Integral With Tubesheet Removable Cover
N
Channel Integral With Tubesheet and Removable Cover
D
Special High-Pressure Closures
Shell Types
E
One-Pass Shell
F
Two-Pass Shell with Longitudinal Baffle
G
Split Flow
H
Double Split Flow
J
Divided Flow
K
Kettle-Type Reboiler
X
Cross Flow
Rear Head Types
L
Fixed Tube Sheet Like "A" Stationary Head
M
Fixed Tube Sheet Like "B" Stationary Head
N
Fixed Tube Sheet Like "C" Stationary Head
P
Outside Packed Floating Head
S
Floating Head with Backing Device
T
Pull-Through Floating Head
U
U-Tube Bundle
W
Externally Sealed Floating Tubesheet

TEMA TYPES



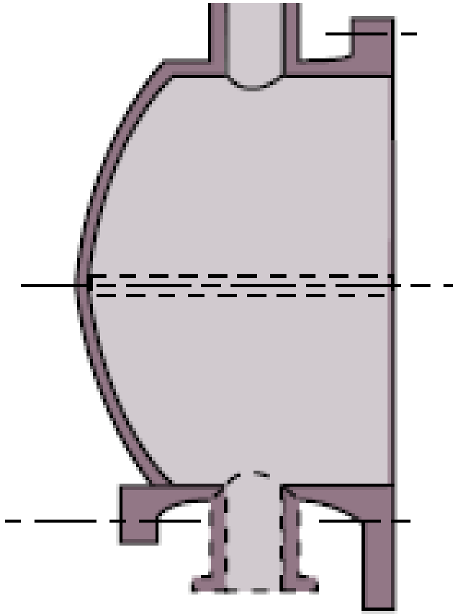
Removable Channel and Cover

A - Type



Integral With Tubesheet
Removable Cover

B - Type

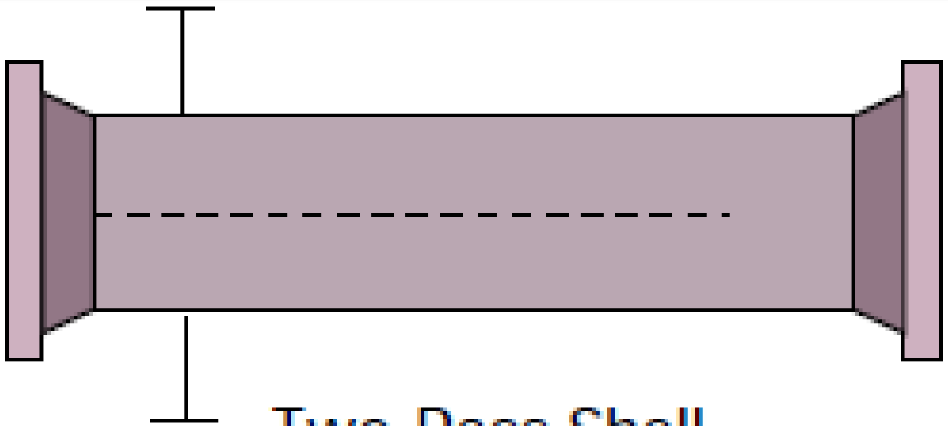


Bonnet (Integral Cover)

C - Type

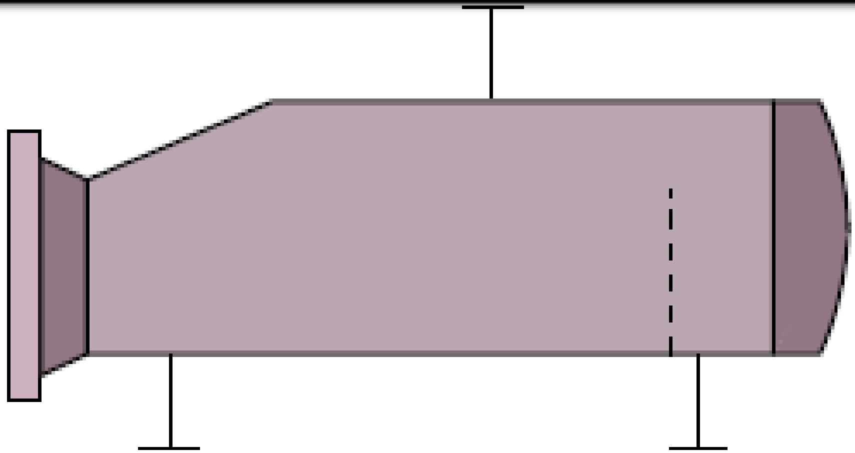
Front Head

Shell Types



Two-Pass Shell with Longitudinal Baffle

F - Type

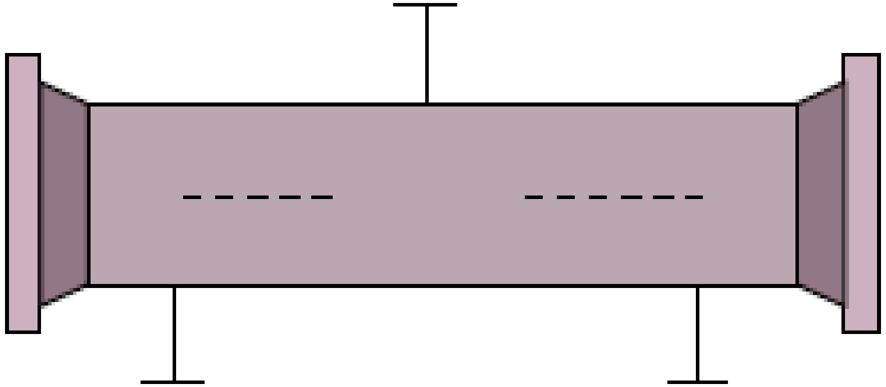


Kettle-Type Reboiler

K - Type

One-Pass Shell

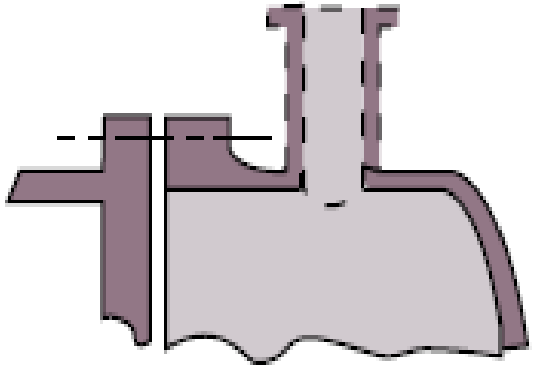
E - Type



Divided Flow

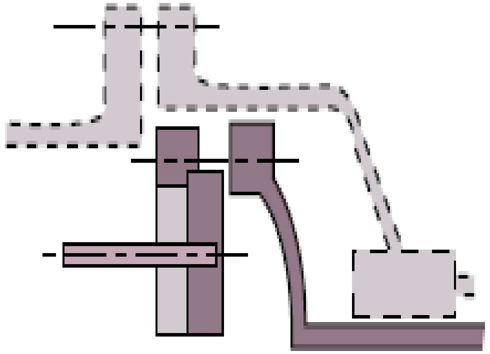
J - Type

Rear End Head Types



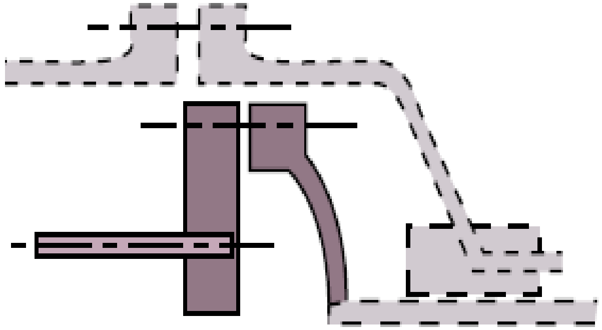
M - Type

Fixed Tubesheet



S - Type

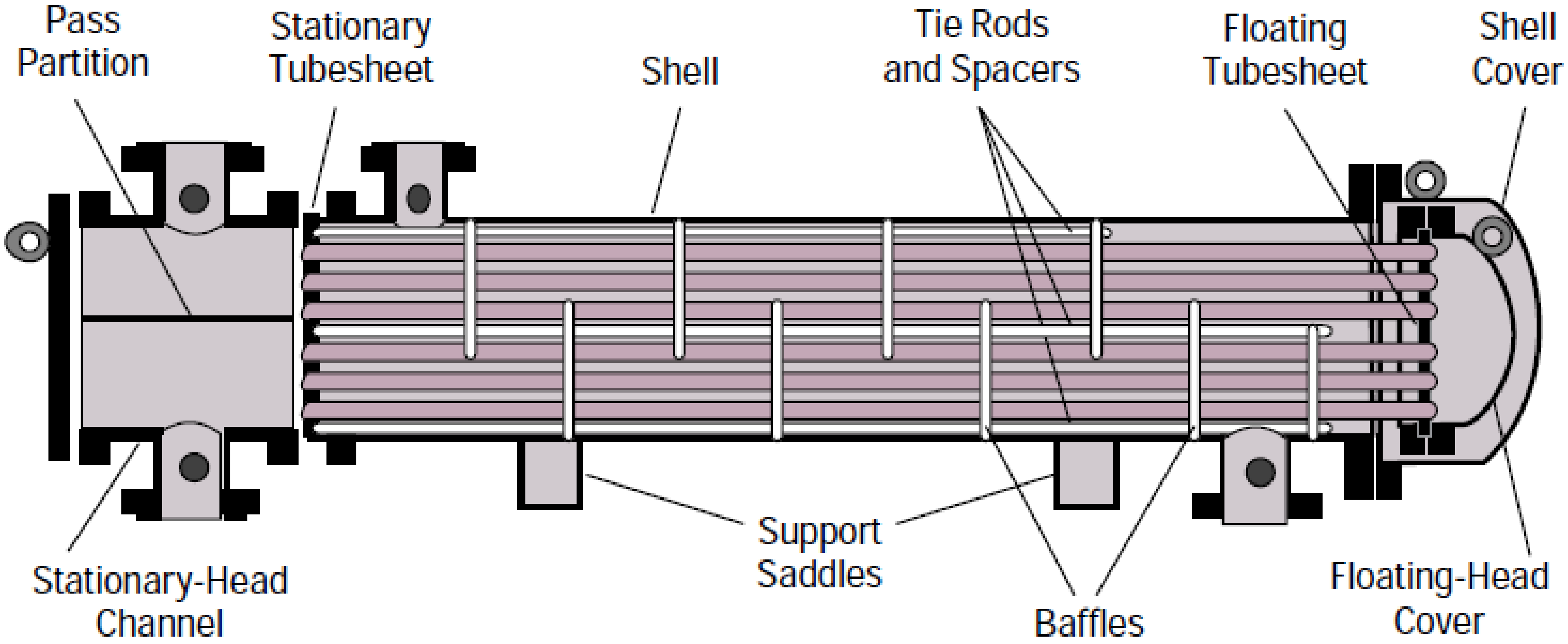
Floating Head



T - Type

Pull-Through
Floating Head

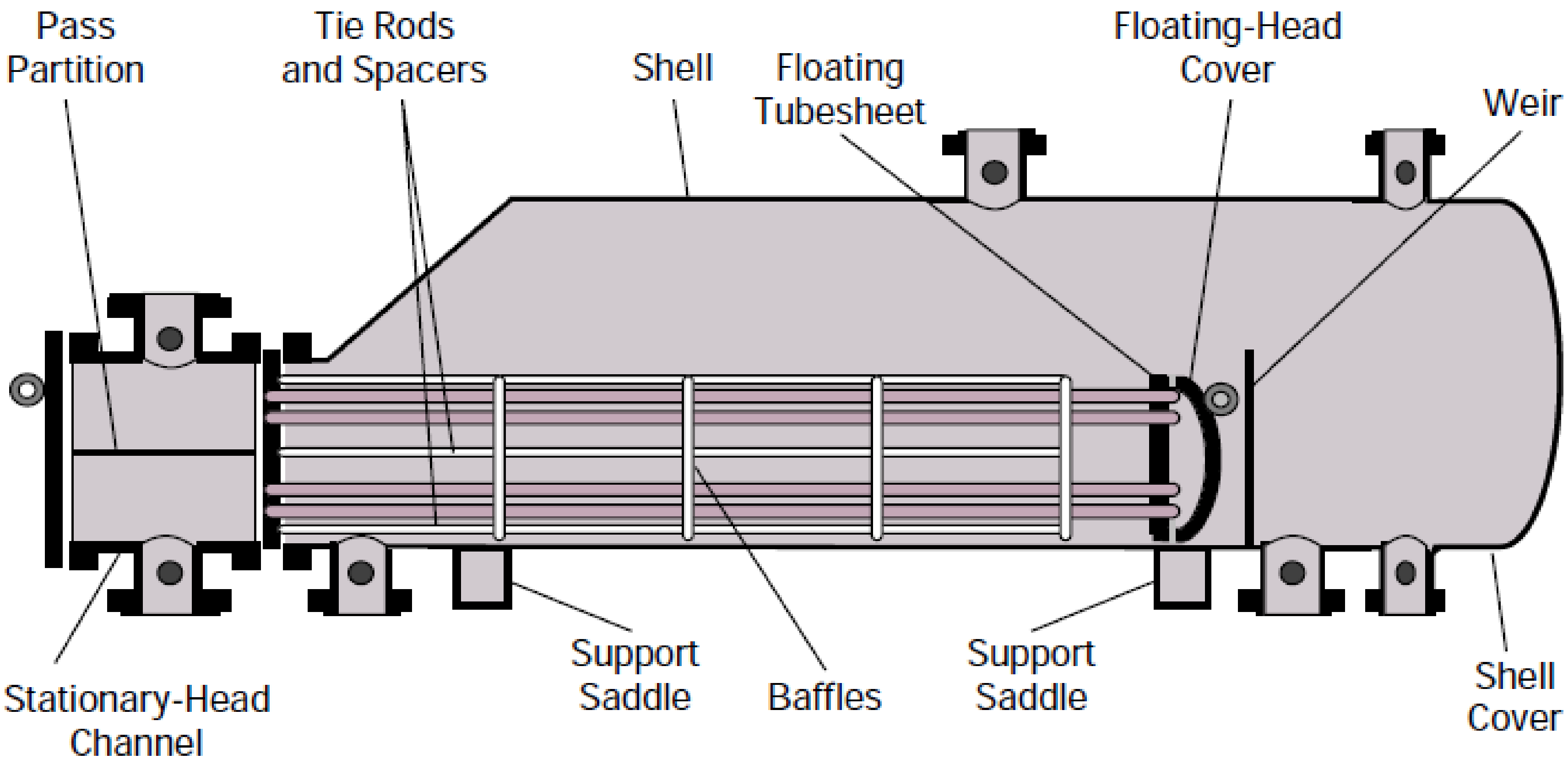
Example



Pass Partition
Stationary Tubesheet
Shell
Tie Rods and Spacers
Floating Tubesheet
Shell Cover
Stationary-Head Channel
Support Saddles
Baffles
Floating-Head Cover

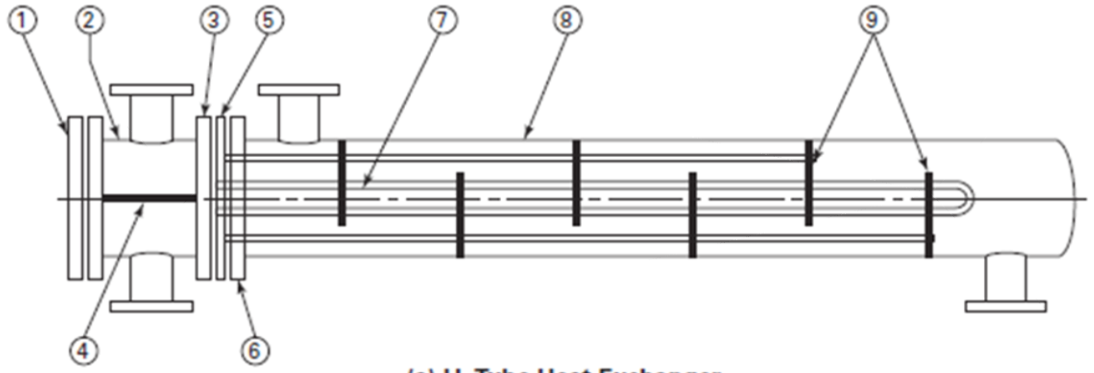
AES

Example

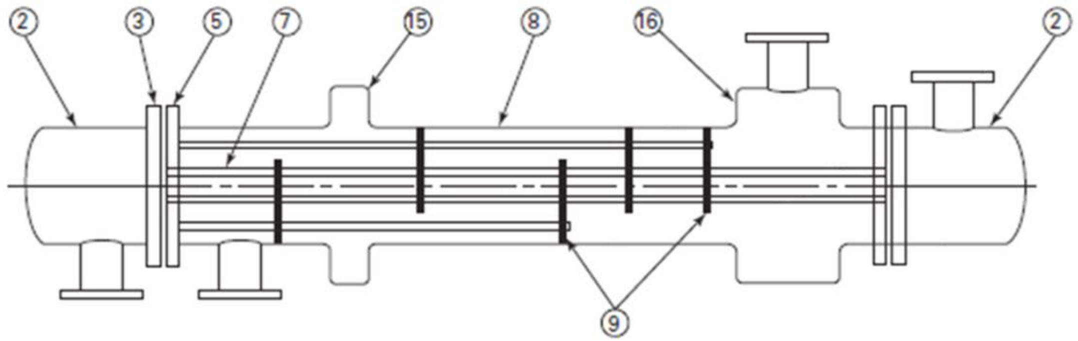

Pass
Partition
Tie Rods
and Spacers
Shell
Floating
Tubesheet
Floating-Head
Cover
Weir
Stationary-Head
Channel
Support
Saddle
Baffles
Support
Saddle
Shell
Cover

AKT

ASME Classification- ASME BPVC Sec. VIII Div.1 Part UHX

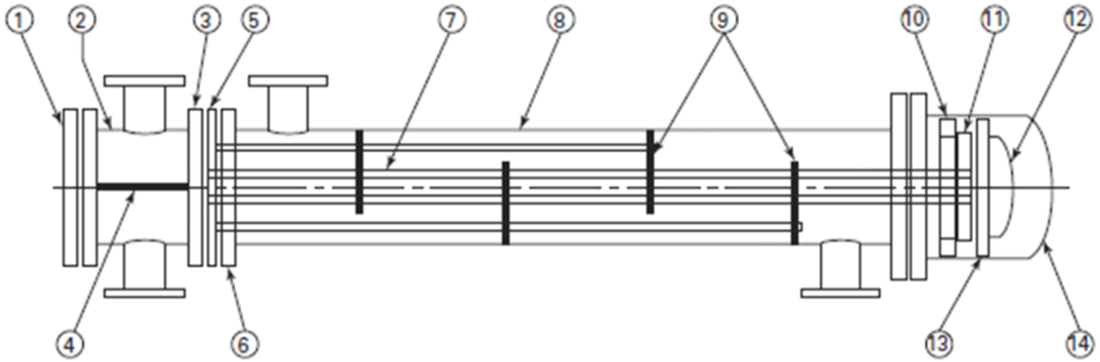


(a) U–Tube Heat Exchanger



(b) Fixed Tubesheet Heat Exchanger

1. Channel cover (bolted flat cover)
2. Channel
3. Channel flange
4. Pass partition
5. Stationary tubesheet
6. Shell flange
7. Tubes
8. Shell
9. Baffles or support plates
10. Floating head backing device
11. Floating tubesheet
12. Floating head
13. Floating head flange
14. Shell cover
15. Expansion joint
16. Distribution or vapor belt



(c) Floating Tubesheet Heat Exchanger

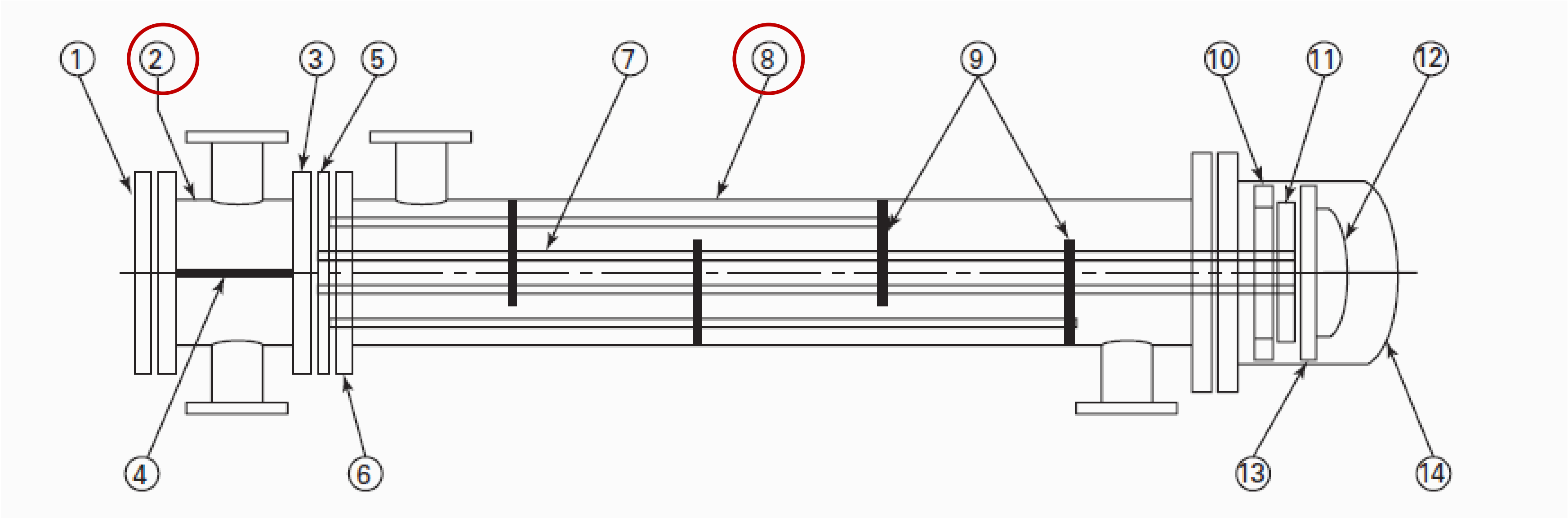
Design Data

No.				
29	Heat Exchanged	BTU / hr MTD (Corrected)		°F
30	Transfer Rate, Service	Clean		BTU / hr sq ft °F
31	**CONSTRUCTION OF ONE SHELL**			Sketch (Bundle/Nozzle Orientation)
32		Shell Side	Tube Side	
33	Design / Test Pressure psig	/	/	
34	Design Temp. Max/Min °F	/	/	
35	No. Passes per Shell			
36	Corrosion Allowance in			
37	Connections In			
38	Size & Out			
39	Rating Intermediate			
40	Tube No. OD in;Thk (Min/Avg)	in;Length	ft;Pitch in	⊲30 △60 □90 ◇45
41	Tube Type	Material		
42	Shell ID OD in	Shell Cover	(Integ.)	(Remov.)
43	Channel or Bonnet	Channel Cover		
44	Tubesheet-Stationary	Tubesheet-Floating		
45	Floating Head Cover	Impingement Protection		
46	Baffles-Cross Type	%Cut (Diam/Area)	Spacing: c/c	Inlet in
47	Baffles-Long	Seal Type		
48	Supports-Tube U-Bend		Type	
49	Bypass Seal Arrangement	Tube-to-Tubesheet Joint		
50	Expansion Joint	Type		
51	ρv^2-Inlet Nozzle	Bundle Entrance	Bundle Exit	
52	Gaskets-Shell Side	Tube Side		
53	Floating Head			
54	Code Requirements	TEMA Class		

Sample Calculations

Internal Pressure Calculations – ASME BPVC Sec. VIII Div.1 UG-27

$$t = \frac{PR}{SE - 0.6\,P} + CA + UT$$

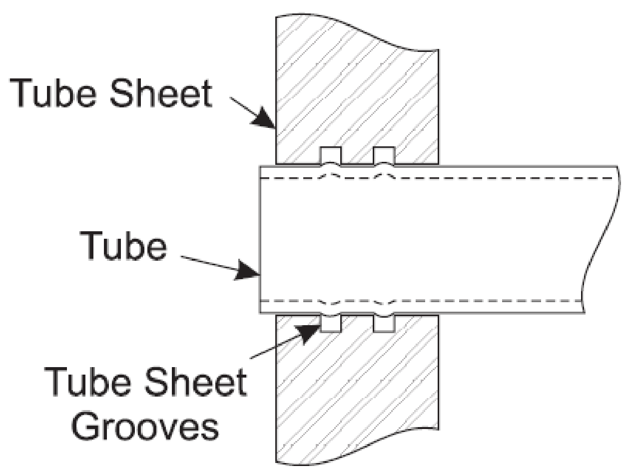


Tube-To-Tubesheet Joints (TTS)

Expanded

Process of expanding a tube to a fully plastic state into contact with tube hole that creates residual interface pressure between the tube and tubesheet

Note: Duplex SS is usually prohibited of rolled joints, except light rolling (<2 %) for positioning (due to possible high hardness)

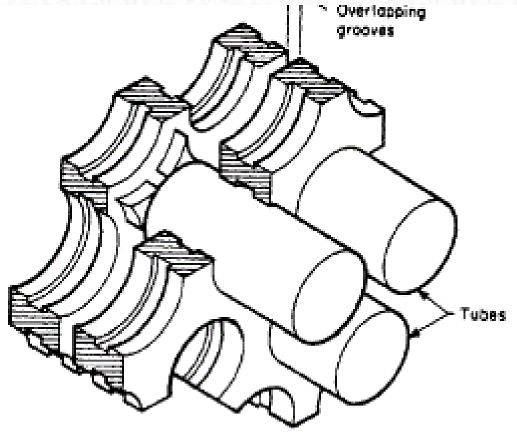


Strength Welded

Weld design strength is equal to or greater than the axial tube strength

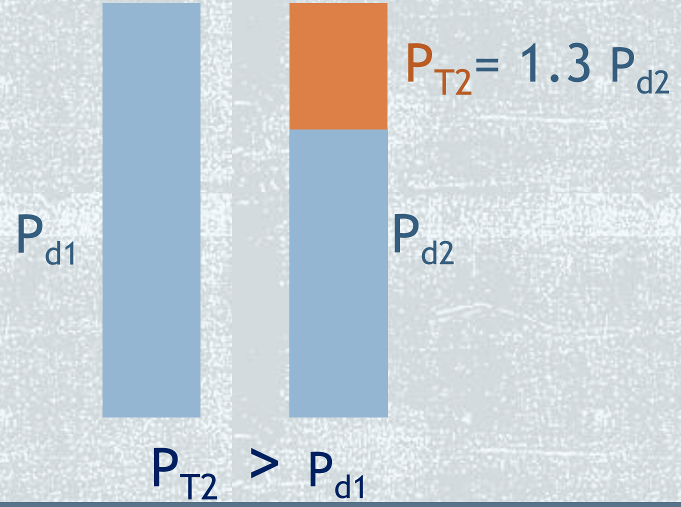
Seal Welded

Weld is used to supplement an expanded tube to tubesheet joint



10/13 Rule for over pressure protection of S&T Exchangers

Loss of containment of the low-pressure side of shell and tube heat exchangers to atmosphere is unlikely to result from a tube rupture where the pressure in the low-pressure side during the tube rupture DOES NOT EXCEED the CORRECTED hydrotest pressure.



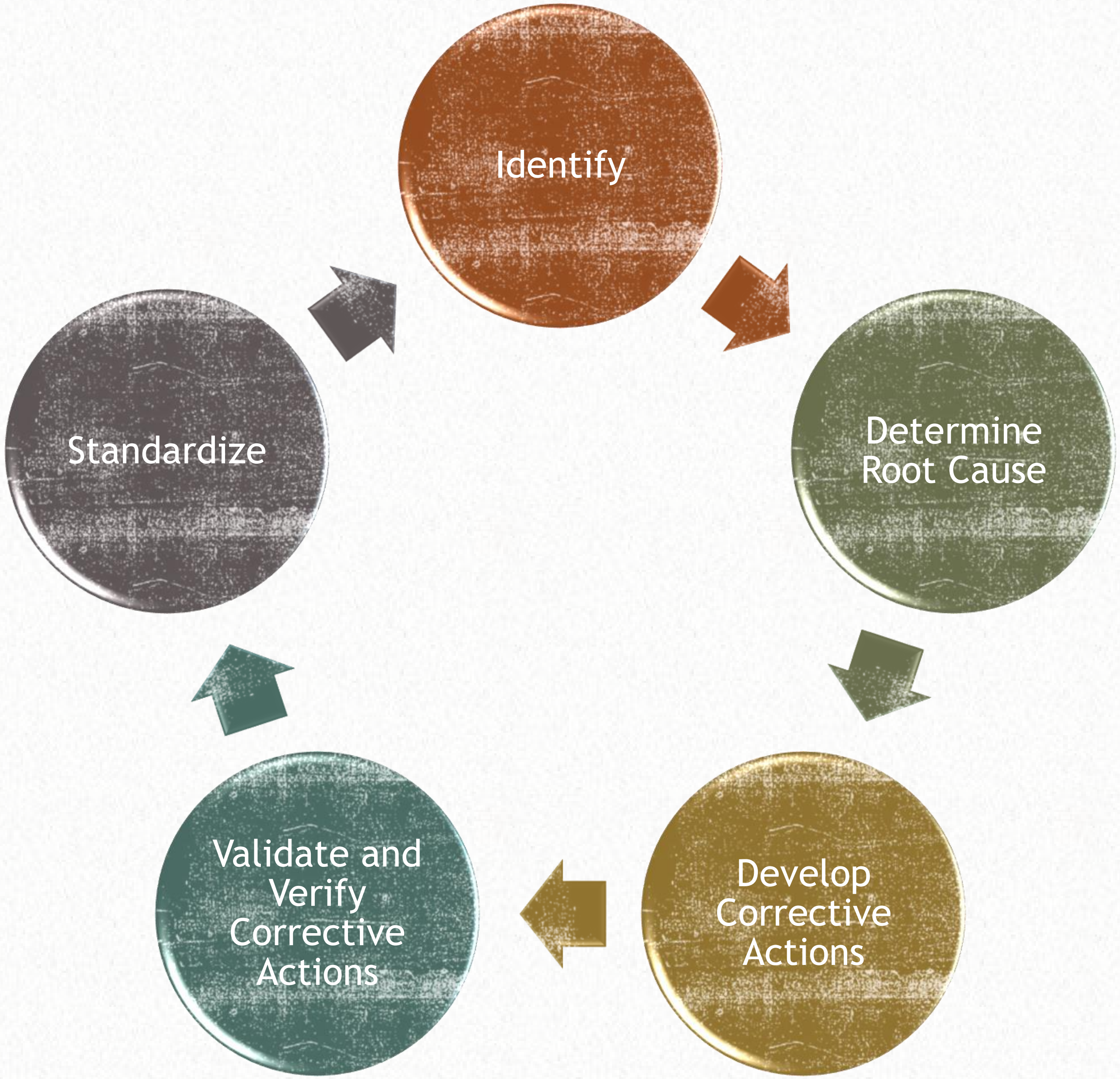
Design Pressure Determination for Both sides

Reference: [API 521 para. 4.4.14.2]

CASE STUDY

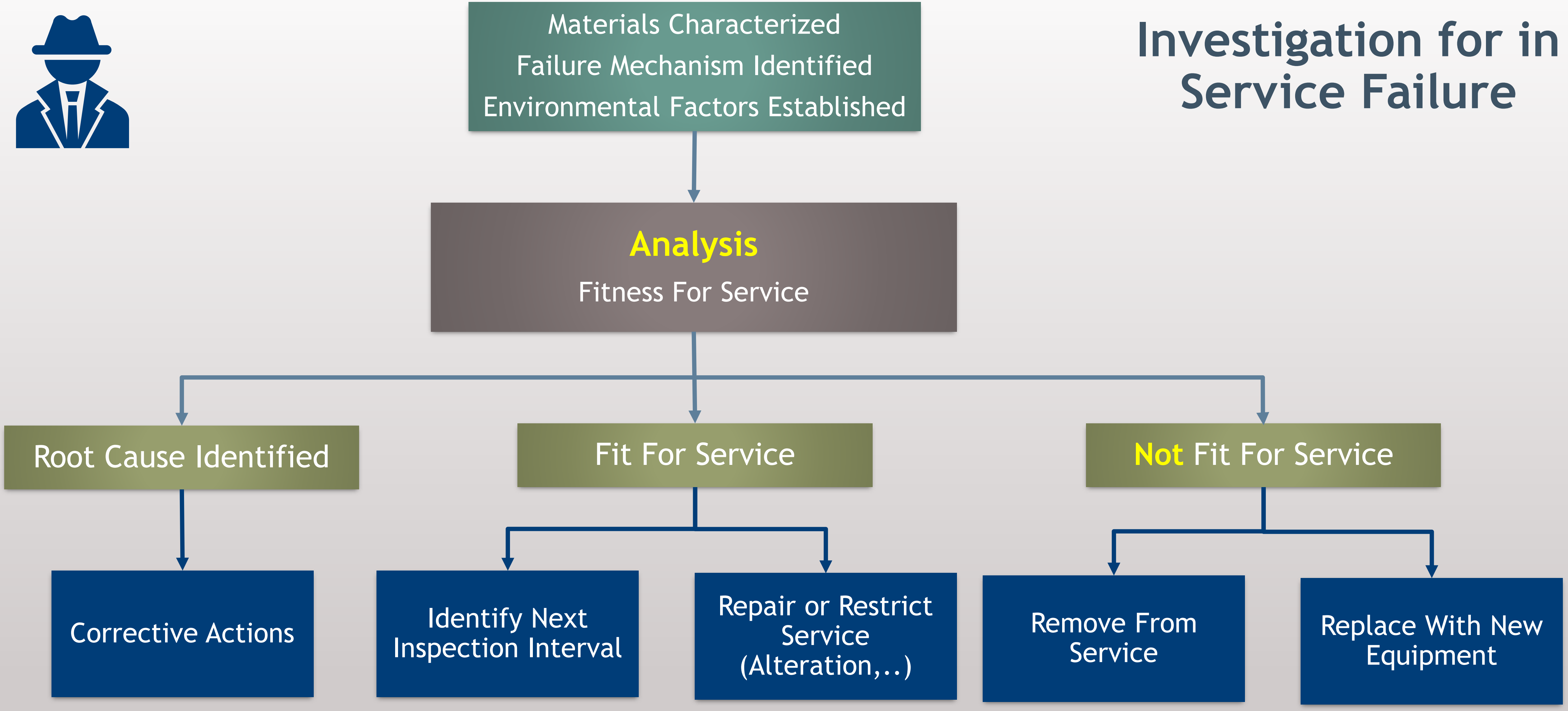
FAILURE ANALYSIS AND CORRECTIVE ACTIONS OF CW HEAT EXCHANGER CORROSION

Problem Solving Model



Source: ASM Metals Handbook Volume 11- Failure Analysis

Investigation for in Service Failure



Customized From: **ASM Metals Handbook Volume 11- Failure Analysis**

Conditions and Findings

Description	Unit	Shell Side	Tube Side
Fluid		Cooling Water	Process Gas (non corrosive)
Pressure Operating/Design	barg	6 / 12	15
Temperature Operating/Design	°C	40/80	240/150
Material		Carbon Steel	Carbon Steel
Tube to Tubesheet **Expanded , 2 grooves**			

Findings

Sever corrosion in the tubes from shell side; pitting and under deposits

85 tubes out of 300 tubes plugged led to …. Limited load

Other tubes found with thinning to different extent < 20 % of the tube thk. Chloride traces detected in the pits in a sample taken from one of the plugged tube

Discussions

Q 7

What are the possible causes / Root Cause of the exchanger failure

Decision taken to replace / upgrade the exchanger

Q 8

What should be the recommended actions and/or upgradations in the new exchanger

Q 9

In case tube material to be upgraded what would be the recommended material: Austenitic SS or Duplex SS or other material and why

Q 10

In case tube materials upgraded, is the thermal design of the exchanger need to be revised. What are the expected changes in the exchanger configurations

Open Discussions