Detailed Material Selection

Equipment-Based

Heat Exchangers

For detailed specification of shell and tube heat exchanger material selection, the following tables are recommended:

		Low Alloy Steels				High Alloy Steels			
Components	**Carbon Steel**	**C-1/2Mo**	**1-1/4Cr-1/2Mo**	**2-1/4Cr-1/2Mo**	**5Cr-1/2Mo**	**12 Cr**	**18Cr-8Ni-3Mo**	**18Cr-8Ni**	**18Cr-8Ni Stabilized**
PLATES: (For rolled and welded shells, shell covers, channels and nozzle necks, heads flat covers, tubesheets and baffles)	SA-285-C SA-515 and 516 (All grades)	SA-204-A SA-204-B or SA-204-C	SA-387-11 Class 1 or 2	SA-387-22 Class 1 or 2	SA-387-5 Class 1 or 2 (Tubesheets and baffles only. Use 12Cr clad for shells and channels.)	Do not use 12Cr for pressure containing parts (except tubes). Use 5Cr-1/2Mo tubesheets with 12Cr tubes.	SA-240-TP316 or SA-240-TP316L	SA-240-TP304 or SA-240-TP304L	SA-240-TP321 or SA-240-TP347
PIPE: (For pipe sized shells and nozzle necks)	SA-106-B or SA-53-B	SA-335-P1	SA-335-P11	SA-335-P22	Not used	Do not use	SA-312-TP316 or SA-312-TP316L (Seamless or welded)	SA-312-TP304 or SA-312-TP304L (Seamless or welded)	SA-312-TP321 or SA-312-TP347 (Seamless or welded)
FORGINGS: (For body and nozzle flanges, blind flanges, couplings and forged flat covers and tubesheets)	SA-105 or SA-181 (Class 60 or 70)	SA-182-F1	SA-182-F11	SA-182-F22	SA-182-F5 or SA-182-F5a (For forged tubesheets and covers only)	Do not use	SA-182-F316 or SA-182-F316L	SA-182-F304 or SA-182-F304L	SA-182-F321 or SA-182-F347
TUBES:	WELDED: SA-214 SEAMLESS: SA-179	SA-209-T1	SA-199-T11	SA-199-T22	SA-199-T5	SA-268-TP405 or SA-258-TP410 (Seamless or welded)	WELDED: SA-249-TP316 or SA-249-TP316L SEAMLESS: SA-213-TP316 or SA-213-TP316L	WELDED: SA-249-TP304 or SA-249-TP304L SEAMLESS: SA-213-TP304 or SA-213-TP304L	WELDED: SA-249-TP321 or SA-249-TP347 SEAMLESS: SA-213-TP321 or SA-213-TP347

		Low Alloy Steels				High Alloy Steels			
Components	**Carbon Steel**	**C-1/2Mo**	**1-1/4Cr-1/2Mo**	**2-1/4Cr-1/2Mo**	**5Cr-1/2Mo**	**12 Cr**	**18Cr-8Ni-3Mo**	**18Cr-8Ni**	**18Cr-8Ni Stabilized**
BOLTS:	SA-193-B7	SA-193-B7	SA-193-B7 or SA-193-B16	SA-193-B7 or SA-194-B16	SA-193-B5	Do not use	SA-193-B8M	SA-193-B8	SA-193-B8T or SA-193-B8C
			Caution: For hydrogen service, verify that Cr and Mo content are high enough to resist H_2 attack.						
NUTS:	SA-194-2H	SA-194-2H	SA-194-2H	SA-194-2H	SA-194-3	Do not use	SA-194-8M	SA-194-8	SA-194-8T SA-194-8C

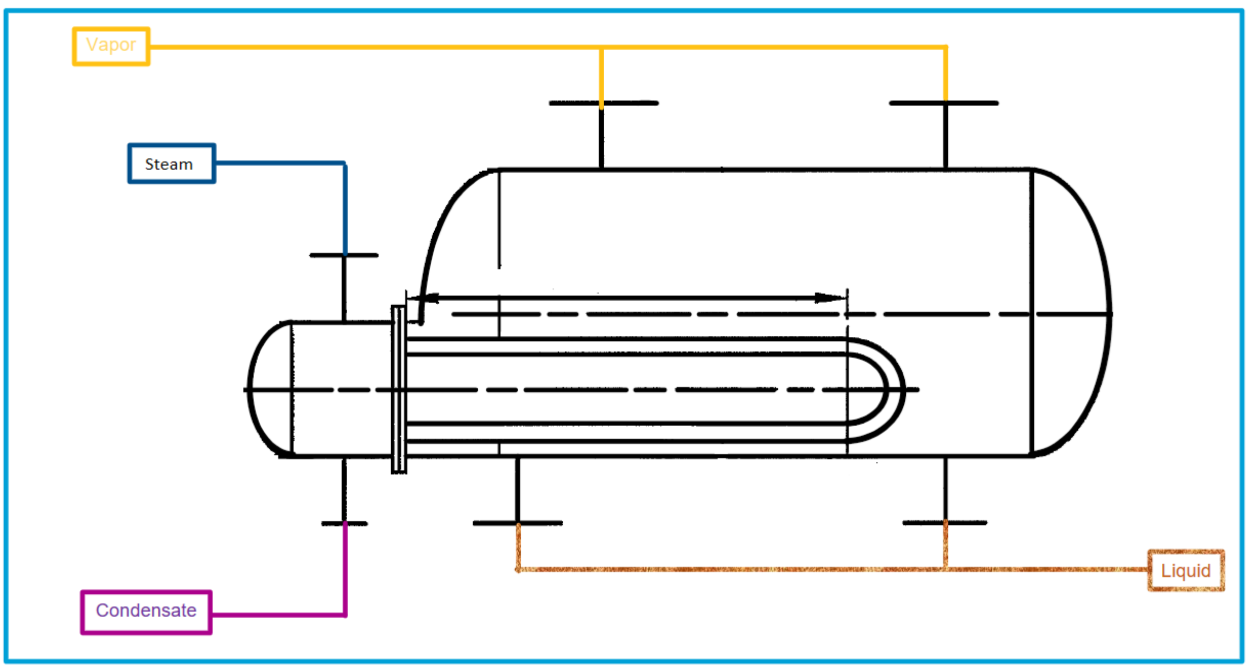
EIEPD Criteria

Component of Channel Side	CS	SS
Head	SA-516 70N	SA-240 304L
Shell	SA-516 70N	SA-240 304L
Channel Flange	SA-266 2N	SA-965 F304L/SA-182 F304
Pass Partition	SA-516 70N	
Nozzle	SA-105N	SA-182 F304L
Flange	SA-105N	SA-312 TP304L

Component of Heat Transfer	CS	SS
Tie Rod	SA-36	SA-479 304
Spacer	SA-179	SA-213 TP304/SA-789/ SA-312
Baffle	SA-516 70N	SA-240 304
Support Plate	SA-516 70N	SA-240 304L
Partition Plate	SA-516 70N	SA-240 304L
Impingement Plate	SA-516 70N	SA-240 304
Tube-sheet	SA-266 2N	SA-182 F304/SA-965

Hex Bolt	SA-193 B7	SA-193 B7/A2-70
Hex Nut	SA-194 Gr 2H	SA-194 Gr 2H/A2-70
Body Flange	SA-266 2N	SA-965 F304/F304L
Shell Side Shell	SA-516 70N	SA-240 304/ SA-387
Tubes/U-Tubes	SA-179	SA-213 TP304/ SA-789
Sealing Strip	SA-516 70N	SA-240 304L

Example 1: Determine the detailed material selection for the following typical reboiler sketch. The hot medium is LP steam and the cold medium is a liquid, both of which are non-corrosive.



Answer: Use the above EIEPD criteria to find the material for different components.

Note: To expedite the material selection, here is a pattern:

CS	SS
Natural Gas	DM Water
Cooling Water	H_2 containing Gases
Steam	Corrosive Process Condensate

Example 2: Specify the material for the heat exchanger with the following datasheet.

Description		Shell Side		Tube Side		Units
		Inlet	Outlet	Inlet	Outlet	
Fluids		Process condensate		Cooling water		
Quantity:	total	47200		166009		kg/h
	liquid	47200	47200	166009	166009	kg/h
	gas					kg/h
Operating temperature		100	65	38	48	°C
Operating pressure		1,5		4,5		bar g
Liquid:	molecular weight	18,02	18,02	18,02	18,02	kg/kmol
	density	958	980	993	989	kg/m³
	viscosity	0,283	0,434	0,681	0,567	cP
	specific heat capacity	4,213	4,184	4,175	4,177	kJ/kg/°C
	thermal conductivity	0,6768	0,6505	0,6199	0,6323	W/m/°C
	boiling temperature	106				°C
Gas:	molecular weight					kg/kmol
	density					kg/m³
	viscosity					cP
	specific heat capacity					kJ/kg/°C
	thermal conductivity					W/m/°C
	dew point					°C

The tube-side fluid is non-corrosive while the shell-side fluid is corrosive. Hence those parts in contact with non-corrosive fluid shall have the base material of CS whereas the base material for those parts in contact with corrosive fluid shall have the base material of SS.

In next page the detailed material specification is provided.

Component of Channel Side	Material
Head	SA-516 70N
Shell	SA-516 70N
Channel Flange	SA-266 2N
Pass Partition	SA-516 70N
Nozzle	SA-105N
Flange	SA-105N
Component of Heat Transfer	Material
Tie Rod	SA-479 304
Spacer	SA-213 TP304/SA-789/SA-312
Baffle	SA-240 304
Support Plate	SA-240 304L
Partition Plate	SA-240 304L
Impingement Plate	SA-240 304
Tube-sheet	SA-182 F304/SA-965

Hex Bolt	SA-193 B7/A2-70
Hex Nut	SA-194 Gr 2H/A2-70
Body Flange	SA-965 F304/F304L
Shell Side Shell	SA-240 304/ SA-387
Tubes/U-Tubes	SA-213 TP304/SA-789
Sealing Strip	SA-240 304L

Example 3: Specify the material for the heat exchanger with the following datasheet.

Operating Data (One Unit)						
Description		**Shell Side**		**Tube Side**		**Units**
		Inlet	**Outlet**	**Inlet**	**Outlet**	
Fluids		Demineralized Water		Reformed Gas		
Quantity:	total	218326		342643		kg/h
	liquid	218326	218326		13198	kg/h
	gas			342643	329446	kg/h
Operating temperature		35	72	139	133	°C
Operating pressure		5		24,8		bar g
Liquid:	molecular weight	18,02	18,02		18,02	kg/kmol
	density	994	977		933	kg/m³
	viscosity	0,723	0,394		0,21	cP
	specific heat capacity	4,174	4,188		4,259	kJ/kg/°C
	thermal conductivity	0,6159	0,6570		0,6873	W/m/°C
	boiling temperature	159				°C
Gas:	molecular weight			12,06	11,90	kg/kmol
	density			9,09	9,1	kg/m³
	viscosity			0,018	0,018	cP
	specific heat capacity			2,619	2,626	kJ/kg/°C
	thermal conductivity			0,1133	0,1149	W/m/°C
	dew point			139		°C

Component of Channel Side	Material
Head	SA-240 304L
Shell	SA-240 304L
Channel Flange	SA-965 F304L/SA-182 F304
Pass Partition	
Nozzle	SA-182 F304L
Flange	SA-312 TP304L
Component of Heat Transfer	Material
Tie Rod	SA-479 304
Spacer	SA-213 TP304/SA-789/SA-312
Baffle	SA-240 304
Support Plate	SA-240 304L
Partition Plate	SA-240 304L
Impingement Plate	SA-240 304
Tube-sheet	SA-182 F304/SA-965

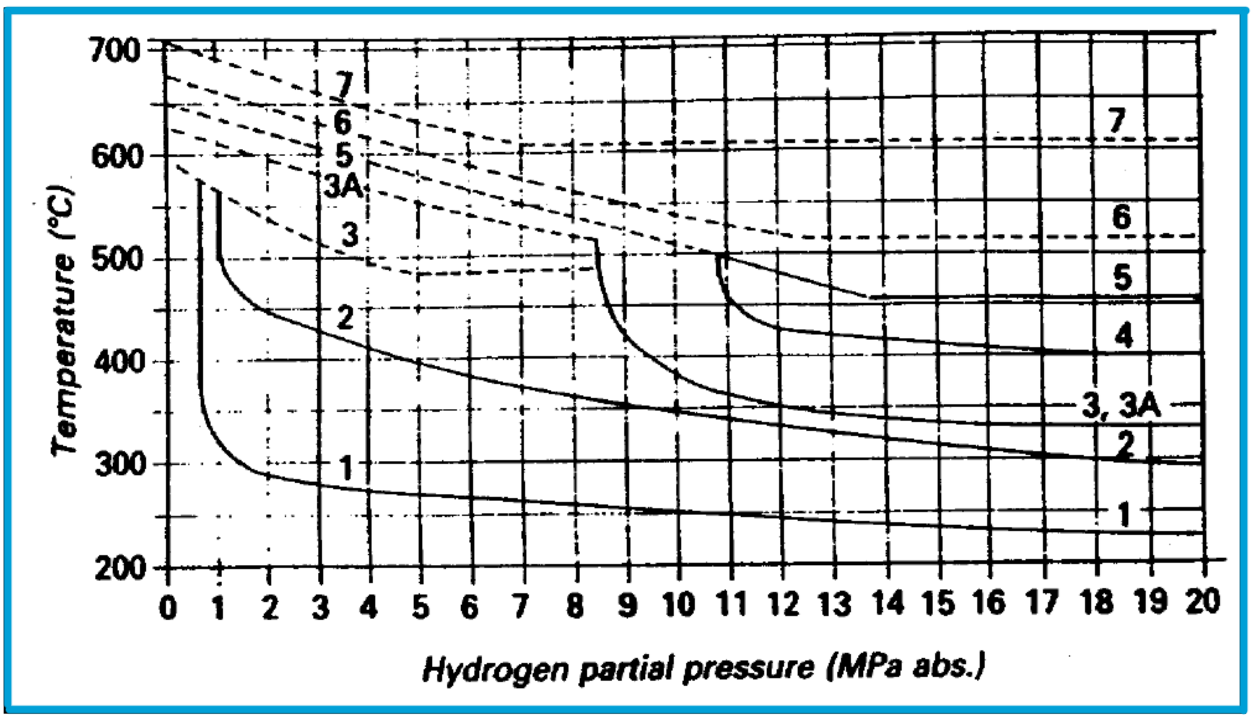
Hex Bolt	SA-193 B7/A2-70
Hex Nut	SA-194 Gr 2H/A2-70
Body Flange	SA-965 F304/F304L
Shell Side Shell	SA-240 304/ SA-387
Tubes/U-Tubes	SA-213 TP304/SA-789
Sealing Strip	SA-240 304L

Hydrogen Attack

Gases containing hydrogen may decarburize steel depending on temperature and hydrogen partial pressure and the hydrogen attack may occur as surface decarburization or internal decarburization. While high temperature and low partial pressure promotes surface attack, modest temperature and high partial pressure promotes internal attack. In surface decarburization carbon migrates to the surface where it combines with hydrogen, and oxygen if present, to form methane and carbon monoxide. The surface is depleted of carbon resulting in loss of strength and hardness, but with an increase in ductility. In the case of internal decarburization, hydrogen permeates the steel and reacts with carbon to form methane, which cannot diffuse out. The methane accumulates in voids, many of which are at grain boundaries, to develop stresses sufficient to fissure crack or blister the steel.

To overcome this, carbide stabilizers such as chromium and molybdenum are added to steel in various proportions to produce a range of steels known as low alloys. (these are often referred to as “carbon-molys” and “chrome-molys”) The low alloy steels are considered for use when hydrogen-bearing gases are involved, termed “hydrogen service”.

The selection of the steel is based on data provided by the following figure, for example, which relate maximum operating temperature to hydrogen partial pressure for various low-alloy steels and carbon steel. The graphs in this figure are known as “Nelson Curves” as they were developed over many years by G.A. Nelson.



Key			
1	Carbon Steel	4	2.0Cr-0.5Mo
2	0.5Mo	5	2.25Cr-1.0Mo
3	1.0Cr-0.5Mo	6	3.0Cr-0.5Mo
3A	1.25Cr-0.5Mo	7	6.0Cr-0.5Mo
Surface Decarburization ------------- Internal Decarburization ———			

How to use it?

Consider a hydrogen bearing gas at 450C in which the hydrogen partial pressure is 5MPa abs. If the curves of the figure are entered horizontally at 450C and vertically at 5 MPa, the coincident point lies between alloys 2 and 3. For safety, the higher number would be selected, number 3 which is a 1% chrome-1/2% molybdenum low-alloy steel.

Heat exchanger units in hydrogen service may have a large temperature range on each side such that several shells in series are required for the duty. For safety, every shell could be made from the particular low-alloy steel which will resist hydrogen attack at the highest temperature in the system, but there is a significant cost incentive not to select a more expensive alloy than necessary. Some purchasers will allow the designer to select the appropriate alloy from the Nelson Curve" for the shell and tube side independently, in each shell, according to the calculated temperature on each side. For example, a multi-shell-in-series system may have all 21/4% chrome-1/2%moly alloy in the hottest shells, all carbon steel in the coldest shells, with other chrome-moly or carbon-moly alloys for the various components of intermediate shells.

The strength of carbon steels falls rapidly above about 400C, whereas many of the low-alloy steels provide greater strengths at this temperature and maintain reasonable strength up to 540C. Oxidation limits for steels in air and steam are about 500C and 425C respectively; for the low-alloys the corresponding values, which increase as the chrome content increases, are about 525-650 C and 450-600C.

Example 1: In ammonia and hydrogen plant at the outlet of ATR there is a superheater to superheat the steam. The idea is to re-use the energy of reformed gas which is a mixture of H_2, CO, CO_2 and N_2. The saturated steam passes through tubes while the reformed gas with operating pressure and temperature of 26 barg and 544C is located on the shell side. The composition of the reformed gas contains 70% H_2, 20%CO, 8%CO_2 and 2% N_2. Select the best material for the shell side.

Step 1: Since we are dealing with hydrogen services, we are supposed to use the Nelson Curves.

Step 2: Based on the example info, the operating temperature and pressure are 544C and 26barg respectively. Remember if we want to use the Nelson Curve, we need to have hydrogen partial pressure in MPa abs.

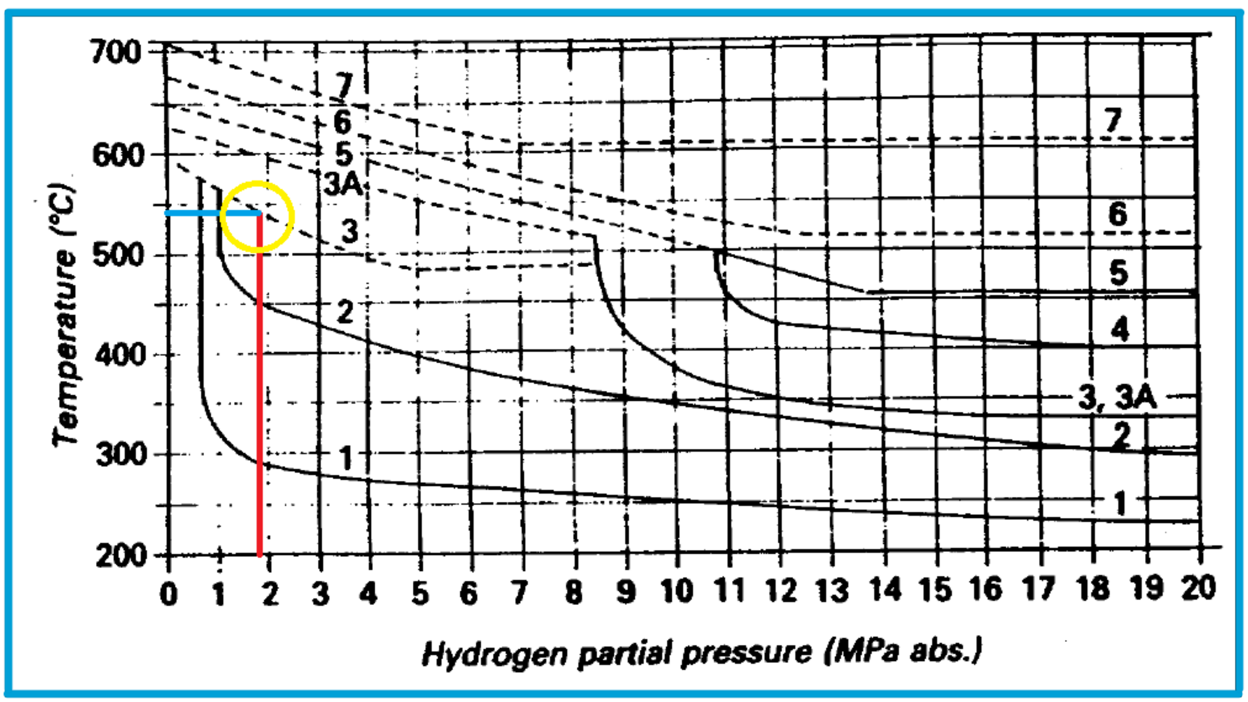
Note: Based on Dalton's Law we have a gaseous mixture the partial pressure of a component in a stream would be:

$$P_i = C_i P_T$$

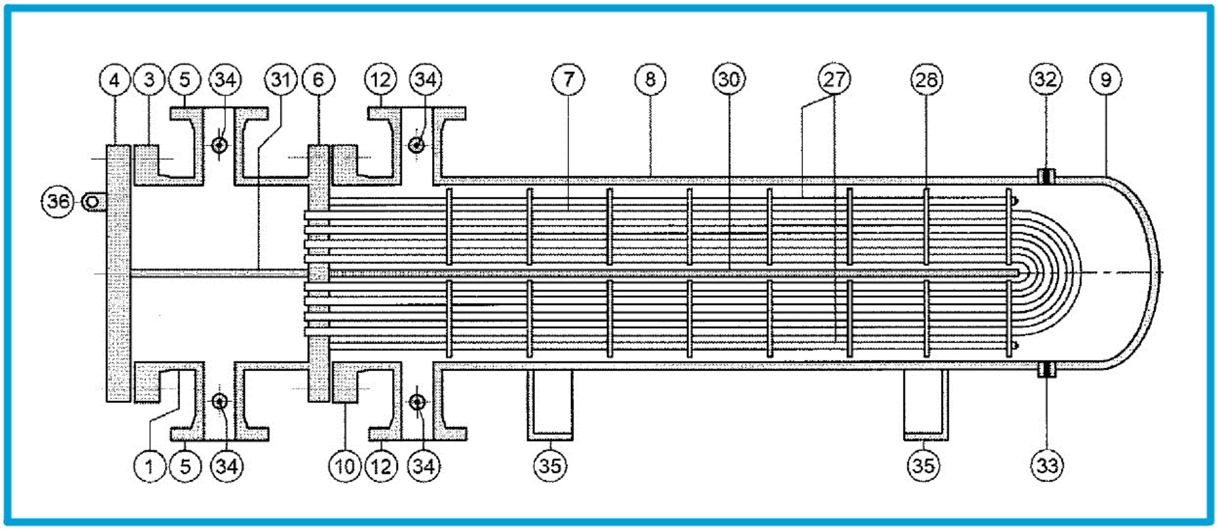
C_i is mole fraction and P_i is partial pressure of component i in the mixture.

In our case the partial pressure of hydrogen is $P_{H2} = 0.7 \times 27$ bara = 19 bara = 1.9 MPa abs.

Step 3: Use the Nelson Curves



Based on the curves, the horizontal and vertical lines intercept at curve 3. Now use the table; based on the table, the corresponding material for curve 3 is 1.0Cr-0.5Mo. So the minimum required material which is suggested is 1.0Cr-0.5Mo. Remember it is the responsibility of material specialist to finalize the material and more importantly, it is stated **minimum required material.**


4
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35
35
33

Control Valves

General Guideline for Valves and PSVs Body

1. Cast Carbon Steel, A216 Gr WCB/WCC or forged carbon steel, A105 is used in non-corrosive service from -28C to 427C. Low temperature carbon steel, A352 Gr LCB/LCC can be used down to -46C (stainless steel may be considered as an alternative)
2. Alloy Steel, A217 Gr WC1, WC6, WC9 is used for temperatures above 427C. WC9 may also be used for flashing services.
3. Stainless Steel, A351 CF8 is used in flashing services, corrosive service and for temperatures below -28C.
4. Monel is used in pure oxygen services.

Valve Trim

1. As standard the material shall be AISI 316, unless otherwise specified.
2. Erosion-resistant trim with hardened or hard-faced surfaces are required when the pressure drop across the valve exceeds 10 bar, the temperature is above 315C, the pressure drop across the valve exceeds 5 bar in steam service, or when there is a risk of flashing /incipient cavitation.
3. Cobalt-based alloys must not be used for hard-facing in boiler feed water and amine service.
4. Anti-cavitation trim is selected for high-pressure drop applications to prevent the onset of cavitation.
5. Anti-noise trim is selected for reducing the noise generated by the fluid.
6. Trim material for butterfly and gate valves may be the same as the body material.

Packing

1. The packing design for linear motion valves shall include a packing flange.
2. PTFE shall be used as standard packing material for bonnet temperature below 230C and graphite for higher temperatures. Higher temperatures can be accepted for PTFE if the bonnet is extended. Packing design and material shall be selected carefully for minimum stem friction and live-loading packing boxes shall be considered for PTFE packing.
3. Vacuum service and special services like oxygen, require special packing materials and should be given special consideration.

Example 4: Select the suitable materials for different control valve components with the following conditions:

1. An application in which we have the condensate passing through a control valve with 25% flashing and pressure drop of 40 bar. Since the pressure drop exceed above criteria and there is a risk of flashing or cavitation AISI 316/hard faced is selected for this application. Since the temperature is more than 230 C then graphite or equivalent is selected as packing for the valve.

Trim Material	Packing Material	Body Material
AISI 316 – Hard Face	Graphite	A217 WC9

2. Natural Gas with pressure drop of 2 bar across valve requires a pressure control valve to regulate the pressure. Since it is non-corrosive and typical application, A 216 WCB is selected for natural gas applications. Since the pressure drop does not exceed above criteria, the temperature is less than 315 and there is no risk of flashing or cavitation AISI 316 is selected for this application.

Trim Material	Packing Material	Body Material
AISI 316	PTFE	A216 WCB

3. A unit shut down valve shall be installed with adjacent piping size of 3 inch for an application in which we have water + dissolved CO_2. A 351 CF8 is selected for these applications since it contains dissolved gases such as CO2 and flashing occurs. Since there is incipient flashing AISI 316/hard faced should be selected.

Trim Material	Packing Material	Body Material
AISI 316 – Hard Face	PTFE	A 351 CF8

Here is an overview of control valves:

Condition / Valve Type	ΔP very high	Solid	V very high	CV high	Crystallization	Large Flow with lowΔP	Tight Shut-off up to 4 inch	Tight Shut-off above 4 inch	Standard
Angle	✓	✓	✓						
Butterfly						✓		✓	
Ball				✓	✓		✓		
Globe									✓

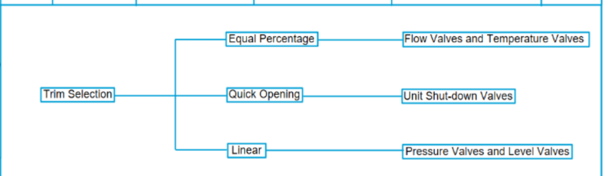
EXAMPLES

Ex. 1 : A condensate with pressure drop of 40 bar across valve in flashing state requires a flow control valve to regulate the flow

Valve Type : Angle

Trim Type : EQ%

Material : A217 WC9



Ex. 2 : Natural Gas with pressure drop of 2 bar across valve requires a pressure control valve to regulate the pressure.

Valve Type : Globe

Trim Type : Linear

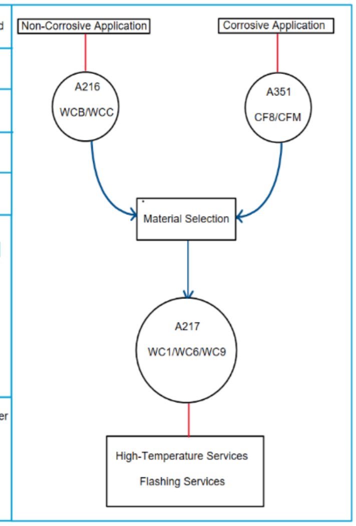
Material : A216 WCB

Ex. 3 : A unit shut-down valve shall be installed with adjacent piping size of 3 inch for an application in which we have water + dissolved CO_2.

Valve Type : Ball Valve

Trim Type : Quick Opening

Material : A351 CF8



Tanks

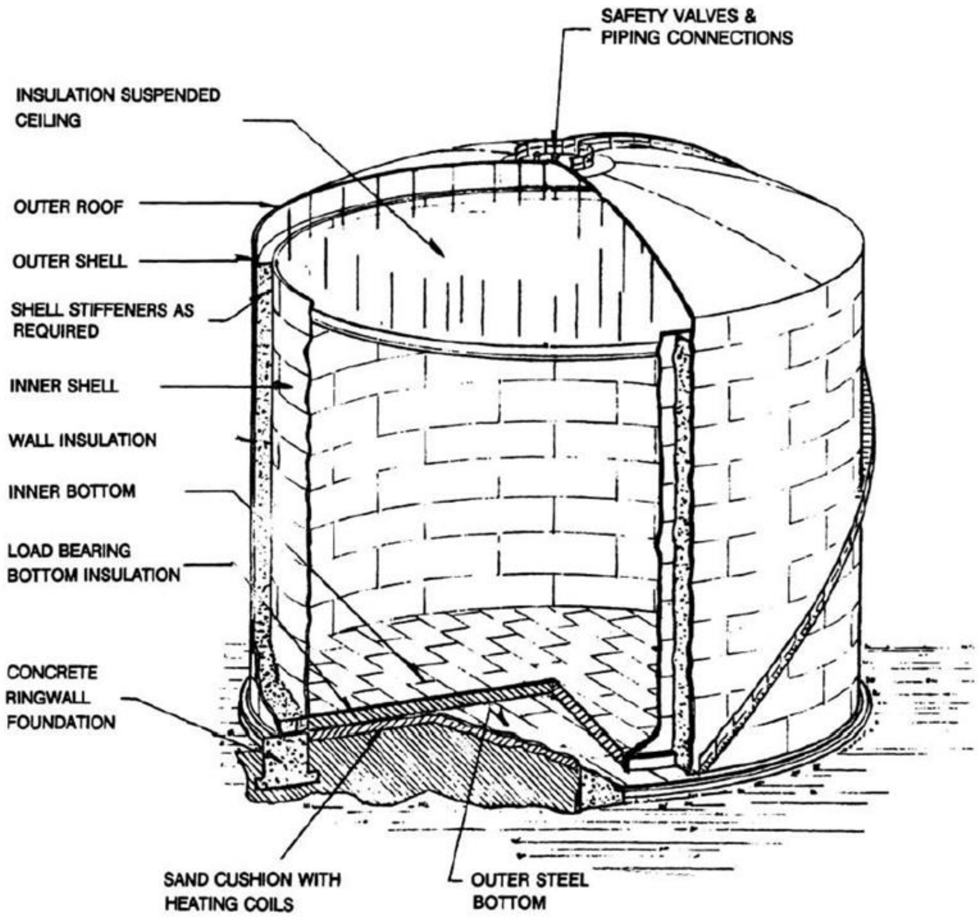


Figure 5.29 - Double wall tank for low-temperature service.

Storage tanks built in accordance with API 650 commonly are made of mild steel. API 653 contains requirements for tank inspection, repair, alteration and reconstruction. As discussed in Chapter 1, as a minimum 1.5 mm (1/16 in.) corrosion allowance normally is specified for storage tanks. Where experience indicates a 1.5 mm (1/16 in.) corrosion allowance is not adequate, internal linings usually are specified. Where tanks are lined internally and painted externally, a zero-corrosion allowance often is specified. Notch tough steel is required when the design metal temperature is 10°C (50°F) or below (lowest one-day mean temperature of 2°C [35"F] or below). High-strength steels sometimes are used in large diameter tanks to minimize cost by reducing the required thickness. Care should be exercised when selecting high-strength steels for fluids containing hydrogen sulfide because of the potential for SSC. As a minimum, the hardness of the welds should meet NACE RP0472.

Corrosion in Petroleum Storage Tanks

Corrosion in atmospheric storage tanks can be divided into three zones: (1) the tank roof, (2) the walls, and (3) the bottom. Corrosion on the underside of the tank roof is controlled by the relative amount of air and hydrogen sulfide, as well as the temperature. The worst condition is 0.5% hydrogen sulfide. Inorganic zinc coatings are used most commonly for corrosion protection of the roof area. Inert gas blankets also can be used to prevent corrosion in cone roof tanks. The corrosion rate as a function of tank wall height. Corrosion in light (API density 50 degrees or lighter) is higher than in heavier products because oxygen solubility is higher. Corrosion is high in the 80% to 90% level of the side wall. In floating roof tanks, corrosion is found in the area where the major travel of the floating roof occurs (often this is halfway up the tank).I8,I9This corrosion is a result of the oxygen that enters the tank around the roof seals, concentrating in the water layers on the gasoline just beneath the floating roofs. The scale formed in this area is then scraped away by the moving roof, exposing fresh metal to attack. Coatings usually are used to solve this corrosion problem. Tank bottom corrosion is a function of the water layer that exists on the bottom of most tanks. The presence of sulfate-reducing bacteria, characterized by shiny pits, is more of a problem in heavy stocks because oxygen cannot get to the bottom. Tank bottom corrosion is controlled by coatings and by draining the water from the tank bottom periodically. API RP 652 contains recommendations on lining above-ground petroleum storage tank bottoms. Both epoxy and polyester coatings reinforced with chopped glass fiber have been used successfully in places where severe corrosion has occurred. For new tanks in which corrosion is expected, coal tar epoxy usually is specified for the bottom. When the tank is on soil or other conductive media and water cannot be prevented from contacting the underside of the tank bottom, cathodic protection in accordance with NACE RP0193 normally is applied. In some locations double bottoms have been used in tanks to minimize leaks into the ground and to facilitate leak detection. The space between the two bottoms often is filled with sand. If the double bottom is a retrofit, accelerated corrosion of the new steel can occur because of the difference in corrosion potential of the new bare material and the old corroded material. Since it is almost impossible to seal the space between the two bottoms, a cathodic protection system usually is used to prevent corrosion.

Low-Pressure, Low-Temperature Tanks

Liquid ammonia, liquefied propane gas (LPG), and liquefied natural gas (LNG) would not be expected to cause corrosion problems since they are stored at low temperatures (-33"C, -42"C, and -162OC [-28"F,-40"F,a nd -260"FI respectively). However, there have been reports of SCC in fully refrigerated (-33°C [-F]) liquid ammonia storage tanks. Cantwell has reported SCC of LPG spheres as a result of trace amounts of hydrogen sulfide in the LPG.23 The primary concern in storing these fluids has been resistance to brittle fracture. Appendix A lists common materials suitable for the low temperatures at which these fluids are stored.

Water Storage Tanks

For tanks it is normal practice to have CS as the base material and a liner rubber or resistant painting as protection.