White Paper:

Materials Selection for SmartLine Pressure Transmitters

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Contents

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Introduction:

The materials selected and used in the construction of Honeywell pressure transmitters for process control systems in processing industries must be suitable for their applications and environments. It is well known the environments in pulp and paper, chemical, petroleum and gas processing industries can be very hostile in terms of temperature, stresses, and the corrosive and erosive nature of the process chemicals and fluids being handled and directly contacting to the materials of construction.

Therefore, the materials of construction directly contacting the chemicals and fluids must be resistant to those chemicals and fluids. For the parts not directly in contact with the chemicals and fluids, they will still interact with the atmosphere usually air with varying degrees of humidity, varying concentrations of corrosive gases, and corrosive contaminants from the chemicals and fluids.

Typical examples of corrosive gases and contaminants from natural, marine and industrial environments are listed in **TABLE 1.** These corrosive gases are not only the prime culprits to the corrosion of electronics but also play critical roles in the attack of metals. Active sulfur compounds including hydrogen sulfide (H_2S), elemental sulfur (S) and organic sulfur compounds rapidly attack silver, copper, aluminum, and steels, even present at a low level of parts per billion. The presence of moisture with small amounts of inorganic chlorine compounds and/or nitrogen oxides greatly accelerate sulfide corrosion. With the presence of moisture, chloride ions from chlorine compounds react readily with silver, copper, tin, and steels. Combustion products of fossil fuels, NO_x compounds (NO, NO_2, N_2O_4), provide a catalytic effect to the corrosion on base metals from chlorides and sulfides. Some of these gases form nitric acid can attack most common metals at the presence of moisture.

Proper selection of the materials in constructing components of a pressure transmitter is very important for the use of process control systems. The information presented here can be used as a guide to the selection of materials for Honeywell pressure transmitters to be able to function and perform well over a wide range of processes and applications. However, due to many factors affecting the performance of materials, the final responsibility of materials selection resides on the users who are the most knowledgeable to their specific processes and applications.

***Table 1: Examples of Corrosive and Contaminants in Natural, Marine and Industrial Environments* [1]**

Chemical	Sources	
Hydrogen Sulfide, H_2S	• Sewage treatment • Fossil fuel processing • Coke plants • Steel making processes	• Sulfuric acid manufacture • Geothermal emission • Pulp and paper processing
Sulfur Dioxide, SO_2	• Power generation • Fossil fuel processing • Sulfuric acid manufacture • Steel making processes	• Oil and gas processing • Automotive emissions • Pulp and paper processing
Chlorine, Cl_2 (Chloride Ions, Cl^-)	• Oceans • Sea coast regions	• Pulp and paper processing • Chlorine manufacture
Nitrogen oxides, NO_x	• Fossil fuel combustion • Automotive emissions	• Chemical industry

Chemical	Sources	
Sodium Chloride, NaCl	• Oceans • Sea coast regions	• Rubber processing • Food processing
Ammonia, NH_3	• Sewage treatment • Fertilizer manufacture	• Fossil fuel processing • Agricultural regions

Corrosion

Corrosion is most often defined as the deterioration of metallic materials and their properties by chemical or an electrochemical reaction/attack from environments. TABLE 2 lists the major factors influencing corrosion. Considering these factors, there are many techniques to mitigate or solve corrosion problems including proper materials selection and proper equipment design for the applicable service environments.

Whether the choice is to use corrosion-resistant materials or less expensive materials with protection coating, the basis of the selection requires consideration of economic factors and understanding of corrosion technology.

The understanding of the basic corrosion mechanisms is essential in materials selection for corrosive environment. Under hostile and harsh environments, it is important to select the materials of high resistance to uniform attack, outstanding localized corrosion resistance, excellent stress corrosion cracking resistance, and ease of welding and fabrication for the construction. The following sections are going to discuss the basics and mechanisms of corrosion on metals.

Table 2: Major Factors Influencing Corrosion

Corrosion Medium	• Chemical content • Concentration • Acidity, pH • Oxidizing power • Temperature	• Viscosity • Pressure • Agitation/stagnant • Solid deposits
Design	• Shape • Surface conditions • Assembly method (weld, riveted, bolted) • Proximity to other metals • Contact with a medium (total or partial immersion) • Methods of protection • Mechanical stresses	
Substrate Material / Coating	• Chemical composition; alloying elements • Manufacturing method (cast, forged, rolled, plated) • Metallurgical state (as-cast, heat-treated) • Protection coating • Inclusions • Impurities	
Service	• Aging of the structure • Modification of coating • Evolution of stresses • Temperature and humidity variability • Maintenance frequency	

Types of Corrosion

Most of the specific forms of corrosion on metals can be classified into two types: (1) electrochemical attack and (2) direct chemical attack. An electrochemical attack is from electrolytic reaction of anodic and cathodic changes taking place in a measurable distance apart on the metals. The direct chemical attack is a result of direct exposure of a bare metal surface to wet corrosive liquid or gaseous agents. The changes in direct chemical attack occur simultaneously at the same spot. The reaction in the electrochemical attack requires an electrolyte medium (usually water H_2O) capable of conducting a tiny electrical current. In both types of corrosion, the metal is converted into a metallic compound (such as: oxide, hydroxide, or sulfate) at the attack sites. The electrochemical corrosion process always involves two simultaneous changes. The metal attacked (or oxidized) suffers what is called anodic change and the corrosive agent is reduced of undergoing cathodic change.

Forms of Corrosion

There are many forms of corrosion depending on the metal or metals involved, size and shape of the part, its function, atmospheric conditions, and the corrosion media present. The major factors influence on the corrosion are summarized in **TABLE 2**. Despite there being many forms of corrosion, corrosion attacks can be categorized into generalized (or uniform) corrosion and localized (such as: pitting, crevice, under stress, and inter-granular) corrosion. Those described in the following sections are the common forms found in the pressure transmitter constructions.

Generalized (Uniform) Corrosion

Generalized (uniform) corrosion refers to a corrosion attack or deterioration of metal that proceeds at approximately the same rate and evenly distributed over the entire metal surface. It is also noted that most corrosion rate data available in literature for metals under different chemical attacks are typically based on uniform corrosion.

Galvanic Corrosion

Galvanic corrosion is an electrochemical attack when two metals of different potentials (bimetallic) are in electrical contact at the presence of an electrolyte. The less noble metal corrodes preferentially to another. Examples of galvanic potential series of metals and alloys are shown in **TABLE 3**. To cause bimetallic galvanic corrosion, three necessary conditions are required: (1) an electrolyte bridging the two metals, (2) electrical circuit connection between the metals, and (3) sufficient difference in galvanic potential between the two metals. Galvanic corrosion can be generalized or localized. The schematic in **FIGURE 1** shows a localized galvanic corrosion cell.

Table 3: Galvanic Potential Series of Metals and Alloys

+ Corroded end (lease noble, or anodic)
Magnesium Magnesium alloy Zinc
Aluminum (1100) Cadmium Aluminum 2024-T4 Steel or Iron Cast Iron Chromium-Iron (active) Ni-resist cast iron
Type 304 stainless steel (active) Type 316 stainless steel (active)
Lead-Tin solder Lead Tin
Nickel (active) Inconel nickel-chromium alloy (active) Hastelloy alloy C (active)
Brass (Cu-Zn alloys) Copper Bronze (Cu-Sn alloys) Copper-nickel alloy Monel nickel-copper alloy, 70Ni-30Cu
Silver Solder Nickel (passive) Inconel nickel-chromium alloy, 80Ni-13Cr-7Fe (passive)
Chromium-Iron (passive) Type 304 stainless steel (passive) Type 316 stainless steel (passive) Hastelloy alloy C (passive)
Silver Titanium Graphite Gold Platinum
– Protected end (most noble, or cathodic)

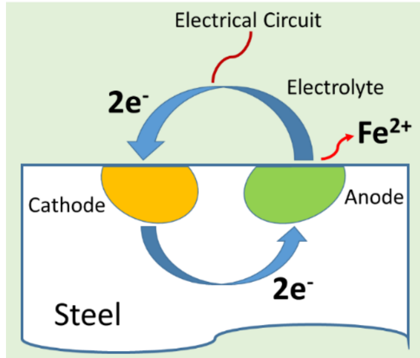


Figure 1: Schematic of a galvanic corrosion cell

The most common corrosion for carbon-iron steel is an oxygen-cell galvanic corrosion. The majority of iron element involves oxidation-reduction galvanic reactions in the presence of an electrolyte of water containing molecular oxygen and hydrogen ions associated with acids. A combination of a cathode, an anode and an electrolyte must be present to form the galvanic cell.

Oxidation (anode): $Fe \rightarrow Fe^{2+} + 2e^-$

Reduction (cathode): $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$

$2H^+ + 2e^- \rightarrow H_2$

The oxidation, or the loss of electrons by the anode, causes the steel surface to produce positive charged iron ions. These positively charged iron ions on the surface attract the negative ions in the electrolyte to form a new compound. The newly formed iron compound (rust or iron oxide) no longer has its original metal characteristics. The reduction, or the gain of electrons, occurs at the cathode. Galvanic corrosion of steel can be accelerated in the vicinity of metals (such as, copper and nickel) which are more noble or cathodic to the steel. Steel substrates are not always homogeneous and uniform from impurities as well various metallurgical and geometric imperfections. Numerous microscopic anode-cathode galvanic cell reactions can occur on the surface of the steel due to these impurities and imperfections.

To prevent and reduce galvanic corrosion, several effective prevention techniques have been applied in the industry. These include application of impermeable non-conductive protective coating, galvanizing with zinc to protect steel base material from zinc's sacrificial anodic action, and electroplating or coating of more noble metals to provide better corrosion resistance.

The techniques are applied to eliminate any one of the three necessary conditions for the galvanic corrosion to occur by (1) electrically insulating the two metals from contact with each other - no electrical bridging (2) ensuring no contact of metals to any electrolyte - no electrolyte, and (3) choosing metals having similar galvanic potential - no galvanic potential.

Pitting Corrosion

Pitting corrosion, or pitting, is a form of localized attack from galvanic corrosion that leads to small holes, cavities and pits in metal. Pitting is often difficult to detect since the pits may be covered by the corrosion products. For stainless steels, the attack often takes place at the locations where the passive layer is weakened by inclusions, imperfections, and/or damaged surfaces as well as at the spots of low-velocity or stagnant conditions resulting in concentrated corrosive. The attacks may occur in neutral or acid solution containing halides or primarily chlorides such as seawater.

Crevice Corrosion

Crevice corrosion is also a localized attack on metal surface at, or nearby to, a crevice or gap formed by two joining surfaces of either metal/metal or metal/non-metallic combination. The attack is induced by a localized concentration difference in some of chemical constituents in fluid, usually oxygen, which set up an electrochemical cell. Outside the crevice being cathodic, the oxygen content and the pH are higher accompanying with lower chlorides concentration. Inside the crevice being stagnant or low velocity, it becomes anodic and with higher chlorides concentration to worsen the situation. Ferrous ions can readily form ferric chloride and attack stainless steel rapidly.

Hydrogen Embrittlement

Atomic hydrogen can diffuse and become adsorbed and trapped inside metallic substrate during forming and finishing operations. If the hydrogen is not fully discharged, it can react with carbon in the steel to form methane or recombines to form hydrogen molecules to cause pressure/stress buildup within the metal lattice. It weakens and takes away the ductility of the metal and leads to embrittlement and even cracking of the metal.

Stress Corrosion Cracking

Stress corrosion cracking (SCC) is the cracking initialization, growth and propagation in metallic substrate induced by the combination of tensile stresses in the substrate and corrosive environment. The tensile stress can be from internal residual stress in the substrate resulted from manufacturing processes and/or from external sources. SCC can lead to unexpected sudden failure of normally ductile metals when subjecting to tensile stresses. The following two sections describe two most common tensile stress assisted corrosion from chloride and sulfide on passive alloys, such as stainless steels, in processing industries.

Passive Alloys and Chloride Induced Stress Corrosion

It is a common practice of using stainless steel or other passive alloys as construction materials to avoid galvanic corrosion to steel. Stainless steel contains minimum of 10.5% chromium and the surface of the steel is passivated with a very thin chrome-oxide film. The passivated film serves and protects the steel against acids to cause galvanic corrosion.

However, in the environments containing chloride ion, the chrome-oxide film can be broken down particularly near areas of tensile stresses (such as at welds where tensile stresses are present). The attacks at the sites of passivated film being breaking down and not self-healed can be continuously occurring.

Sulfide Stress Cracking

Sulfide stress corrosion is common in oil/gas exploration and production with hydrogen sulfide present. This corrosion attack also happens in the other applications, such as geothermal energy recovery and waste treatment, where considerable amounts of hydrogen sulfide are produced. Susceptible alloys, especially steels, are attacked and reacting with hydrogen sulfide to form metal sulfides and atomic hydrogen as a corrosion byproduct. Atomic hydrogen recombines to form hydrogen molecules on the surface or diffuses into metal substrate to cause hydrogen induced stress cracking and embrittlement of the metal.

CO_2 Corrosion

Carbon dioxide (CO_2) can be found in oil and gas fields at various concentrations. It can be absorbed and dissolved into water-containing fluid. The formation of weak carbonic acid and cathodic depolarization in the CO_2-containing fluid can be quite corrosive to steels. Corrosion attack on the material in contact with the fluid depends on several factors; such as, material type, operating conditions, water chemistry content, concentration of CO_2, and other compounds like H_2S.

Hydrogen Permeation

Hydrogen (H) is the simplest and smallest atom element in nature. Water, acids, bases and entire family of organic compounds all contain hydrogen. Hydrogen is normally found in diatomic state as a molecule composed of two hydrogen atoms (H_2). In this state, molecules will not penetrate the thin metal barrier diaphragms. However, if the hydrogen splits into two hydrogen ions (H^+ atoms), it can penetrate through barrier diaphragms because H^+ ions are smaller than the lattice space of the barrier diaphragm material.

To prevent hydrogen permeation through thin metal barrier diaphragm and then into fill fluid, a pure gold coating needs to be applied on the metal diaphragm surface to act as a diffusion barrier for hydrogen. The gold coating will significantly slow down and reject the permeation of most of the hydrogen ions (**FIGURE 2**).

In contrast, hydrogen ions can permeate through a bare diaphragm metal of no gold coating and then into fill fluid. The trapped hydrogen ions can form hydrogen gases and bubbles in the fill fluid to cause measurement deviation and damages on the diaphragm.

It is also known that the permeation rate of hydrogen ions depends on the process pressure and temperature. Higher temperature and higher pressure increase the permeation rate.

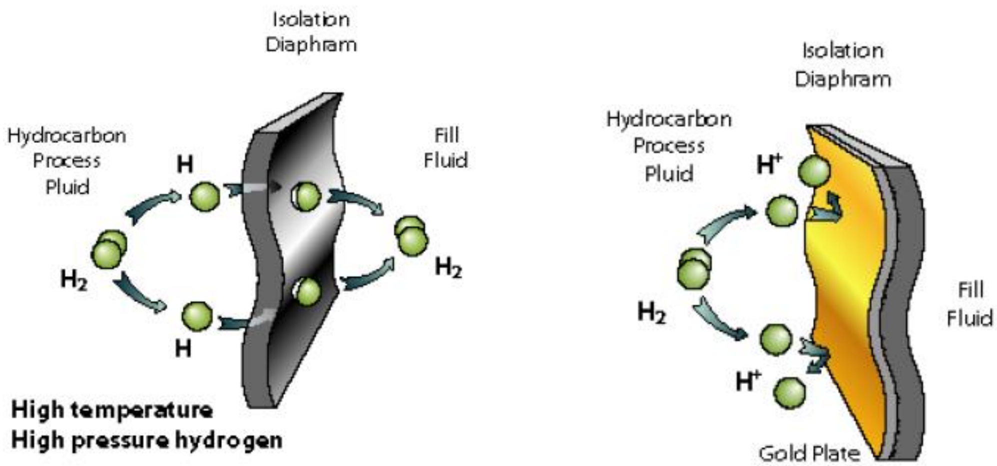


Figure 2: Schematics of hydrogen permeation through bare diaphragm metal (left) and then into fill fluid and hydrogen rejected at gold-plated surface (right).

Inter-granular Corrosion

Inter-granular corrosion is a form of localized corrosion where the vicinity of grain boundaries of metals is more susceptible to attack. The cause of the attack is from chemical segregation in the material along or at grain boundaries due to depletion or enrichment of one of the alloying elements. In the case of a stainless steel, the chromium depletion due to precipitation of chromium carbides along the gain boundaries can be subjected to inter-granular corrosion attack.

Erosion Corrosion

Erosion corrosion is an attack on metal surface due to the mechanical impingement from corrosive fluid. Metal is mechanically swept away and removed from the surface by the impingement as dissolved ions or a form of solid corrosion products.

Passivity of Metals and Coatings for Corrosion Resistance

A metal or an alloy is said to be in a passive state when the metal resists corrosion attacks in an environment where it reacts spontaneously and becomes substantially decreasing in free energy to a thermodynamically stable state. Some of the metals can be spontaneously passivated in air and their protective films have self-healing or self-passivating capability when damaged. The most important ones are chromium, titanium, tantalum, aluminum, and stainless steels among the metals. If the passive films are adherent and protective, the metals are protected from corrosion.

The spontaneous passivity is a prerequisite for the development and use of corrosion-resistant metallic materials. Spontaneous passivation takes place because the presence of the air-form film except when the material is exposed to highly oxidizing environments to enforce the formation of a passive film.
The corrosion resistance of an alloy is determined primarily by the composition of the passive film from its alloying makeup, passivity. The passivity is not a simple characteristic of a metal or an alloy. It is a characteristic with respect to a environment or environments being exposed to. The passive state can be temporary and unstable. Its stability depends on temperature, concentration, and the flow rate of the fluid being handled. Stainless steel alloys contain a minimum of 10.5% chromium, sufficient to form a thin and self-healing passive chrome-oxide film on the metal surface. This film is approximately 8 to 18 nm (80 to 180 Å) thick, tightly adhered and transient. It can be an oxide film, a mixture of oxides, or somewhat hydrated. Its stability in various environments can be improved and strengthened by alloying with other elements, such as manganese, molybdenum, and nickel. In the case of stainless steels, the partial pressure of oxygen in air is enough to form a compact and well-adhered film under normal atmospheric conditions.

Besides the corrosion protection from the formation of passive film on metals, corrosion resistant coatings (e.g. conversion coatings, organic coatings, and metallic thin and thick films by other coating techniques) have also been widely used to provide better corrosion resistance to less corrosion-resistant metallic components.

Zinc has inherently good corrosion resistance to normally prevailing atmospheres. However, because zinc is considerably more electronegative than iron, when the two metals are coupled in the presence of an electrolyte zinc tends to sacrificially dissolve, leaving the iron or steel un-corroded. Hence, it is used extensively to protect iron or steel, by coating it with zinc using a variety of processes (such as galvanizing from hot dip and electrodeposition). Zinc chromate is a chromate conversion coating on galvanized parts to make them more durable.

Schematics of Transmitter Assembly

A few schematic examples of pressure transmitter assembly will be shown in the next few sections to explain the importance of the parts and components in wetted and un-wetted conditions for selecting proper materials. The schematics example of dual head differential pressure transmitter assembly is shown in **FIGURE 3** including meter body, diaphragm, bolts/nuts, process head, vent bushing/plug, flange, and gasket under either wetted or non-wetted condition.

Material Option / Selection for Various Parts

The term "wetted parts" in this report is used for those parts, components and surfaces of the pressure transmitter assembly that are in direct contact and exposure to the process medium under pressure. Depending upon the corrosiveness of the medium, the wetted parts are subjected to a great risk of corrosion attacks by the medium if improper corrosion resistant materials are selected and used. The wetted parts in the transmitter assemblies can be internal seals, gaskets, welds, flanges, process heads/reference heads, drains, vents, plugs, and barrier diaphragms depending whether they are in direct contact and exposure to the process medium or not. The thin barrier diaphragm, under wetted conditions, requires special attention for its chemical compatibility to the process medium. Improper material selection for the thin diaphragm can result in fast failure of the diaphragm from corrosion attacks. Although those un-wetted parts are not in direct contact with the process medium, they are still exposed to the atmosphere affected by the hostile environment from process medium.

TABLE 4 lists the material options for various components in the differential pressure (DP) transmitter construction as shown in **FIGURE 3**. Corrosion resistant stainless steel 316L, Hastelloy C-276, Monel 400, zinc-plated carbon steel are the common materials used for both wetted and non-wetted components. The corrosion resistances and chemical compatibilities of these materials under various process fluids will be discussed later in the report.

Depending upon the design of the pressure transmitter assemblies, the transmitters can be installed in-line, threaded, flange mounted and/or connected to remote seals at various positions to complete the instrument installations for differential, gauge and/or absolute pressure measurements. The mounting of transmitters determines which parts, components and surfaces on the assemblies will be in direct contact and exposure to process medium to distinguish their wetted and un-wetted conditions.

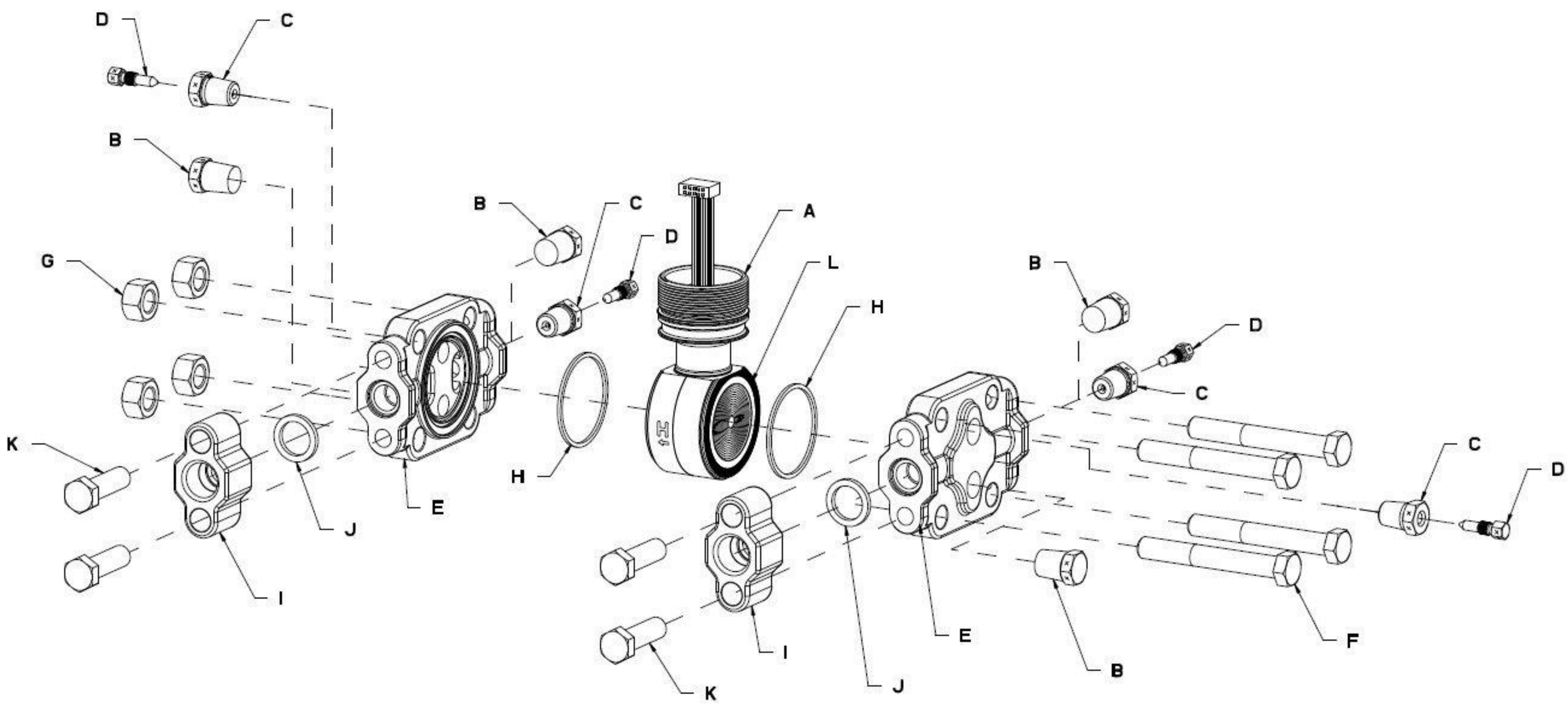
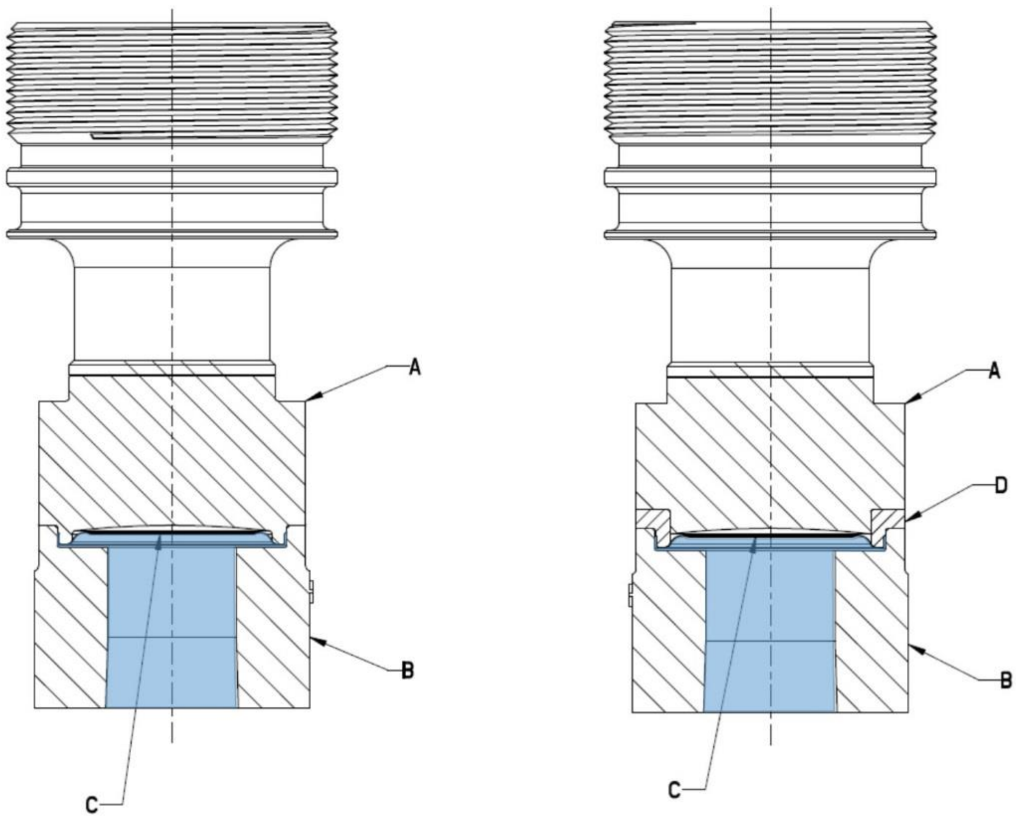


Figure 3: Schematics of dual head differential pressure (DP) transmitter assembly

Table 4: Material Options of Various Components in Differential Pressure (DP) Transmitter Construction

Drawing (Fig. 3)	Components	Wetted or Non-Wetted	Material Options
L	Barrier Diaphragm	Wetted	• 316L Stainless Steel • Hastelloy C-276 • Monel 400 • Tantalum • Gold-coated 316 Stainless Steel, Hastelloy C-276, or Monel 400
B, C, D	Pipe Plug, Vent Bushing, Vent Plug	Wetted	• 316L Stainless Steel • Hastelloy C-276 • Monel 400
E	Process Head	Wetted	• Carbon Steel (Zinc Plated) • 316L Stainless Steel • Hastelloy C-276 • Monel 400
I	Flange, Adapter	Wetted	Same as Process Head
A	Meter Body	Non-Wetted;	• 316 Stainless Steel
F, G, K	Bolts/Nuts for Process Head, Bolts for Flange Adapter	Non-Wetted	• Carbon Steel (Zinc Plated) • 316 Stainless Steel • 304 Stainless Steel • NACE A286 (Grade 660) SS Bolts with NACE 304 SS Nuts • NACE A286 (Grade 660) SS Bolts & Nuts • Monel K500 • Super Duplex • B7M
Not Shown	Mounting Bracket	Non-Wetted	• Carbon Steel (Zinc Plated) • 316 Stainless Steel • 304 Stainless Steel
Not Shown	Electronic Housing	Non-Wetted	• Stainless Steel • Polyester Powder Coated Low Copper (<0.4%) Aluminum
H, J	Gaskets for Process Head, Flange Adapter	Wetted	• PTFE glass-filled • Viton® • Graphite

Two different constructions of in-line transmitter are depicted in FIGURE 4 and their material options are listed in TABLE 5. The highlighted light blue regions in the drawings indicate the wetted area being directly in contact with processing medium. One of the constructions as shown in FIGURE 4(a) only has the selection of stainless steel 316 for barrier diaphragm, meter body and process head. A small part of the meter body near the diaphragm is exposed to the medium as shown in FIGURE 4(a). The other construction as shown in FIGURE 4(b) uses a more corrosion resistant material Hastelloy C-276 for both the diaphragm and the ring. The ring is constructed to prevent any portion of the 316 stainless steel meter body in contact with the medium. Either 316 stainless steel or Hastelloy C-276 can be selected for the process head.



(a) (b)

Figure 4: Schematics of dual head differential pressure (DP) transmitter assembly

Table 5: Material Options of Various Components for Two In-Line Pressure Transmitter Constructions

Drawing		Components	Wetted or Non-Wetted	Material Options
FIGURE 4(a)	C	Barrier Diaphragm	Wetted	316L Stainless Steel
	B	Process Head	Wetted	316L Stainless Steel
	A	Meter Body	Wetted;	316 Stainless Steel
FIGURE 4(b)	C	Barrier Diaphragm	Wetted	Hastelloy C-276
	B	Process Head	Wetted	• 316L Stainless Steel • Hastelloy C-276
	A	Meter Body	Non-Wetted;	316 Stainless Steel
	D	Ring	Wetted	Hastelloy C-276

Two examples of flange mounted transmitter assembly are shown in Figure 5 and FIGURE 6 for a pseudo flange mounted and a flange mounted with extended diaphragm construction, respectively. Their material options for the parts and components under wetted and non-wetted conditions are listed in TABLE 6. Examples of material options for wetted and non-wetted parts in remote seal construction are listed in TABLE 7.

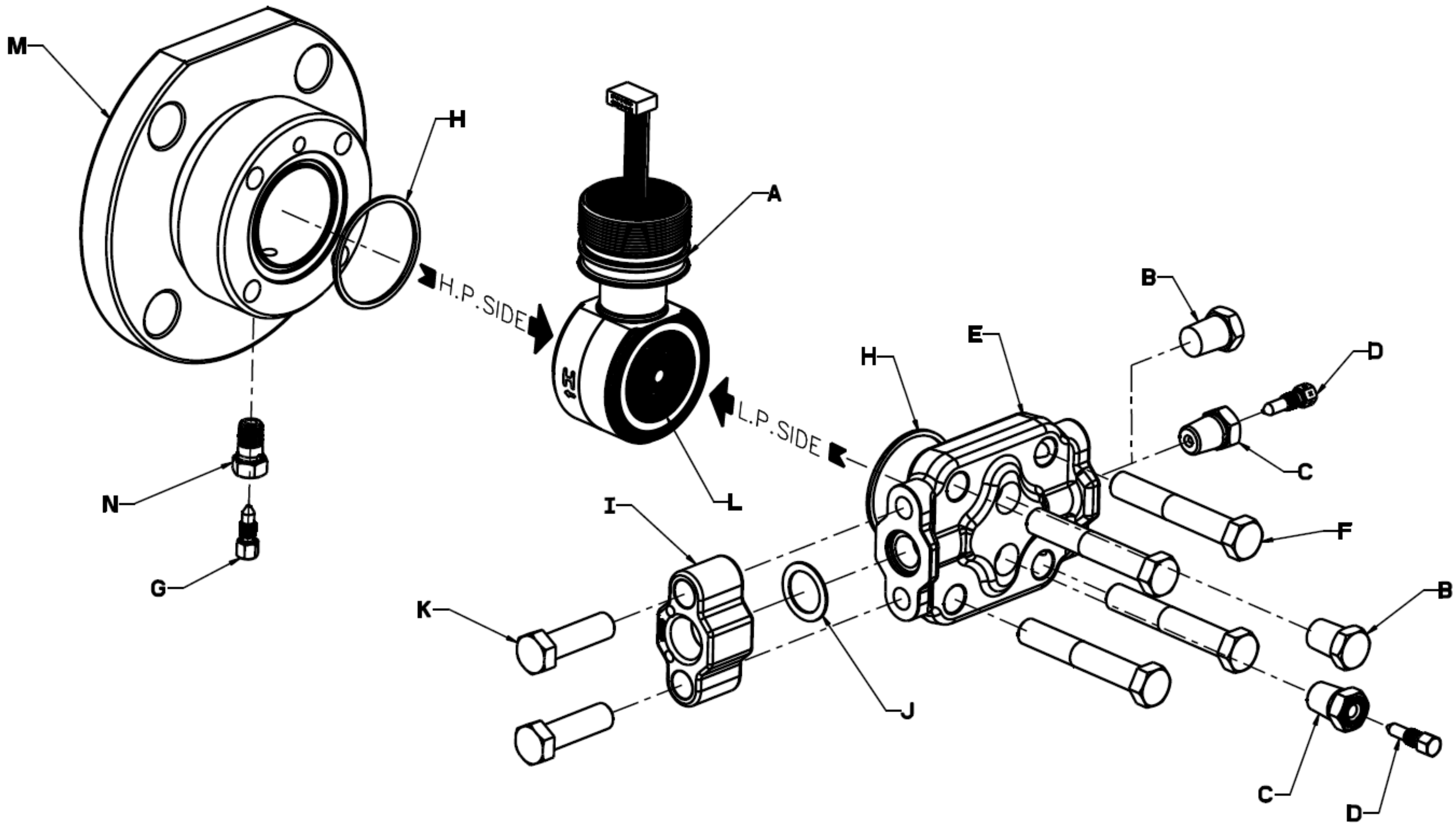


Figure 5: Schematics of pseudo flange mounted transmitter assembly

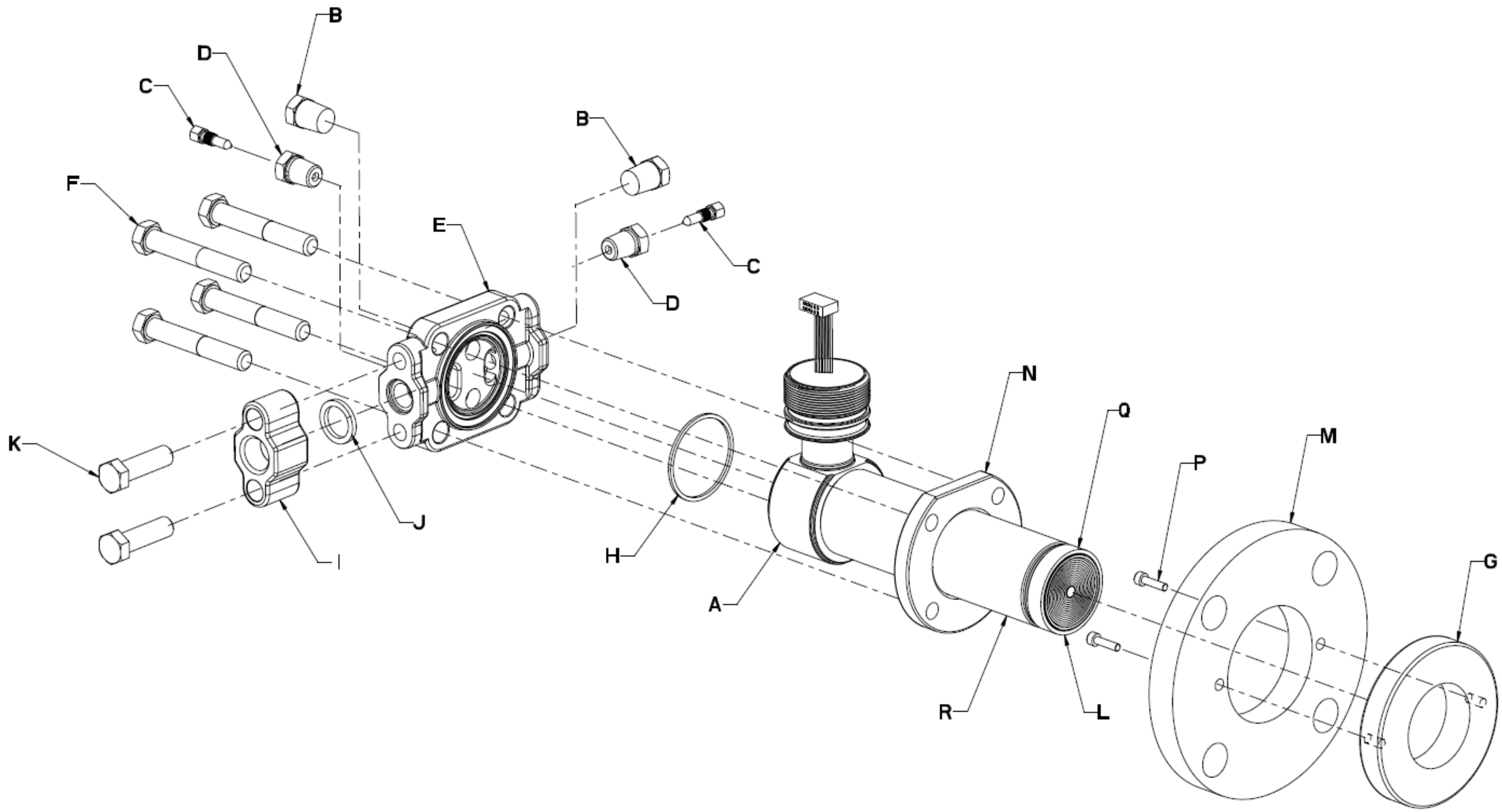


Figure 6: Schematics of flange mounted transmitter assembly of extended diaphragm

Table 6: Material Options of Various Components in Pseudo Flange and Flange Mounted with Extended Diaphragm Constructions

Design		Components	Wetted or Non-Wetted	Material Options
Pseudo **Drawing (Figure 5)**	**Extended Diaphragm** **Drawing (Figure 6)**			
L	L	Barrier Diaphragm[+]	Wetted	• 316L Stainless Steel • Hastelloy C-276
--	Q	Diaphragm Plate[+]	Wetted	• 316L Stainless Steel • Hastelloy C-276
A	A	Meter Body	Non-Wetted	• 316L Stainless Steel
B, C, D	B, C, D	Pipe Plug, Vent Bushing/Plug on Reference Head[+]	Wetted	• 316L Stainless Steel • Hastelloy C-276 • Matches Head Material
E	E	Process Reference Head[+]	Wetted	• Carbon Steel (Zinc Plated)[*] • 316 Stainless Steel • Hastelloy C-276
--	G	Gasket Ring	Wetted	• 316/316L Stainless Steel • Hastelloy C-276
--	R	Extension Tube	Wetted	316L Stainless Steel
M	M	Mounting Flange	Wetted (Pseudo Flange)	316L Stainless Steel
			Non-Wetted (Flush or Extended Diaphragm)	• Carbon Steel (Zinc Chromate Plated) • 304 Stainless Steel • 316 Stainless Steel
F	F	Bolts for Process Head	Non-Wetted	• Carbon Steel (Zinc Plated) • 316 Stainless Steel • NACE A286 (Grade 660) Stainless Steel Bolts & Nuts
Not Shown	Not Shown	Electronic Housing	Non-Wetted	• 316 Stainless Steel (Grade CF8M) • Polyester Powder Coated Low Copper (<0.4%) Aluminum
H	H	Gaskets	Wetted	• Teflon or PTFE (Glass-filled) • Viton or Fluorocarbon Elastomer
I	I	Flange, Adapter	Wetted	• The same as process reference head • Carbon Steel (Zinc Plated)[*] • 316 Stainless Steel • Hastelloy C-276
J	J	Gaskets, Process Head	Wetted	• Teflon or PTFE (Glass-filled) • Viton or Fluorocarbon Elastomer

[+] Referred to model selection for flush, extended, pseudo flange on material selection/combination of reference head, vent drain valve on reference head, and barrier diaphragm (an extension for extended model).

[*] Carbon steel heads are zinc-plated and not recommended for water service due to hydrogen migration.

Table 7Material Options of Various Components in Remote-Seal Pressure Transmitter Construction

Components	Wetted or Non-Wetted	Material Options
Seal Barrier Diaphragm	Wetted	• 316L Stainless Steel • Hastelloy C-276 • Monel 400 • Tantalum • Gold-coated 316 Stainless Steel, Hastelloy C-276, or Monel 400
Remote Seal Body	Wetted	• 316L Stainless Steel • Hastelloy C-276 • Monel 400
Seal Gasket	Wetted	• Klinger C-4401 (Non-Asbestos) • Grafoil • Teflon • Gylon 3510
Capillary Tubing	Non-Wetted	• Armored Stainless Steel • PVC Coated Armored Stainless Steel
Transmitter Meter Body & Diaphragm	Non-Wetted	316 Stainless Steel (Standard)
Adapter Head	Non-Wetted	In-Line Gauge: • 316 Stainless Steel Bonnet • 316 Stainless Steel for Close-Couple Dual Head DP: • 316 Stainless Steel (Bolt-on Heads) • 316 Stainless Steel for Close-Couple • 316 Stainless Steel with All-Welded Meter Body
Bolt/Nuts for Transmitter Head	Non-Wetted	• Carbon Steel (Zinc Plated) • 316 Stainless Steel Bolts/Nuts • NACE A286 Stainless Steel Bolts/304 Stainless Steel (NACE) Nuts
Mounting Bracket	Non-Wetted	• Carbon Steel (Zinc Chromate Plated) • 316 Stainless Steel • 304 Stainless Steel
Electronic Housing	Non-Wetted	• Stainless Steel • Polyester Powder Coated Low Copper (<0.4%) Aluminum

A remote seal (or diaphragm seal) is connected to the pressure transmitter using a direct connection or capillary. The chamber between the diaphragm seal and the transmitter contains system fill fluid that transfers the pressure of the process media to the transmitter. Only the remote seal is in contact with the process media. A remote seal is mounted to the process by thread, flanged, in-line, sanitary, or other connections. Similar to in-line and flange mounted transmitters, only the parts and components on the remote seals are in direct contact with the process media for the remote seal connections. Typical applications of using remote seals for the transmitters are the services where one or more of the following conditions exist:

- High process temperatures
- Viscous or suspended solids
- Highly corrosive process materials
- Sanitary applications

- Applications with hydrogen permeation possibilities
- Level applications with maintenance intensive wet legs
- Applications requiring remote transmitter mounting
- Tank applications with density or interface measurements

It is noted that the materials lists here in the tables may not reflect the current material options for the parts in the assemblies. Please refer to the current model specifications for available material options of wetted and non-wetted parts to meet your application requirements. Special attentions are also needed to look for parts, components and surfaces are exposed to wetted conditions in service for different types of transmitter assembly.

Materials Selection

FIGURE 7 shows the ranges of corrosion resistance for several highlighted corrosion resistant alloys/metals used in the construction of transmitters. It is adapted from ASM Materials Properties Handbook: Titanium Alloy. The most corrosion resistant tantalum can be used for a wide range of applications in both oxidizing and reducing chloride agents. Different applicable ranges are observed for the corrosion resistant alloys Hastelloy C, Monel and stainless steels under either chloride or non-chloride condition.

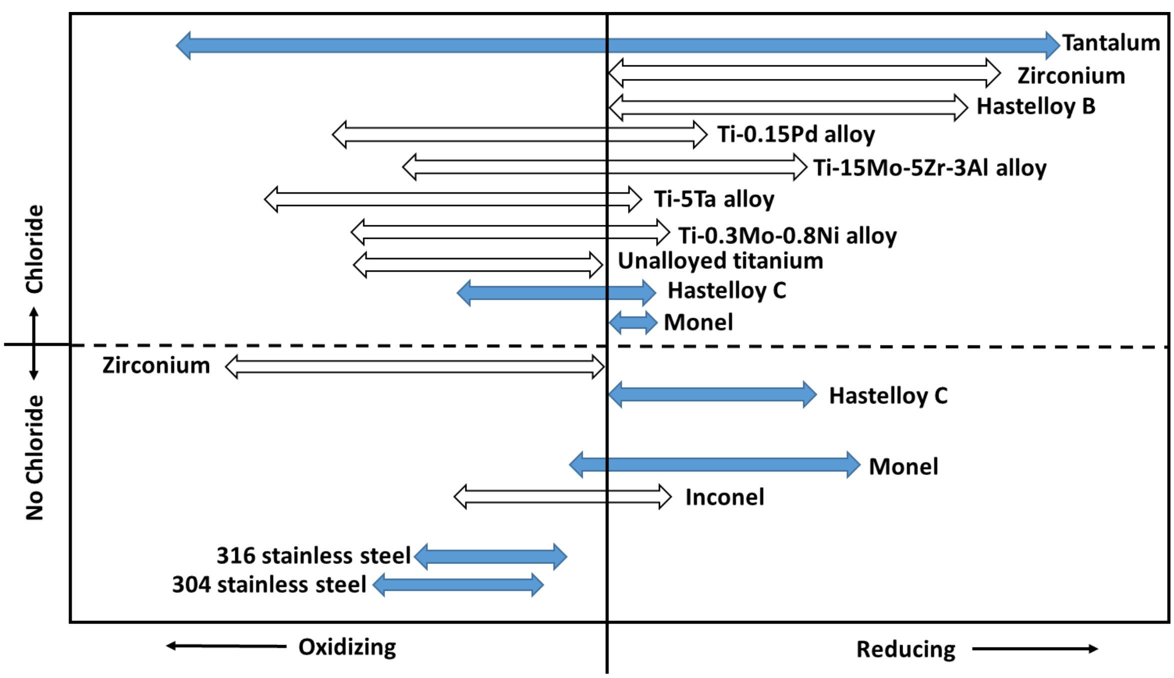


Figure 7: Range of corrosion resistance of metals [2]

8 summarizes the chemical resistance, typical applications and limitations of the common materials in transmitter construction. It is noted that the materials can be used in both wetted and non-wetted applications depending on their functions and exposed environments. Due to the nature of thin diaphragm material in construction, it is crucial to select a correct material compatible to the process for the diaphragm. A good practice in selection and use also requires to take into account the fabrication methods for the components (such as, casting, forming, machining, and welding) affecting the final structure, properties and corrosion resistance of the components. More specific details on the applications and the properties of the materials of construction are discussed in the following sections.

Seawater / Marine Environment

Under seawater or marine environment, the most obvious forms of corrosion on stainless steel are crevice and pitting corrosion. Both corrosion attacks are caused by the presence of chloride ions in a solution and are also influenced by temperature and oxidation strength of the fluid (e.g. chlorination). Crevice corrosion occurs at locations where there is a contact between two identical materials or between a metal and non-metal material (such as: gasket, washer, or deposits) from construction or contaminant accumulation. Compared to crevice corrosion, pitting can occur without any contact with another material. Pitting attacks often take place at locations where the passive layer of stainless steels is weakened by slag inclusions, a damaged surface or imperfections in the passive layer.
Once the attacks have started, the material can be completely penetrated within a short time. However, pitting attacks can be prevented through (1) proper selection of materials with known resistance to the service environment, (2) use higher alloys (ASTM G48) of increased resistance to pitting corrosion, and (3) control acidity pH value, chloride concentration and temperature of process fluid.

ERROR! REFERENCE SOURCE NOT FOUND.9 summarizes typical applications and limitations of 316 stainless steel, Alloy 400 and Hastelloy C-276 under marine environment. 316 stainless steel can be used in limited marine applications but is susceptible to pitting and crevice corrosion in warm seawater. Alloy 400 has been widely used in marine applications. It exhibits very low corrosion rates in flowing seawater, but crevice and pitting corrosion can be induced under stagnant conditions. C-276 is known as the most universally corrosion resistant material available today. Besides its resistance to a variety of environments from moderately oxidizing to strong reducing conditions, it exhibits excellent resistance to corrosion by seawater especially under crevice conditions.

Table 8: Summary of Corrosion Resistance, Typical Applications and Limitations for Various Materials

Application	Material	Corrosion Resistance / Typical Applications	Notes / Comments
Wetted and/or Non-Wetted	Hastelloy C-276	• Excellent resistance to corrosion by seawater especially under crevice conditions, which induce attack in other commonly used materials • Excellent resistance to pitting and crevice corrosion under reducing conditions in seawater and chloride salts • Can be used in many inorganic and organic chemical process • Resistance to wet chlorine and concentrated hypochlorite solutions • Good resistance to a wide range of non-oxidizing media (sulfuric, phosphoric, and acetic acids) • Good resistance to oxidizing acid mixture (nitric/sulfuric acid, chromic/sulfuric acid, sulfuric acid/copper sulfates, di-chromates, permanganates)	• Susceptible to hydrogen permeation • Gold coating to mitigate hydrogen permeation
	Monel 400 (Alloy 400)	• Resistance to many reducing media (fluorine, hydrofluoric acid, sulfuric acid, hydrogen fluoride and their derivatives) • Excellent resistant to seawater	• Not recommended for caustic liquor evaporators and concentrators • Susceptible to hydrogen permeation • Gold coating to mitigate hydrogen permeation
	316 Stainless Steel	• Extra-low carbon version 316L stainless steel minimizing harmful carbide precipitation due to welding • Exhibit better corrosion resistance than type 304 • Excellent pitting resistance and good resistance to most chemicals involved in the paper, textile and photographic industries • Good resistance to pitting and crevice corrosion in chloride-containing media, seawater, and chemical environments (such as sulfuric acid compounds, phosphoric and formic acids, and other organic acids) • Good resistance to neutral and alkaline salts, including those of a strongly oxidizing nature	• May develop stress corrosion cracking in chloride solutions under internal or external tensile stresses • Can be attacked by non-oxidizing acids (sulfuric acid and hydrochloric acid in most concentration) • Subject to pitting and crevice corrosion in warm chloride environments, and to stress corrosion cracking above 60°C (140ºF)
	Tantalum	• Excellent corrosion resistance to most acids (hydrochloric, nitric, phosphoric, sulfuric, acidic ferric chloride solutions), aqueous salt solutions, and organic chemicals	• Can be attacked by sulfur trioxide, hydrofluoric acid, and strong alkaline solutions • Can suffer embrittlement in service with hydrogen, or high temperature oxygen or nitrogen
Wetted Gasket	PTFE	• PTFE filled will glass fibers offers improved wear resistance	• Attacked by fluorine and hydrofluoric acid

Table 9: Summary of Corrosion Resistance of Various Alloys under Marine/Seawater Environment

Alloy	Applications / Limitations
316 SS	• Suitable for coastal service environments, splash zone application, and intermittent submersion in seawater • Susceptible to pitting and crevice corrosion in warm seawater • Not suitable for wetted parts under continuous submersion in seawater
Alloy 400	• Widely used in marine applications • Very low corrosion rate in flowing seawater • Induced pitting and crevice corrosion under stagnant seawater conditions
C-276	• Excellent resistance to corrosion by seawater especially under crevice conditions

Wetted and Non-Wetted Parts

Stainless Steel 316 and 316L (UNS S31600 and UNS S31603)

Stainless steel 304 (18Cr-8Ni) contains 18% chromium and 8% nickel while stainless steel 316 (16Cr-10Ni-2Mo) contains 16% chromium, 10% nickel and 2% molybdenum. Both 304 and 316 are austenitic stainless steels and perform best with corrosion resistance to those oxidizing conditions which are most harmful to ordinary steels and many non-ferrous metals and alloys. The addition of molybdenum in 316 provides resistance to pitting and crevice corrosion from chloride-containing media, seawater and chemical environments (such as sulfuric acid compounds, phosphoric, and acetic acids) and are also of increased strength at elevated temperature. However, it cannot provide the same resistance in warm seawater. 316L is an extra-low carbon version of 316 stainless steel that minimizes harmful carbide precipitation along grain boundaries, or sensitization, from welding and reduces the risk of inter-granular corrosion at welds. Both 316 and 316L stainless steels exhibit better corrosion resistance than 304. Their properties are similar to 304 except that they are somewhat stronger at elevated temperatures. However, they are subjected to pitting and crevice corrosion in warm chloride environments, and to stress corrosion cracking above about 60°C (140°F). The casting equivalent of 316 stainless steel is supplied as Grade CF8M.

Hastelloy C-276 (Alloy C-276, UNS N10276) Nickel Alloy

Nickel alloys are an important group of materials of construction because of their excellent corrosion resistance and strength. Alloy C-276 (54Ni-16Mo-16Cr) is a solid-solution strengthened nickel (nickel-molybdenum-chromium) alloy with a small amount of tungsten. Molybdenum and chromium are added into the alloy to improve its resistance to oxidizing. It is a versatile material resistant to generalized corrosion, stress corrosion cracking, pitting and crevice corrosion in a broad range of severe environments from moderately oxidizing to strong reducing conditions. The casting equivalent of C-276 is supplied as Grade CW12MW.

Alloy C-276 is among a few materials that can withstand hypochlorite and chlorine dioxide solutions up to 71°C (160°F) and wet chlorine gas to 38°C (100°F), which are commonly used chemicals in pulp and paper and in textile bleaching. It has excellent resistance to sulfuric, hydrochloric, and phosphoric acids. It can be used in many inorganic and organic chemical process applications. It is also resistant to sulfur dioxide and hydrogen sulfide.

C-276 has excellent resistance to localized attacks from stress corrosion cracking. It also shows excellent resistance to pitting and crevice attacks under reducing conditions in seawater and acid chloride salts. It resists carbide precipitation during welding to maintain corrosion resistance in the heat-affected zones of the weld. However, low Cr content in the alloy has limited its resistance when dealing with strong oxidizing environments, such as hot and concentrated nitric acid solutions.

Monel 400 (Alloy 400, UNS NO4400) Nickel-Copper Alloy

Monel 400 or Alloy 400 (67Ni-33Cu) is a single-phase solid-solution nickel-copper alloy. It offers superior resistance over a wide range of temperatures to many corrosive environments. Alloy 400 has been widely used in many applications in marine and chemical processing. Being a homogeneous single-phase solid-solution alloy, its corrosion resistance is better than nickel in reducing conditions and copper in oxidizing conditions. Overall, it has better corrosion resistance than either of its principal constituents.

Alloy 400 exhibits excellent resistance to corrosion attack by many reducing agents. It is one of the few alloys that can be used in contact with fluorine, hydrofluoric acid, hydrogen fluoride and their derivatives. Excellent corrosion resistance has been proven for the alloy in handling hydrofluoric acid of all concentrations up to the boiling point. It is resistant to many forms of sulfuric and hydrochloric acids under reducing conditions. Its resistance in seawater is also excellent.

Tantalum

Tantalum is a refractory metal and one of the most corrosion resistant ductile materials. Its excellent corrosion resistance has resulted from the formation of a protective oxide film (passivation) when exposed to normal atmospheric conditions. Tantalum is immune to corrosion attacks by salt solutions and many acids at temperatures close to their boiling points. However, it is subjected to hydrogen embrittlement in alkaline solutions. Its protective film is insoluble in most corrosive media except for sulfur trioxide, hydrofluoric acid, and strong alkaline solutions.

Gold-Plated Hastelloy C-276, Monel 400 or Stainless Steel 316

Hastelloy C-276, Monel 400 and 316 stainless steel are susceptible to the permeation of hydrogen through a thin diaphragm to cause permeated hydrogen gas being trapped in the fill fluid. The trapped hydrogen gas bubbles can severely affect the performance of transmitter and may cause cracking and failure of the barrier diaphragm. Plating these diaphragms with gold can greatly slow down and prevent the permeation of hydrogen on the diaphragms even under high process pressure and high temperature conditions. The gold coating is selected to protect the diaphragm against hydrogen permeation and at the same time it can provide additional chemical resistance.

Electronic Housing

Besides cast stainless steels, cast aluminum alloys are also used to construct the electronic housing. Alloying elements (such as: silicon, copper, and magnesium) are added to aluminum alloys to improve casting, strength, and machinability. However, preferential galvanic corrosion of aluminum matrix can occur due to large galvanic potential between copper and aluminum. The corrosion rate increases as the copper content increases. To provide the required corrosion resistance for the housing of transmitter, an aluminum alloy of low copper content (< 0.4%) is used with a polyester protection coating.

NACE MR0175/ISO 15156 and NACE MR0103 Compliance

To provide materials recommendations for sour services and applications containing hydrogen sulfide H_2S, the National Association of Corrosion Engineers (NACE) has developed two standards MR0175 and MR0103. NACE MR0103 "Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refining Environments" is used for downstream (refining and gas processing) environments or for other sour services where no brine or salt water is present. NACE MR0175 "Petroleum and natural gas industries – Material for use in H_2S-containing environments in oil and gas production – Parts 1, 2, and 3" is primarily developed for upstream sour oil and gas exploration and production containing brine or salt water.

In these environments, not only is hydrogen sulfide stress corrosion cracking a concern for the materials of construction, but also the presence of brine or salt water introduces the additional issue of chloride stress corrosion cracking. The NACE MR0175 is also globally recognized as ISO 15156 standard. Both NACE standards are used to ensure the materials of construction with appropriate resistance to sulfide stress corrosion. Honeywell transmitters are available with certification of compliance to both NACE standards at request. Certifications and traceability recorders of the materials in construction are also available as needed or at request. Please see **TABLE 4-7** for the examples of NACE compliant parts.

Bolts / Nuts

For non-wetted bolts and nuts, the material selections consist of 304 stainless steel, Monel K500, super duplex stainless steels and B7M, in addition to carbon steel and 316 stainless steel utilizing their high strength and corrosion resistance properties. Monel K500 is a precipitation hardened nickel-copper alloy with the addition of aluminum and titanium alloying elements. It has approximately three times the yield strength and double the tensile strength when compared to Monel 400 (nickel-copper alloy). ASME SA193 B7M is a modified version of B7 that is used for “sour service” (NACE MR0175) applications for environments exposed to the H_2S (hydrogen sulfide) from oil/gas fields.

Gasket

Chemical resistant plastic PTFE with glass fiber reinforcement, graphite, as well as chemical resistant elastomer Viton (fluoropolymer) are typically used for the process head gaskets depending upon process conditions. GYLON Style 3510 is a high performance, barium sulfate filled PTFE gasket material. It is designed for use in strong caustics and toxic chemicals, such as chlorine, ammonia, and phosgene, where initiating and maintaining an extremely tight seal is critical. GRAFOIL flexible graphite sealing material is made from pure, natural graphite flake. It is resistant to heat, fire, corrosion and chemicals. KLINGERSIL C-4401 is made from synthetic fibers with nitrile binder.

Materials Selection Chart

Corrosion and degradation on materials depend on many factors as shown previously in **TABLE 2**. Due to many factors affecting the process, the materials chemical compatibility chart can only be used as a guide and do not always apply to the actual process conditions at the end-user.

The final responsibility of material selection resides with the users who know their specific process conditions. These ratings are the compilation of property data from many sources all believed to be reliable, including handbooks, materials vendors and literature. However, the information accuracy of these ratings cannot be guaranteed.

In the chart, the ratings of corrosion resistance of metals are briefly described in ERROR! REFERENCE SOURCE NOT FOUND.**10.** Gasket materials use the similar ratings for their corrosion resistance but no A^+ rating for metals is used. A (acceptable), B (conditional), C (not recommended) and blank (no data) are rated based on their compatibilities to corresponding chemicals instead of the corrosion rate for metal. The chemical compatibility ratings for pure PTFE and glass fiber reinforcement materials are listed in two different columns. The chemical compatibility of glass fiber reinforced PTFE needs to combine two rating together.

Table 10: Ranking of Corrosion Resistance of Materials

Ranking	**Metals**		**Non-Metallics**
	Corrosion Resistance	**Corrosion Rate (mpy, mills per year)**	**Chemical Compatibility**
A^+	Excellent	< 2	
A	Good	> 2 and < 20	Resistant, acceptable
B	Conditional; process and temperature dependent, corrosion expected	> 20 and < 50	
C	Not recommended	> 50	Not recommended
Blank	No data		No data

				Process Head, Flange, Drain/Vent Plug, Extension				Barrier Diaphragm				Gasket			
Process Fluid	**Other Name / Formula**	Max. Fluid Temp. °F	Concentration %	Carbon Steel	316L Stainless Steel	Monel 400	Hastelloy C-276	316L Stainless Steel	Monel 400	Hastelloy C-276	Tantalum	Teflon (PTFE)	Viton	Graphite	Glass Fiber
Acetic Acid	$C_2H_4O_2$	200	>50	C	A	A	A	A	A	A^+	A^+	A	C	A	A
Acetic Acid	$C_2H_4O_2$	200	<50	C	A^+	A	A^+	A^+	A	A^+	A^+	A	C	A	A
Acetic Anhydride	$C_4H_6O_3$	200	-	C	A	A	A^+	A	A	A^+	A^+	A	C	A	A
Acetone	C_3H_6O	150	-	A	A^+	A^+	A^+	A^+	A^+	A^+	A^+	A	C	A	A
Acetylene (Dry)	C_2H_2	200	100	A^+	A^+	A^+	A^+	A^+	A^+	A^+	A^+	A	A	A	A
Acrolein	2-Propenal C_3H_4O	200	100	C	A	A	A	A	A	A	A	A	C		
Alcohols				A^+	A^+	A^+	A^+	A^+	A^+	A^+	A^+	A	A	A	A
Aluminum Chloride	$AlCl_3$	150	-	C	C	C	C	C	C	C	A	A	A	A	B
Aluminum Sulfate	Alum $Al_2(SO_4)_3$	150	<50	C	A^+	A	A^+	A^+	C	A^+	A^+	A	A	A	A
Aluminum Sulfate	Alum $Al_2(SO_4)_3$	150	>50	C	B	B	A^+	A^+	C	A^+	A^+	A	A	A	A
Ammonia Anhydrous	Ammonia NH_3	300	100	A	A^+	A^+	A^+	A^+	A^+	A^+		A	C	A	A
Ammonium Chloride	Sal Ammoniac NH_4Cl	200	10 - 20	C	A^+	A^+	A^+	A	A	A^+	A^+	A	A	A	A
Ammonium Chloride	Sal Ammoniac NH_4Cl	200	<10	C	A^+	A^+	A^+	A^+	A	A^+	A^+	A	A	A	A
Ammonium Hydroxide	Ammonia Water NH_3 in Water	200	<30	C	A^+	B	A^+	A^+ (< 70F)	C	A^+	C	A	C	A	A
Ammonium Nitrate	Norway Saltpeter NH_4NO_3	200	<50	A	A^+	B	A^+	A^+	C	A	A^+	A	C	A	A
Ammonium Sulfate	$(NH_4)_2SO_4$	200	<40	C	A^+	B	A^+	A	B	A	A^+	A	C	A	A
Amyl Acetate	$C_7H_{14}O_2$	250	-	A	A^+	A^+	A^+	A^+	A^+	A^+	A^+	A	C		
Aniline	$C_6H_5NH_2$	200	>99	A^+	A^+	A^+	A^+	A^+	A	A	A^+	A	C	A	A
Beer		200	-	A^+	A^+	A^+	A^+	A^+	A^+	A^+	A^+	A	C	A	A
Benzene	Benzol C_6H_6	200	<50	A^+	A	A^+	A^+	A	A^+	A	A^+	A	C	A	A

				Process Head, Flange, Drain/Vent Plug, Extension				Barrier Diaphragm				Gasket			
Process Fluid	**Other Name / Formula**	Max. Fluid Temp. °F	Concentration %	Carbon Steel	316L Stainless Steel	Monel 400	Hastelloy C-276	316L Stainless Steel	Monel 400	Hastelloy C-276	Tantalum	Teflon (PTFE)	Viton	Graphite	Glass Fiber
Benzoic Acid	$C_7H_6O_2$	200	<70	C	A	A	A+	A	A	A+	A+	A	A		
Black Liquor (Sulfate)		200	-	B	A	A	A+	A	A	A+	A+	A	A	A	
Boric Acid	H_3BO_4		10	C	A	A	A+	A	A	A+	A+	A	A	A	
Bromine (Dry)	Br	140	>99		B	B	B	C	C	C	A+	C	A	C	A
Bromine (Wet)	Br	140		C	B	B	B	C	C	C	A+	C	A	A	A
Bromobenzene	C_6H_5Br	200	>99	C	A	A	A	A	A	A	A	A	A		
Butadiene	Butylene C_4H_6	200	>99	A	A	A+		A	A		A+	A	C	A	B
Butane	C_4H_{10}	200	-	A+	A	A+	A	A	A+	A	A+	A	A	A	B
Butyl Alcohol	Butanol C_4H_9OH	200	-		A+	A+	A	A+	A+	A	A+	A	A	A	A
Butyric Acid	$C_4H_8O_2$	200	<10	C	A	B	A+	A	B	A+	A+	A	A		
Calcium Bisulfite	$Ca(HSO_3)_2$	250	>90	B	A	A+	A+	A	C	A	A+	A	A		
Calcium Chloride	$CaCl_2$	200	>50	A	A	A	A+	A	A	A+	A+	A	A	A	A
Calcium Chloride	$CaCl_2$	200	<50	A+	A	A	A+	A	A	A+	A+	A	A	A	A
Calcium Hydroxide	Slaked Lime $Ca(OH)_2$	200	>99	C	A	C	A+	A	C	A	A+	A	A		A
Calcium Hydroxide	Slaked Lime $Ca(OH)_2$	200	10	A	A	A	A+	A	A	A+	A+	A	A		A
Calcium Hydroxide	Slaked Lime $Ca(OH)_2$	200	30	C	A	C	A+	B	C	A+	A+	A	A		A
Calcium Hypochlorite	$Ca(OCl)_2$	75	<5	C	C	C	A	C	C	A	A+	A	A	A (90°F)	A
Carbon Dioxide (Gas)	CO_2	150		A+	A	A+	A+	A	A+	A+	A+	A	A	A	A
Carbon Monoxide (Gas)	CO	200	>99	A+	A+	A+	A+	A+	A+	A+	A+	A	A	A	
Chlorinated Water		70	<10 ppm	C	C	A	A+	C	B	A+	A+	A	A	A (73°F)	A
Chlorinated Water (To Saturation)		120	-	C	C	A	A+	C	B	A+	A+	C	C	A (73°F)	A

				Process Head, Flange, Drain/Vent Plug, Extension				Barrier Diaphragm				Gasket			
Process Fluid	Other Name / Formula	Max. Fluid Temp. °F	Concentration %	Carbon Steel	316L Stainless Steel	Monel 400	Hastelloy C-276	316L Stainless Steel	Monel 400	Hastelloy C-276	Tantalum	Teflon (PTFE)	Viton	Graphite	Glass Fiber
Chlorine Gas (Dry)	Cl_2	200	>99	C	A	A	A^+	B	A	A	A^+	C	A	A	A
Chlorine Gas (Wet)		160	>90	C	C	A	A	C	A	B	A^+	C	C	A	A
Chloroacetic Acid	$C_2H_3ClO_2$	150	<30	C	C	A	A	C	C	C	A	C	C		
Chloroform (Dry)	Trichloromethane $CHCl_3$	100	>99	A^+	A^+	A^+	A	A	A^+	A	A^+	A	C	A	
Chromic Acid	Chromium Trioxide H_2CrO_4	200	10 - 30	C	A	C	A	A	C	A	A^+	A	C	C	
Chromic Acid	Chromium Trioxide H_2CrO_4	200	<10	C	A	B	A	A	B	A^+	A^+	A	C	C	
Citric Acid	$C_6H_8O_7$	200	<50	C	A^+	A^+	A^+	A^+	A	A^+	A^+	A	A	A	A
Citric Acid	$C_6H_8O_7$	200	>50	C	C	A^+	A^+	C	A	A^+	A^+	A	A	A	A
Copper Nitrate	Cupric Nitrate $Cu(NO_3)_2$	200	<10	C	A^+	C	C	A^+	C	C	A^+	A	A	A	
Copper Sulfate	Cupric Sulfate $CuSO_4$	200	<40	C	A	C	A^+	A	C	A^+	A^+	A	A	A	A
Creosote	Coal-Tar	200	-	A	A	A	A	A	A	A	A^+	A	A		
Cresol	C_7H_8O	175	>99	B	A	A	A	A	A	A		A	A	C	A
Crude Oil (Sour)		<200	<5	A	A^+	A^+	A^+	A	A^+	A^+		A	A	A	A
Crude Oil (Sweet, Low Sulfur)		200	-	A	A^+	A^+	A^+	A	A^+	A^+		A	A	A	A
Cupric Chloride	$CuCl_2$	200	<5	C	C	C	A	C	C	A	A^+	C	C	A	
Dow Therm A Heat Transfer Fluid		300	-	A	A	A	A	A	A	A	A	A	C	A	
Ethyl Acetate	$C_4H_8O_2$	<200	-	A	A	A	A	A	A	A	A^+	A	C		A
Ethyl Alcohol	Ethanol C_2H_5OH	200		A	A	A	A^+	A	A	A^+	A^+	A	A	A	A
Ethyl Chloride (Dry)	C_2H_5Cl	<200	>99	A^+	A^+	A	A	A^+	A	A	A^+	A	A	A	A
Ethyl Chloride (Wet)	C_2H_5Cl	<200		C	A^+	A^+	A	A	A	B	A^+	A	A	A	A
Ethylene Glycol	Glycol $C_2H_6O_2$	200	>40	A	A	A	A^+	A	A	A^+	A^+	A	A	A	A

				Process Head, Flange, Drain/Vent Plug, Extension				Barrier Diaphragm				Gasket			
Process Fluid	**Other Name / Formula**	Max. Fluid Temp. °F	Concentration %	Carbon Steel	316L Stainless Steel	Monel 400	Hastelloy C-276	316L Stainless Steel	Monel 400	Hastelloy C-276	Tantalum	Teflon (PTFE)	Viton	Graphite	Glass Fiber
Ethylene Oxide	ETO C_2H_4O	100	>99	B	A	A	A^+	A	B	A^+		A	C		
Ferric Chloride	$FeCl_3$	100	<40	C	C	B	A	C	C	A^+	A^+	A	A (170°F)	A	A
Ferric Chloride	$FeCl_3$	200	<40	C	C	C	C	C	C	C	A^+	A	A (170°F)	A	A
Ferric Sulfate	$Fe_2(SO_4)_3$	150	<5	C	A^+	C	A^+	A^+	C	A^+	A^+	A	A (170°F)	A	A
Ferrous Chloride	$FeCl_2$	200	10	C	C	C	A	C	C	A	A^+	A	A (170°F)	A	
Ferrous Sulfate	$FeSO_4$	200	10	B	A	C	A	A	C	A	A^+	A	A (170°F)	A	
Fluorine Gas (Dry)	F_2	200	>99	B	A	A^+	A	A^+	A^+	A	C	A	A	A (300°F)	C
Fluorine Gas (Wet)	F_2	200		C	C	C	A	C	C	A	C	A	A	A (300°F)	C
Fluorosilicic Acid	Fluosilicic Acid H_2SiF_6	140	<30	C	A	B	B	A	B	B	C	A	B	A	
Formaldehyde	CH_2O	200	40	C	A^+	A	A	A^+	A	A	A^+	A	A	A	A
Formic Acid	CH_2O_2	100	>50	C	A^+	B	A^+	A	B	A^+	A^+	A	C	A	A
Formic Acid	CH_2O_2	100	<50	C	A	B	A^+	B	B	A^+	A^+	A	C	A	A
Formic Acid (Hot)	CH_2O_2	150	>50	C	B	B	A	C	C	B	A^+	A	C	A	A
Formic Acid (Hot)	CH_2O_2	150	<50	C	A	A	A	B	B	A	B	A	C	A	A
Furfural	$C_5H_4O_2$	200	<10	A	A	A	A	A	A	A	A^+	A	C		
Gasoline		200	-	A^+	A^+	A^+	A^+	A^+	A^+	A^+	A^+	A	A	A	A
Glucose	Corn Syrup $C_6H_{12}O_6$	300	-	A	A^+	A^+	A^+	A^+	A^+	A^+	A^+	A	A		
Glycerine	Glycerol $C_3H_5(OH)_3$	200	-	C	A^+	A^+	A^+	A^+	A^+	A^+	A^+	A	A	A	A
Hexane (Dry)	C_6H_{14}	200	>99	A	A^+	B	A^+	A^+	B	A^+	A^+	A	A	A	A
Hydrazine	N_2H_4	100	-	C	C	C	C	C	C	C	C	A	C	A	C
Hydrobromic Acid	HBr	140	-	C	C	C	C	C	C	C	A^+	A	A	A	A
Hydrochloric Acid	Muriatic Acid HCl	100	<1	C	C	A	A	C	A	A	A^+	A	A	A	A

				Process Head, Flange, Drain/Vent Plug, Extension				Barrier Diaphragm				Gasket			
Process Fluid	**Other Name / Formula**	Max. Fluid Temp. °F	Concentration %	Carbon Steel	316L Stainless Steel	Monel 400	Hastelloy C-276	316L Stainless Steel	Monel 400	Hastelloy C-276	Tantalum	Teflon (PTFE)	Viton	Graphite	Glass Fiber
Hydrochloric Acid	Muriatic Acid HCl	100	>2	C	C	C	B	C	C	C	A^{+}	A	A	A	A
Hydrofluoric Acid	HF	120	>50	C	C	A^{+}	A	C	A	A	C	C	A	A	C
Hydrofluoric Acid	HF	120	<50	C	C	A^{+}	A^{+}	C	A	A	C	C	A	A	C
Hydrofluosilic Acid	Fluosilicic Acid	140	<30	C	A	B	B	A	B	B	C	A	B	A	
Hydrogen Gas	H_2	200	-	A^{+}	A^{+}	A^{+}	A^{+}	A^{+}	A^{+}	A^{+}	A^{+}	C	A		A
Hydrogen Peroxide	H_2O_2	100	<30	C	A	B	A^{+}	A	B	A	A^{+}	A	C	A	A
Hydrogen Sulfide (Dry)	H_2S	140	-	B	A^{+}	A^{+}	A^{+}	A^{+}	A	A	A^{+}	C	C	A	A
Hydrogen Sulfide (Wet)	H_2S	140	-	A	A	A^{+}	A^{+}	A	C	A^{+}	A^{+}	C	C	A	A
Kerosene	Kerosine	200	>99	A^{+}	A	A	A^{+}	A	A	A^{+}	A^{+}	A	A	A	A
Latic Acid	$C_3H_6O_3$	<100	10	C	A	B	A	A	B	A	A^{+}	A	A	A	
Latic Acid	$C_3H_6O_3$	<100	5	C	A^{+}	C	A	A^{+}	C	A	A^{+}	A	A	A	
Latic Acid (Hot)	$C_3H_6O_3$		10	C	A	C	A	A	C	A	A^{+}	A	A	A	
Magnesium Chloride	$MgCl_2$	200	5	A	A	A	A^{+}	A	A	A^{+}	A^{+}	A	A	A	A
Magnesium Sulfate	Epsom Salts $MgSO_4$	200	<40	A	A	A^{+}	A	A	A^{+}	A	A^{+}	A	A	A	A
Mathanol	CH_3OH			A^{+}	A^{+}	A^{+}	A^{+}	A	A	A^{+}	A^{+}	A	C	A	
Mercuric Chloride	$HgCl_2$	100	<2	C	A	C	A	A	C	B	A^{+}	A	A	A	
Mercuric Chloride	$HgCl_2$	200	<2	C	A	C	B	A	C	C	A^{+}	A	A	A	
Mercury	Quicksilver Hg	200	>99	C	A^{+}	A	A^{+}	A^{+}	A	A^{+}	A^{+}	A	A	A	
Methane (Dry, No H_2S)	CH_4	200	-	A	A^{+}	A^{+}	A^{+}	A^{+}	A^{+}	A^{+}	A^{+}	A	A		A
Methyl Ethyl Ketone	M.E.K.	120	>99	A	A	A	A	A	A	A	A	A	C	A	
Milk				A	A^{+}	C	A	A^{+}	C	A	A^{+}	A	A		A
Morpholine	C_4H_8ONH	200	>99	B	A			A				A	C		
Naphtha		200	>99	B	A	A	A	A	A	A	A	A	A		
Naphthalene	Tar Camphor $C_{10}H_8$		>99	A	A^{+}	A	B	A^{+}	A	B	A	A	A		
Natural Gas (Liquid)		150		A^{+}	A^{+}	A^{+}	A^{+}	A^{+}	A^{+}	A^{+}	A^{+}	A	A		A
Nickel Chloride	$NiCl_2$	200	<80	C	B	B	A^{+}	B	B	A^{+}	A	A	A	A	
Nickel Sulfate	$NiSO_4$	200	-	C	A	B	A	A	B	A	A^{+}	A	A	A	

Process Fluid	Other Name / Formula	Max. Fluid Temp. °F	Concentration %	Process Head, Flange, Drain/Vent Plug, Extension				Barrier Diaphragm				Gasket			
				Carbon Steel	316L Stainless Steel	Monel 400	Hastelloy C-276	316L Stainless Steel	Monel 400	Hastelloy C-276	Tantalum	Teflon (PTFE)	Viton	Graphite	Glass Fiber
Nitric Acid	HNO_3	200	<20	C	A^+	C	C	A	C	C	A^+	A	C	A	A
Nitric Acid	HNO_3	<100	<20	C	A^+	C	A	A^+	C	C	A^+	A	C	A	A
Nitric Acid	HNO_3	boiling	<65	C	A	C	C	C	C	C	A^+	A	C	A	A
Nitric Acid	HNO_3	<100	<95	C	C	C	C	C	C	C	A^+	A	C	C	A
Nitric Acid (Fuming)	HNO_3	<100	<95	C	A^+	C	A	A^+	C	A	A^+	A	C	C	A
Nitrous Oxide	Laughing Gas N_2O	<100	>97	A	A	C	A	A	C	A	A^+	A	C	A	
Oleic Acid	$C_{18}H_{34}O_2$	200	-	B	A^+	A	A	A^+	A	A	A	A	C	A	A
Oxalic Acid	$C_2H_2O_4$	100	<10	C	A	A	A	A	B	A	A^+	A	A	A	A
Oxalic Acid	$C_2H_2O_4$	200	<10	C	A	A	A	A	B	A	A^+	A	A	A	A
Oxalic Acid	$C_2H_2O_4$	200	<50	C	A	A	B	A	B	B	A^+	A	C	A	A
Oxygen Gas	O_2	120	-	A	A^+	A^+	A^+	A^+	A^+	A^+	A^+	A	C	A	A
Ozone	O_3	120	<8	C	A	A		A	A			A	A	C	A
Palmitic Acid	$C_{16}H_{32}O_2$	160	>99	C	A	B	B	A	C	B		A	A	A	
Phenol	Carbolic Acid C_6H_6O	120	>90	A	A^+	A^+	A^+	A^+	A^+	A^+	A	A	A	A	A
Phosphoric Acid	H_3PO_4	100	>50	C	A	C	A	B	C	A	A^+	A	A	A	A
Phosphoric Acid	H_3PO_4	100	<50	C	A^+	C	A^+	A^+	C	A^+	A^+	A	A	A	A
Phosphoric Acid	H_3PO_4	boiling	<10	C	B	C	B	B	C	B	A^+	A	A	A	A
Phosphoric Acid	H_3PO_4	boiling	50 - 85	C	B	C	C	B	C	C	A^+	A	A	A	A
Phthalic Anhydride	$C_8H_4O_3$	200	>99	A	A^+	A^+	A^+	A^+	A^+	A^+	A^+	A	A		A
Picric Acid	$C_6H_3N_3O_7$	100	<10	C	A	C	A	B	C	B	A^+	A	A		
Potassium Chloride	KCl	200	30	C	A^+	A^+	A^+	A^+	A	A^+	A^+	A	A	A	A
Potassium Hydroxide	KOH	200	50	C	B	A	A	B	A	A	C	A	C	A	A
Potassium Hydroxide	KOH	160	50	C	A	A^+	A	A	A^+	A	C	A	C	A	A
Potassium Hydroxide	KOH	175	30	C	A	A^+	A	A	A^+	A	C	A	C	A	A
Potassium Nitrate	Saltpeter KNO_3	200	<50	A	A	A	A	A	A	A	B	A	A	A	
Potassium Nitrite	KNO_2	200	<5		A	A	A	A	A	A	A	A	C		

				Process Head, Flange, Drain/Vent Plug, Extension				Barrier Diaphragm				Gasket			
Process Fluid	**Other Name / Formula**	Max. Fluid Temp. °F	Concentration %	Carbon Steel	316L Stainless Steel	Monel 400	Hastelloy C-276	316L Stainless Steel	Monel 400	Hastelloy C-276	Tantalum	Teflon (PTFE)	Viton	Graphite	Glass Fiber
Potassium Permanganate	$KMnO_4$	140	<20	A	A	A	A	A	A	A	B	A	A		A
Propane	C_3H_8	200	>99	A^+	A^+	A^+	A^+	A^+	A^+	A^+	A^+	A	A	A	A
Rosin (Molten)		200	-	C	A^+	A^+	A^+	A	A^+	A^+	A^+	A	A		A
Sea Water	Ocean Water	200	-	C	C	B	A	C	B	A	A	A	A	A	A
Sewage (Raw)		100	-	A^+	A^+	A^+	A^+	A^+	A^+	A	A^+	A	A	A	A
Silver Nitrate	$AgNO_3$	200	<50	C	A^+	C	B	A	C	B	A^+	A	A	A	
Skydrol		200	100	C	A	A	A	A	A	A	A	A	C		
Sodium Bicarbonate	Baking Soda $NaHCO_3$	<200	<20	C	A^+	A^+	A^+	A^+	A^+	A^+	A^+	A	A	A	A (160°F)
Sodium Bisulfate	$NaHSO_4$	<160	<30	B	B	A	A	C	A	A	A^+	A	A	A	A (160°F)
Sodium Bisulfite	$NaHSO_3$	<150	<40	C	A^+	A	A	A	A	A	A^+	A	A	A	
Sodium Carbonate	Soda Ash Na_2CO_3	<200	<25	B	A	A^+	A	A	A^+	A	A^+	A	A	A	A (160°F)
Sodium Chloride	Table Salt NaCl	<200	<30	B	A	A^+	A^+	A	A^+	A^+	A^+	A	A	A	A (160°F)
Sodium Chromate	Na_2CrO_4	<200	<60	A	A	A	A	A	A	A	A	A	C	C	
Sodium Cyanide	NaCN	<140	-	B	A^+	C	A	A	C	A	A	A	A	A	
Sodium Dichromate	S. Bichromate $Na_2Cr_2O_7$	70	<20	A	A		A	A		A	A	A	A (160°F)	A	
Sodium Hydroxide	Caustic Soda NaOH	<175	<40	C	A^+	A^+	A^+	A	A	A	C	A	C	A	C
Sodium Hydroxide	Caustic Soda NaOH	<175	40 - 70	C	A	A^+	A^+	B	A^+	A^+	C	A	C	A	C
Sodium Hypochlorite	NaOCl	120	10	C	C	C	A	C	C	A	A	A	A		
Sodium Nitrate	Chile Saltpeter $NaNO_3$	<200	<40	A	A^+	A	B	A^+	A	B	A	A	A	A	A
Sodium Nitrite	$NaNO_2$	<200	<40	B	A	A	A	A	A	A	A	A	C	A (100°F)	
Sodium Peroxide	Na_2O_2	<200	<10	C	A	A	A	A	A	A		A	A		A
Sodium Phosphate (Alkaline)	TSP Na_3PO_4	<200	-	A	A	A	A	A	A	A	A	A	A	A	A

				Process Head, Flange, Drain/Vent Plug, Extension				Barrier Diaphragm				Gasket			
Process Fluid	**Other Name / Formula**	Max. Fluid Temp. °F	Concentration %	Carbon Steel	316L Stainless Steel	Monel 400	Hastelloy C-276	316L Stainless Steel	Monel 400	Hastelloy C-276	Tantalum	Teflon (PTFE)	Viton	Graphite	Glass Fiber
Sodium Silicate	Water Glass	<200	-	A	A	A	A	A	A	A	A	A	A	A	
Sodium Sulfate	Na_2SO_4	<200	<30	A	A^+	A	A	A	B	B	A^+	A	A	A	A
Sodium Sulfide	Na_2S	<200	50	C	A	A	A	A	A	A	A	A	A	A	
Sodium Sulfite	Na_2SO_3	<200	10	C	A^+	A	A^+	A^+	A	A	A^+	A	A (170°F)	A	
Sodium Thiosulfate	$Na_2S_2O_3$	<175	<20	C	A	B	B	A	B	B	A^+	A	A	A	A
Sour Gas / Oil		150	<5				A^+			A^+		A	C	A	
Stannous Chloride	Tin Dichloride $SnCl_2$	<175	<20	C	A^+	C	A^+	A^+	C	A^+	A^+	A	A	A	
Steam		<300	-	A^+	A^+	A^+	A^+	A^+	A^+	A^+	A^+	A	C	A	A
Stearic Acid	$C_{18}H_{36}O_2$	<200	-	C	A^+	C	A^+	A^+	C	A^+	A	A	C	A	A
Stoddard's Solvent		<100	-	A	A	A	A^+	A	A	A^+		A	A	A	A
Sulfur	S	250	>95	C	A^+	A^+	A^+	A	A	A^+	A^+	A	A	A	
Sulfur Dioxide (Dry)	SO_2	140	-	A	A	A	A	A	A	A	A^+	A	A	A	A
Sulfur Dioxide (Wet)	SO_2	140	-	C	A	C	A	A	C	A	A^+	A	A	A	A
Sulfur Trioxide (Dry)	SO_3	140	>99	A	A	A	A	A	A	A	C	A	A	C	
Sulfuric Acid	H_2SO_4	<175	<50	C	C	C	A	C	C	A	A	A	C	A	A
Sulfuric Acid	H_2SO_4	<175	>95	C	C	C	A	C	C	A	A	A	C	C	A
Sulfuric Acid	H_2SO_4	boiling	10	C	C	C	C	C	C	C	A	A	C	A	A
Tannic Acid	Tannin $C_{76}H_{52}O_{46}$	<150	-	C	A	A	A	A	A	A	A	A	A	A	A
Tartaric Acid	$C_4H_6O_6$	<150	<50	C	A^+	A	A	A^+	A	A	A^+	A	A	A	A
Tin Chloride	Stannous Chloride $SnCl_2$	<175	<20	C	A^+	C	A^+	A^+	C	A^+	A^+	A	A	A	
Toluene	Toluol C_7H_8	<200	>99	A^+	A^+	A^+	A^+	A^+	A^+	A^+	A^+	A	A	A	A (150°F)
Trichloroacetic Acid	$C_2HCl_3O_2$	<200	<50	C	C	A	A	C	A	A	A	A	C	A	A
Trichloroethane 1,1,1 (Dry)	Methyl Chloroform $C_2H_3Cl_3$	<150	>98	A	A	A	A	A	A	A	A	A (200°F)	C		

				Process Head, Flange, Drain/Vent Plug, Extension				Barrier Diaphragm				Gasket			
Process Fluid	**Other Name / Formula**	Max. Fluid Temp. °F	Concentration %	Carbon Steel	316L Stainless Steel	Monel 400	Hastelloy C-276	316L Stainless Steel	Monel 400	Hastelloy C-276	Tantalum	Teflon (PTFE)	Viton	Graphite	Glass Fiber
Trichloroethylene (Dry)	Trichloroethene C_2HCl_3	<200	80 - 100	A	A	A^+	A^+	A	A^+	A	A^+	A	C	A	A
Turpentine		<200	>98	B	A^+	B	B	A^+	B	B	B	A	A	A	A
Urea	Carbamide CH_4N_2O	<200	<50		B	B	A	B	B	A	A^+	A	C		A
Vinyl Chloride	C_2H_3Cl	<100	>99	A^+	A^+	A^+	A^+	A	A^+	A^+		A	C	A	A
Water (Demineralized)	H_2O	<200		C	A	A	A^+	A	A	A^+	A^+	A	A		A
Water (Fresh)	H_2O	<200		C	A	A^+	A^+	A	A^+	A^+	A^+	A	B	C	A

References:

[1] ISA-71.04-1985, *Environmental Conditions for Process Measurement and Control Systems: Airborne Contaminants*
[2] *ASM Materials Properties Handbook; Titanium Alloy*, ASM International
[3] Philip A. Schweitzer, *Corrosion Resistance Tables*, 2nd Edition (1986)
[4] S.L. Chawla and R.K. Cupta, *Materials Selection for Corrosion Control*, ASM International
[5] Philip A. Schweitzer, *Corrosion-Resistant Piping Systems*, Marcel Dekker, Inc. (1994)

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