

Corrosion and Its Effects



INTRODUCTION

The potential for damage due to corrosion is an important concern in the design of instrumentation for most process control systems. Rosemount pressure transmitters are available with several choices of materials of construction that can be expected to perform well in a wide range of applications. This technical data sheet briefly discusses some of the reasons why corrosion occurs and the problems that can result. References are given to assist the user in making the appropriate material choices for an application.

The information presented here is intended only as a guide to the selection of material options. Any material will behave differently under the influence of such variables as temperature, pressure, flow rate, abrasives, and contaminants. All of the components of a process fluid should be considered when selecting materials. It should be noted that fluids that contain individual chemicals may react differently with a material than fluids that contain a combination of chemicals or a series of chemicals. The chemicals present in small amounts could also impact material selection. It is the user's responsibility to make a careful analysis of all process parameters when specifying materials. Rosemount Inc. cannot guarantee that a material is suited to a particular application under all possible process conditions.

If materials other than the standard materials discussed here are needed, contact your local Rosemount sales office for assistance.



Corrosion and Its Effects

CORROSION BASICS

Corrosion is the gradual destruction of a metal by chemical or electrochemical means. The most generic form of corrosion is galvanic corrosion. A combination of a cathode, an anode, and an electrolyte must be present for this type of corrosion to occur. This combination of cathode, anode, and electrolyte is called a galvanic cell. Simply stated, a galvanic cell consists of two electrically connected, dissimilar metals and a medium, usually an aqueous solution, by which electron transfer can take place.

To fully understand the corrosion process, these terms must be better defined.

Anode—The electrode at which chemical oxidation occurs (or + current leaves the electrode and enters the electrolyte).

Cathode—The electrode at which chemical reduction occurs (or + current enters the electrode from the electrolyte).

A potential difference results when the electrically connected anode and cathode are separated by a physical distance in a conductive media. This potential difference causes the positively charged cations to flow from the anode to the cathode through the conductive medium. To complete the circuit, the negatively charged electrons flow from the anode to the cathode through the electrical connection. The resulting corrosion takes place at the anode. The cathode may also corrode, but not to the same extent.

The loss of electrons by the anode is called oxidation, and it causes the metal surface to become positively charged. These positively charged metal ions on the surface, called cations, attract the negative ions (anions) found in the electrolyte to form a new compound. This new compound no longer has its former metal characteristics, but rather it takes a new form such as rust or iron oxide.

The gain of electrons at the cathode is referred to as reduction. Reduction allows the metal at the cathode area to retain its metallic characteristics (see Figure 1).

The tendency for corrosion to occur is governed by the magnitude of potential difference developed between the anode and the cathode. Generally, those metals with the highest potentials are at the anodic end of the galvanic series (see Table 1). Metals with the lowest potentials are at the cathodic end of the series. However, the level of potential can vary with different conditions and with different environments. In general, the farther apart the metals are positioned on the galvanic chart, the more likely they are to corrode when placed together in a solution.

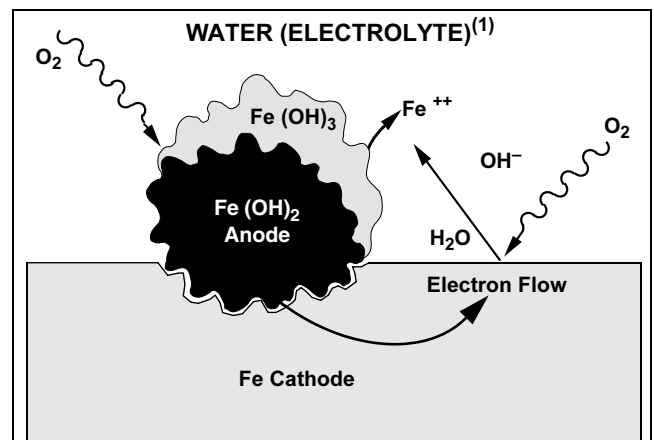
TYPES OF CORROSION

Generally, all corrosion is interrelated, however, it can take many forms. Corrosion can be uniform or localized. It may also combine with other forms of attack to produce even more undesirable effects. In the following discussion, some of the most common forms of corrosion are presented, including a separate section on sulfide stress cracking.

Uniform Corrosion

This is characterized by an even distribution of corrosion that leaves the surface clean or coated with corrosion products. This even distribution is due to the movement of the anodic and cathodic sites on the metal's surface. With uniform attack, fouling of the metal is usually a bigger problem than failure.

FIGURE 1. Classic Corrosion Cell.



As current flows through the electrolyte from the anode to the cathode, an anodic reaction ($Fe = Fe^{++} + 2e^{-}$) results. Simultaneously, the iron ion, Fe^{++} , is liberated and combines with the OH^{-} to produce ferrous hydroxide, $Fe(OH)_2$. Next, the ferrous hydroxide combines with oxygen and water to produce ferric hydroxide, $Fe(OH)_3$, or common iron rust.

1 Electrolyte is seawater.

Technical Data Sheet

Online Only 00816-0100-3045, Rev CA
May 2003

Corrosion and Its Effects

Pitting

One of the most destructive forms of corrosion is pitting. It is a form of localized attack that causes small holes to form in the metal. It is promoted by low-velocity, stagnant-type conditions where concentrated “bubbles” of corrosives could form. Pitting is often difficult to detect because the pits may be covered by corrosion products. Pitting may take months to years before its effects are visible. However, once started, a pit penetrates the metal at an ever increasing rate. Pitting also has a tendency to under cut the surface. This makes detection even more difficult and subsurface damage more severe than the surface condition appears.

Galvanic Corrosion

When two dissimilar metals come into contact and are immersed in a conductive medium, an electric potential develops. The corrosion rate of the more active (anodic) metal increases while the corrosion rate of the more noble (cathodic) metal decreases. The resulting corrosion can be uniformly distributed or localized.

Erosion-Corrosion

Erosion-Corrosion is the increase in rate of attack on a metal from abrasive effects. It can be characterized by grooves, holes, and waves, but usually exhibits a directional pattern. This form of corrosion is more common in the softer metals, and usually occurs after the protective film on the surface of the metal has been stripped away.

TABLE 1. Galvanic Series of Metals and Alloys.⁽¹⁾

Protected End Cathodic or Noble End
Platinum
Gold
Graphite
Titanium
Silver
Hastelloy C
316 Stainless Steel (passive)
304 Stainless Steel (passive)
410 Stainless Steel (passive)
Inconel (passive)
Nickel (passive)
Silver Solder
Monel
Copper-Nickel Alloys
Bronzes
Copper
Brasses
Chlorimet
Hastelloy B
Inconel (active)
Nickel (active)
Tin
Lead
Lead-Tin Solders
316 Stainless Steel (active)
304 Stainless Steel (active)
410 Stainless Steel (active)
Cast Iron
Steel or Iron
2024 Aluminum
Cadmium
Commercially Pure Aluminum
Zinc
Magnesium Alloys
Magnesium
Anodic or Active End Corroded End

⁽¹⁾ Electrolyte is seawater.

Corrosion and Its Effects

Stress Corrosion

By definition, SCC is a phenomenon that, by virtue of the simultaneous application of a tensile stress and corrosive environment, promotes a brittle-type failure at stress levels well below the yield strength of the metal. The higher the tensional stress the shorter the time to failure. Although time to cracking at low stress levels may be long, there is no practical minimum stress below which cracking will not occur, given sufficient time in a critical environment.

For austenitic steels, such as type 316 stainless, the two major damaging ions are hydroxyl and chloride (OH⁻ and Cl⁻).

Crevice Corrosion

This localized corrosion occurs within crevices and other shielded areas on the metal surface. The solution within the crevice becomes highly concentrated and acidic. Crevice corrosion might occur inside holes, at metal-to-metal surfaces, and on sealing surfaces.

Intergranular Corrosion

This form of corrosion is a selective attack on the grain boundaries (the surface of crystal mismatch between adjacent grains) of a metal without appreciable attack on the grains (individual crystal of a microstructure) themselves. The attack mechanism results from a difference in potential between the grain boundaries and the grain. Because welding often causes segregation of impurities at grain boundaries, or precipitation of intermetallics, welded areas are a common source of intergranular corrosion. The attack causes a loss of strength and ductility much greater than the loss due to the amount of metal destroyed.

Hydrogen Embrittlement

Almost all metals lose ductility when they absorb hydrogen. This is especially noticeable at temperatures below 100 °C. The exact mechanism involved is still undetermined; however, the leading theories suggest that hydrogen causes a highly localized alteration of the metallic bonds at a flaw or crack tip under stress. This may either decrease the cohesive strength of the bonds or lower the shear stress required for slip. In either case, the metal fractures in a brittle manner at loads well below the macroscopic yield strength of the structure.

Hydrogen embrittlement is a common problem when tantalum is placed in hydrogen service.

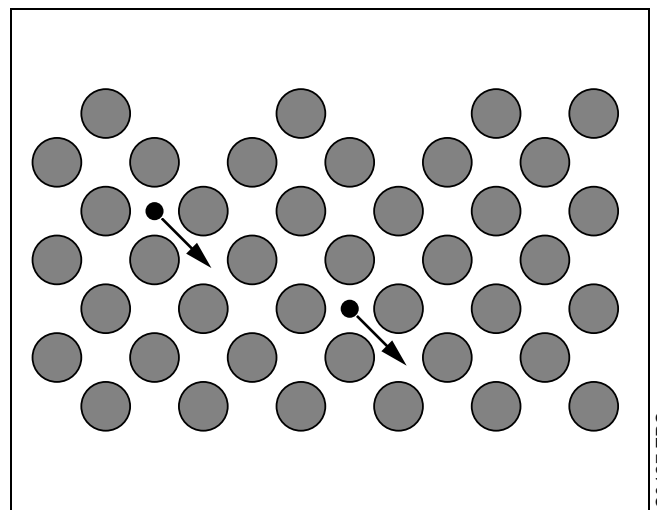
Hydrogen Permeation

Hydrogen permeation is the process where hydrogen atoms diffuse through the metal by either an interstitial mechanism or a vacancy mechanism. Although the mechanism is much more involved, for the sake of simplicity, this definition will be sufficient.

Two ways that hydrogen atoms can move from a high concentration area (process fluid) to a low concentration area (module fill fluid) are by an interstitial mechanism and a vacancy mechanism.

An atom is said to diffuse by an interstitial mechanism when it passes from one interstitial site to one of its nearest-neighbor interstitial sites without permanently displacing any of the matrix atoms (see Figure 2).

FIGURE 2. Path of Atom Diffusion by Interstitial Mechanism.



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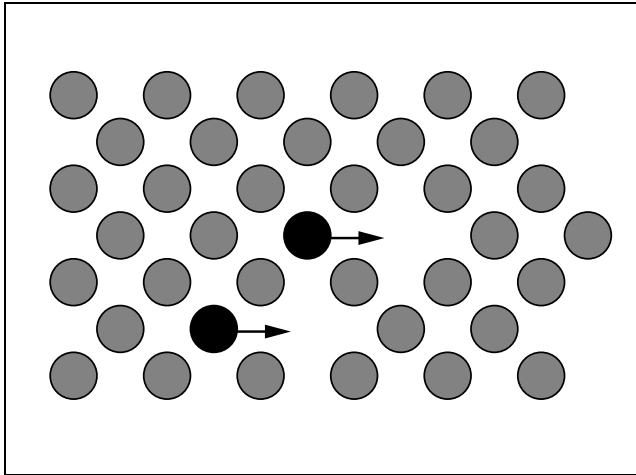
Technical Data Sheet

Online Only 00816-0100-3045, Rev CA
May 2003

Corrosion and Its Effects

In all crystals, some of the lattice sites are unoccupied. These unoccupied sites are called vacancies. If one of the atoms on an adjacent site jumps into the vacancy, the atom is said to have diffused by a vacancy mechanism (see Figure 3).

FIGURE 3. Movement of an Atom into Adjacent Vacancy.



C0128.EPS

Because some transmitter diaphragms are very thin, hydrogen atoms permeating through the diaphragm can unite to form molecular hydrogen. Because molecular hydrogen is too large to permeate back through the diaphragm it gets trapped and forms bubbles in the fill fluid. These bubbles can severely affect transmitter performance.

Care must be taken to prevent placing certain dissimilar metals in close proximity where atomic hydrogen could be generated. Positioning cadmium or cadmium-plated parts near high-nickel alloys, such as SST or Hastelloy, in the presence of an electrolyte such as water, can result in the creation of a Ni Cad battery effect where atomic hydrogen is released. This atomic hydrogen can then permeate a thin diaphragm.

In general, in applications where atomic hydrogen is present, materials that are not susceptible to permeation should be chosen. Metals that contain a lot of nickel are more susceptible to permeation. Increased temperatures also increase the rate of permeation. See the Materials of Construction section for more information.

SULFIDE STRESS CRACKING

Sulfide stress cracking is a common form of corrosion in oil field environments. When exposed to “sour” environments, sulfide stress cracking may occur in susceptible materials. Sour environments can be defined as a fluid containing liquid water and hydrogen sulfide such as sour gas and sour crude.

The rapidity with which hydrogen atoms absorbed on a metal surface combine to form H_2 is affected by the catalytic properties of the electrode surface. If a catalyst poison like hydrogen sulfide is present, the rate of formation of molecular H_2 is decreased, while the accumulation of absorbed hydrogen on the electrode surface is increased. The increased concentration of surface hydrogen favors entrance of hydrogen atoms into the metal lattice, causing hydrogen embrittlement. In some stressed, high-strength ferrous alloys it may also induce spontaneous hydrogen cracking.

NACE MR0175

National Association of Corrosion Engineers (NACE) standard MR0175 defines material requirements for sour oilfield environments. To be considered within the scope of this standard for sour gas, total system pressures must be above 65 psia and the partial pressure of H_2S in the gas must be 0.05 psia or greater. For sour crude oil, total system pressures must be above 265 psia. Below these pressures, the MR0175 standard does not apply. For over 25 years this document has provided recommendations for proper use of various metals and alloys to avoid problems with sulfide stress corrosion (SSC). NACE has added to its recommendations practical limits to avoid stress corrosion cracking or SCC.

MR0175-2003 limits exposed 300 series stainless steel to 60°C mainly to reduce problems with SCC which are related to brackish conditions commonly associated with sour reserves. Parts made from corrosion resistant Ni-Cr-Mo alloys like Hastelloy C are widely used for even the most severe sour environment conditions.

Corrosion and Its Effects

This NACE standard is not a code document and makes no provision for certification to the materials and procedures described therein. Instead, it's the user's responsibility to determine what parts will be satisfactory in the intended environment. Defined limits apply to parts that are directly exposed to sour conditions. Table 2 can aid the selection process by listing which Rosemount pressure transmitters parts meet the MR0175-2003 metallurgical requirements.

MATERIALS OF CONSTRUCTION

Rosemount Inc. offers a wide variety of materials of construction to cover almost any application. The following discussion will aid in the understanding of various materials offered. It should be noted that Rosemount Inc. may offer materials of construction not listed in this paper. Only the most widely used materials are presented.

Type 316 Stainless Steel

Alloys with a chromium content over 11 percent and an iron content well over 50 percent are known as stainless steels. The designation "stainless steels" can be attributed to their ability to withstand most corrosives under many conditions.

Type 316 stainless steel (16–18Cr and 10–14Ni) belongs to the group of austenitic stainless steels. This group is essentially nonmagnetic and cannot be hardened by heat treatment. The nickel content contributes to the improved corrosion resistance, and it is also responsible for the retention of the austenitic structure.

Type 316 SST has a high resistance to corrosion. It is rust resistant in the atmosphere and is resistant to most concentrations of nitric acid. However, it is attacked by nonoxidizing acids such as sulfuric and hydrochloric acid in most concentrations.

Most salt solutions have little effect on type 316 SST, although the halide salts (fluorine, chlorine, bromine, iodine) can cause severe pitting and possibly stress-corrosion cracking.

Type 316 SST performs very well against hydrogen diffusion and is a good choice as a diaphragm material when the process is hydrogen gas.

Type 316 SST has good resistance to alkaline solutions, organic acids, and other organic compounds.

Nickel-Based Alloys

Nickel is the basis of an important group of materials used for corrosive applications. High-nickel alloys provide good resistance to a wide variety of corrosives. The nickel content helps provide good resistance as well as good physical and mechanical properties.

In general, nickel alloys have the basic corrosion resistance of nickel combined with the added resistance associated with the alloyed metal. This combination makes the alloy as good as, or even better than, nickel against corrosion.

Monel

Monel (67Ni-33Cu) has good resistance at ambient temperatures to most of the nonoxidizing acids, such as hydrofluoric, sulfuric, and phosphoric acids. It also resists nonoxidizing salts. The nickel in the alloy improves its resistance toward alkalies.

Hydrogen may penetrate Monel in high hydrogen concentration applications. When used as a diaphragm material, hydrogen atoms may permeate the diaphragm allowing hydrogen bubbles to form within the fill fluid. Therefore, Monel should not be used as a diaphragm material when the process is hydrogen gas.

Gold-Plated Monel

Plating Monel with gold provides protection against hydrogen permeation while providing the corrosion resistance of Monel to processes such as hydrofluoric acid.

Gold plating should only be used with metals that are susceptible to hydrogen permeation. It is not necessary for all hydrogen service applications. See the section on 316 SST.

Hastelloy C

In Hastelloy C (54Ni-16Mo-16Cr), chromium and molybdenum are added to nickel to improve the alloy's resistance to oxidizing conditions. This alloy also retains a considerable degree of resistance to nonoxidizing conditions. For example, Hastelloy C withstands oxidizing acids and also the acid salts such as ferric and cupric chlorides. Hydrochloric and sulfuric acids in most concentrations do not affect Hastelloy C at moderate temperatures. Hastelloy C is well suited to provide protection against alkalies, organic acids, and other organic compounds.

Technical Data Sheet

Online Only 00816-0100-3045, Rev CA
May 2003

Corrosion and Its Effects

Hastelloy C, like Monel, allows the permeation of hydrogen and should be used with caution as a diaphragm material.

Both Monel and Hastelloy C have excellent corrosion resistance against atmospheric conditions and fresh water. In addition, Hastelloy C is resistant to stagnant seawater.

Tantalum

Tantalum has proved to be a useful material in corrosive applications involving hydrochloric acid and acidic ferric chloride solutions. This accounts for the wide acceptance of tantalum in the chemical industry. Tantalum has a high melting point and good strength even at elevated temperatures. Its high strength allows thin sections to be used. This is important because tantalum is very expensive.

Tantalum has superior corrosive resistance to most acids, chemical solutions, and organic compounds. In general, tantalum has good resistance to hydroiodic, hydrobromic, boiling hydrochloric, nitric, phosphoric, and sulfuric acids. Liquid metals generally do not affect tantalum. In addition, it has good resistance to most other acids. However, tantalum can be attacked severely by hydrofluoric acid, fluosilicic acid, hot fuming sulfuric acid, and fluorine. Also, it is attacked by strong alkaline solutions and by fused alkalis.

Tantalum can suffer severe embrittlement if in service with high-temperature oxygen or nitrogen, or with hydrogen at any temperature.

Cadmium-Plated Carbon Steel

Cadmium plating serves as a limited but significant type of corrosion protection. When the base metal cannot provide the needed protection, cadmium plating offers an inexpensive solution. For applications that do not require maximum protection, cadmium plating may be the right choice.

Cadmium is applied as a thin coating sufficient to withstand atmospheric corrosion. Its resistance to corrosion by most chemicals is low.

In most applications, cadmium acts as a sacrificial anode. This means the underlying metal is protected at the expense of the cadmium plating—even when the cadmium is scratched or nicked, exposing the substrate. This is a positive attribute of cadmium plating in association with galvanic corrosion.

Nickel-Plated Carbon Steel

Nickel plating is an effective means for giving metal surfaces a corrosion resistant coating. Nickel has good resistance against most of the common acids, except those of an oxidizing nature such as nitric acid. In general, neutral and alkaline solutions leave nickel relatively unattacked. It has good resistance to the milder forms of atmospheric conditions, to oxidation, to higher temperatures, and to halogen gases.

Nickel-plated flanges and adapters can be used along with Hastelloy C diaphragms. The large potential difference resulting from the use of cadmium-plated flanges and Hastelloy C diaphragms is now eliminated.

FIGURE 4. Rosemount 1151 Pressure Transmitter Exploded View Showing Wetted Parts.

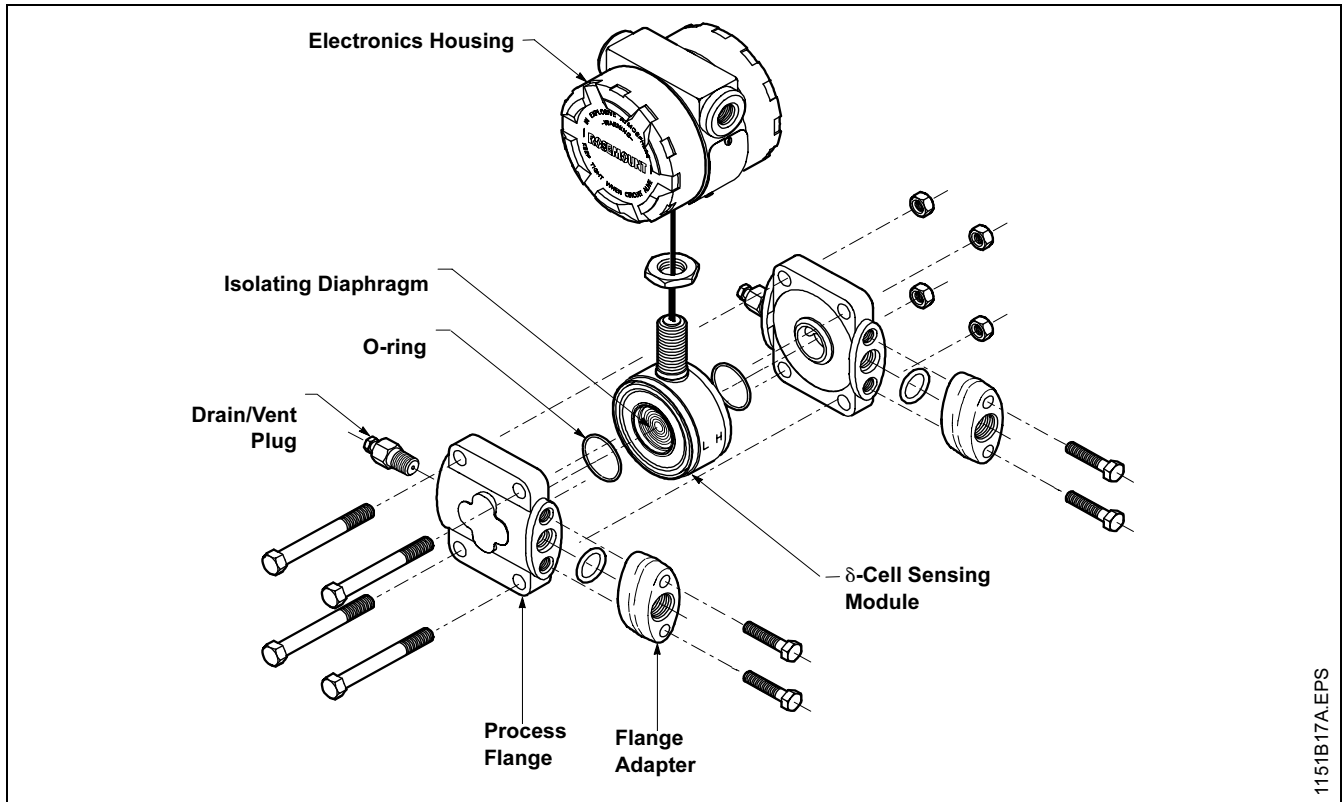
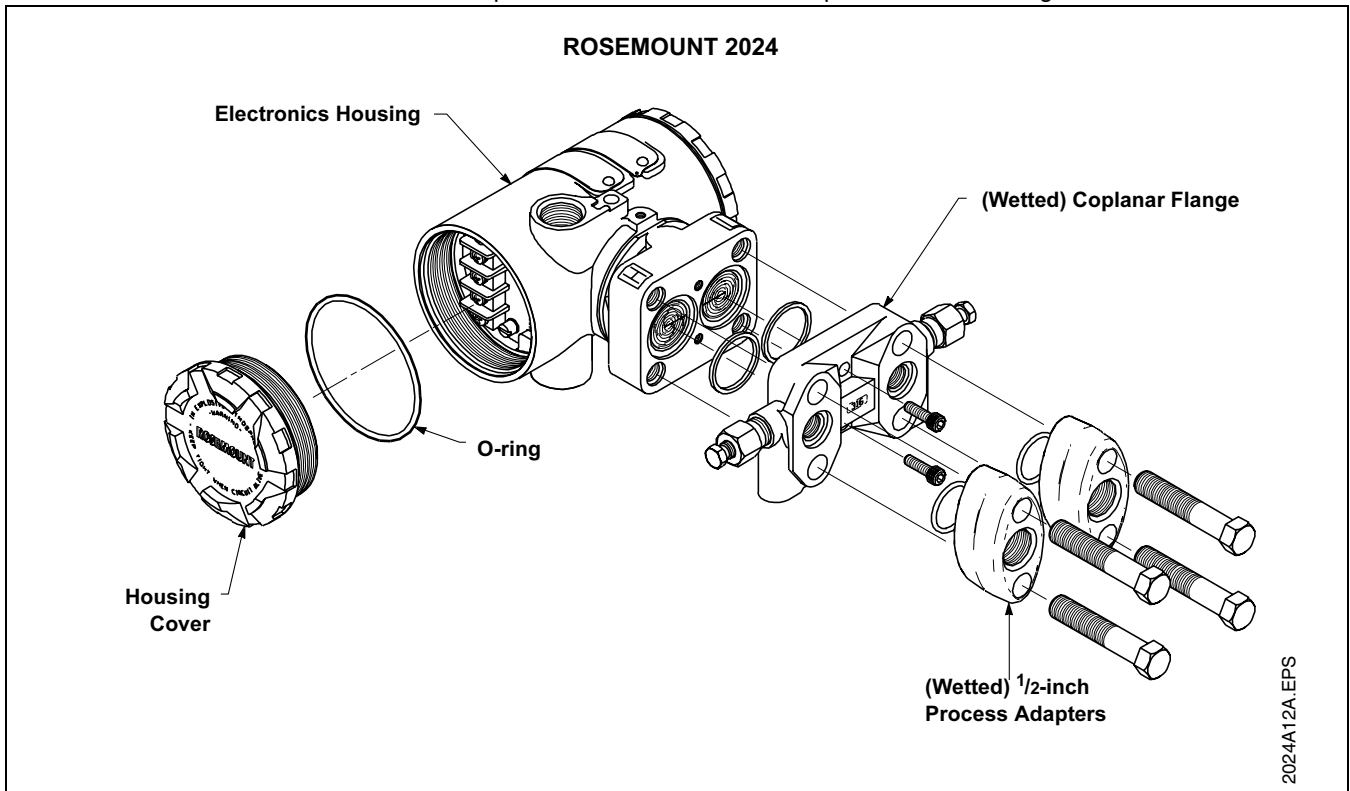


FIGURE 5. Rosemount 2024 Coplanar Pressure Transmitter Exploded View Showing Wetted Parts.



Technical Data Sheet

Online Only 00816-0100-3045, Rev CA
May 2003

Corrosion and Its Effects

FIGURE 6. Rosemount 3051C Coplanar Pressure Transmitter Exploded View Showing Wetted Parts.

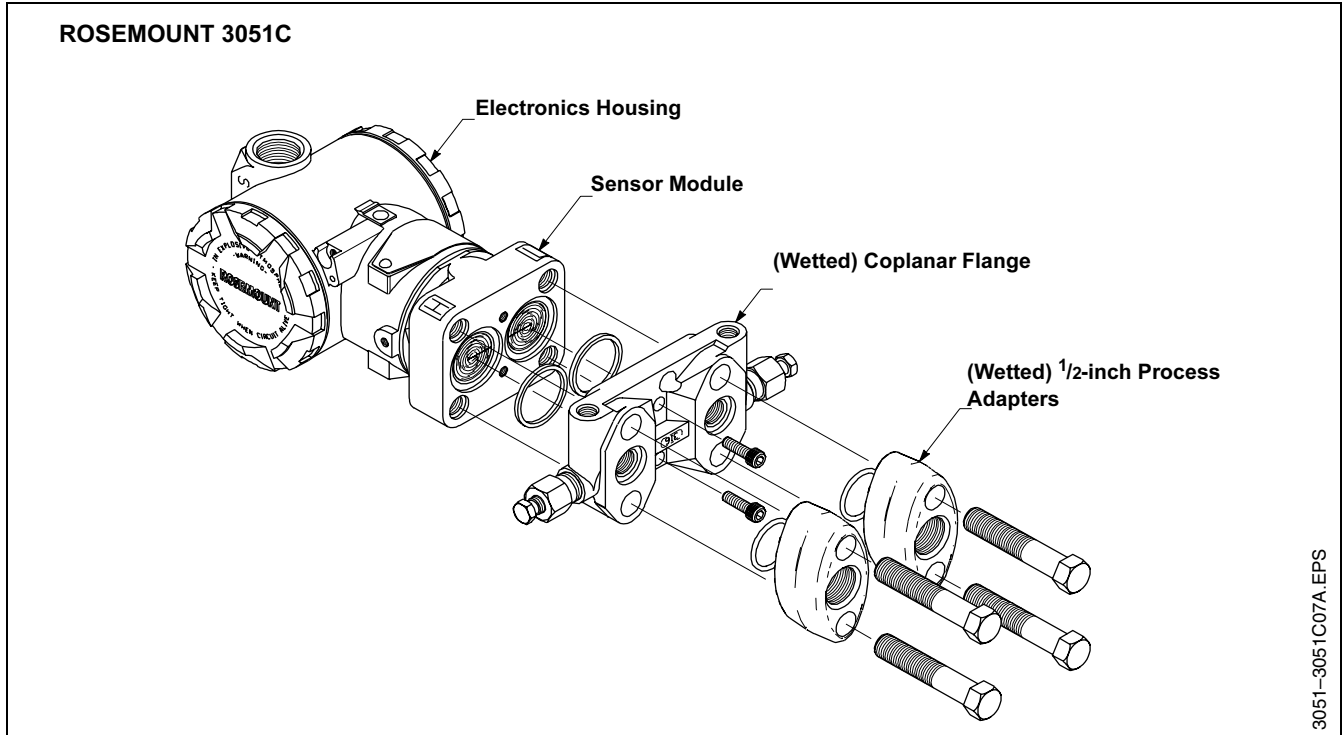
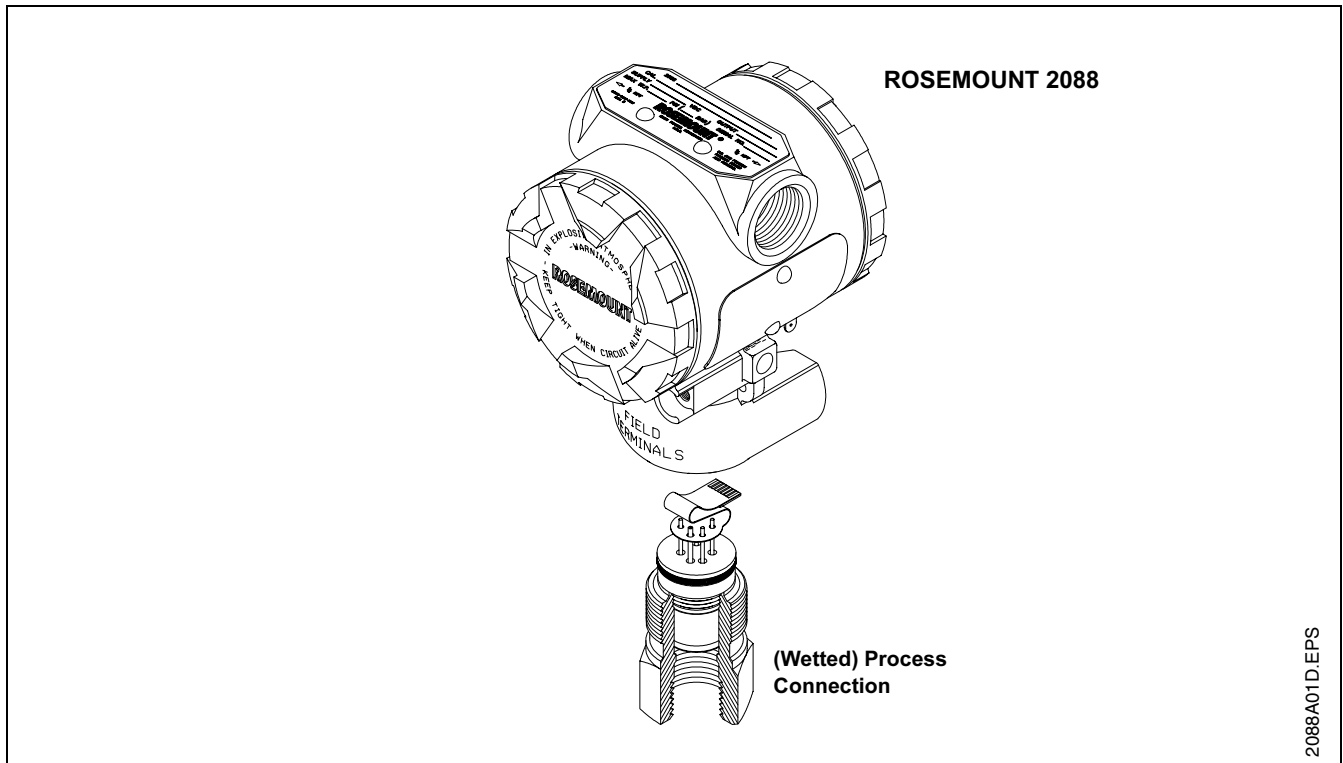


FIGURE 7. Rosemount 2088 Pressure Transmitter Exploded View Showing Wetted Parts.



Corrosion and Its Effects

MATERIAL SELECTION REFERENCES

Schweitzer, Philip A., P.E. *Corrosion Resistance Tables: Metals, Nonmetals, Coatings, Mortars, Plastics, Elastomers and Linings, and Fabrics*. Third Edition, Marcel Dekker, Inc., 1991.

National Association of Corrosion Engineers. *Corrosion Data Survey, Metals Section*, 6th Edition, 1985.

ASM Metals Handbooks, Volume 13 (Corrosion), 9th Edition, American Society of Metals, Sept. 1987.

Cor-sur and *Cor-sur2*, personal computer software versions of *Corrosion Data Survey for Metals and Non-metals*, National Association of Corrosion Engineers and National Bureau of Standards. PO Box 218340, Houston, TX 77218.

Corrosion Data Survey for Metals and Non-metals, National Association of Corrosion Engineers and National Bureau of Standards. PO Box 218340, Houston, TX 77218.

NA: Not Available

TABLE 2. Suggested Materials of Construction for Pressure Transmitters Exposed to Sour Oilfield Environments. ⁽¹⁾

Transmitter and Parts	316 SST ⁽²⁾	Hastelloy C	Monel	Tantalum	Ni Plated Carbon Steel	Cd Plated Carbon Steel ⁽³⁾
Rosemount 3051S/ 3051C						
Flanges and Adapters	yes	yes	no	NA	yes	NA
Drain/ Vents	no	yes	no	NA	NA	NA
Isolating Diaphragm	yes	yes	no	no	NA	NA
Rosemount 3051T/ 2088/ 4600						
Process Connector	yes	yes	NA	NA	NA	NA
Isolating Diaphragm	yes	yes	NA	NA	NA	NA
Rosemount 1151						
Flanges and Adapters	yes	yes	NA	NA	yes	no
Drain/ Vents	no	yes	no	NA	NA	NA
Isolating Diaphragm	yes	yes	NA	no	NA	NA
Pipe Plugs	yes	yes	no	NA	yes	no
Rosemount 2024						
Flanges and Adapters	yes	NA	no	NA	yes	NA
Drain/ Vents	no	yes	no	NA	NA	NA
Isolating Diaphragm	yes	yes	NA	NA	NA	NA
Pipe Plugs	yes	yes	NA	NA	NA	NA

NA = Not Applicable

- (1) Comments are based on NACE MR0175-2003 that applies only to petroleum production, drilling, gathering and flow line equipment, and field processing facilities to be used in H₂S bearing hydrocarbon service. It is not intended for refinery applications. A new NACE specification, MR0103, has been released for refineries.
- (2) Caution is advised when considering the use of 316 stainless steel in sour environments. MR0175-2003 limits exposed austenitic stainless steel to 60°C mainly to reduce the risk of chloride stress corrosion cracking problems. Other environmental restrictions do apply. Consult standard for more detail.
- (3) Although considered outside the scope of MR0175, Emerson Process Management, Rosemount Division does consider exposed cadmium or zinc plated products not satisfactory due to increased risk of corrosion.

Technical Data Sheet

Online Only 00816-0100-3045, Rev CA
May 2003

Corrosion and Its Effects

MATERIALS SELECTION GUIDE⁽¹⁾

E =Excellent resistance. Corrosion rate <0.002 in. (0.05 mm) per year. Best choice for diaphragm material.

G = Good resistance. Corrosion rate <0.020 in. (0.50 mm) per year.

F = Fair resistance. Corrosion rate 0.020–0.050 in. (0.50–1.27 mm) per year.

P = Poor resistance. Corrosion rate >0.050 in. (1.27 mm) per year.

– = Data not available.

(The numeric values for corrosion rate hold true only for selecting the isolating diaphragm, not for selecting the flange and adapter materials. When selecting the flange/adapter and O-ring materials, the “E, G, F, and P” ratings describe the performance of that material as excellent, good, fair, and poor.)

¹ = May cause stress corrosion cracking.

² = May cause pitting.

* = This signifies that the process fluid can be either aerated or non-aerated. If there is a significant difference in performance of the material, two letters may be separated by a slash (aerated/non-aerated data).

NOTE

All data is based on a temperature of 70 °F (20 °C) unless noted otherwise.

Since a material's resistance to corrosion can vary greatly due to many factors such as impurities, temperature, pressure, velocity, etc., this chart should be used only as a general guide.

Rosemount Inc. makes no guarantee for the suitability of any transmitter material. The responsibility for material selection rests with the user.

(1) *Data for material selection guide compiled from NACE publication Corrosion Data Survey, metals section, sixth edition.*

Corrosion and Its Effects

Process Fluid	Flange/Adapter				Isolating Diaphragm				Wetted O-Rings			
	316 SST	Monel	Hast. C	Ni. Pl. C.S.	316L SST	Monel 400	Hast. C-276	Tantalum	Buna-N	Viton	Teflon	Eth. Prop.
Acetic Acid (<50%)*	E	G/E	E	P/F	E	F/E	E	E	G	F	E	E
Acetic Acid (>50%)*	E	G/E	E	P/F	E/G	F/E	E	E	G	F	E	E
Acetic Acid (<50%, <200 °F)*	E	P/E	E	P	E	P/E	E	E	P	P	E	E
Acetic Acid (>50%, <200 °F)*	E	P/E	E	P	G	P/E	E	E	P	P	E	E
Acetic Acid (>50%, >200 °F)*	F/-	-/E	-/E	P	P/-	-/E	-/E	E	P	P	E	E
Acetylene (100%, <250 °F)*	E	E	E	E	E	E	E	E	G	E	E	E
Alcohols	E	E	E	G	E	E	E	E	F	E	E	E
Air	E	E	E	E	E	E	E	E	E	E	E	E
Aluminum Sulfate (<50%, <200 °F)	E	G	E	P	E ¹	F	E	E	F	E	E	G
Aluminum Sulfate (>50%, <200 °F)	F	F	E	P	P ¹	P	E	E	F	E	E	G
Ammonia (anhyd., <500 °F)	E	E	E	E	E	E	E	-	G	P	E	G
Ammonium Acetate (<200 °F)	E	E	E	E	E	E	E	E	G	P	E	E
Ammonium Bicarbonate (<175 °F)	E	P	E	P	E	P	G	E	P	E	E	E
Ammonium Bromide (<20%)	E	E	E	G	G ²	G	G	E	-	-	E	-
Ammonium Chloride (<10%, <200 °F)	E	E	E	G	E ^{1,2}	G	E	E	P	E	E	E
Ammonium Chloride (10-20%, <200 °F)	E	E	E	G	G ^{1,2}	G	E	E	P	E	E	E
Ammonium Hydroxide (<40%)	E	F	E	F	E	P	E	P	P	F	E	G
Ammonium Nitrate (<200 °F)	E	F	E	F	E	P	G	E	E	E	E	E
Ammonium Oxalate (<40%, <200 °F)	E	E	E	P	G	G	G	E	E	E	E	-
Ammonium Phosphate (Mono Basic)	E	G	E	F	E	F	E	E	G	E	E	G
Ammonium Phosphate (Di Basic)	E	G	E	-	E	F	E	-	G	E	E	G
Ammonium Phosphate (Tri Basic)	E	E	E	-	E	G	E	-	G	E	E	G
Ammonium Sulfate (<40%, <200 °F)	E	F	E	G	G	F	G	E	G	E	E	E
Aniline (100%, <200 °F)	E	E	E	G	E	G	G	E	G	G	E	G
Beer	E	E	E	E	E	E	E	E	G	E	E	F
Benzene	E	E	E	E	E	E	G	E	P	G	E	P
Black Liquor (sulfate)	E	G	E	-	G ^{1,2}	G	E	E	F	G	E	-
Brines (Calcium, dil.)	G	G	E	G	P ²	F	E	E	E	E	E	E
Bromine (dry)	F	F	F	G	P	P	P	E	P	G	E	P
Bromine (wet)	F	F	F	F	P	P	P	E	P	G	E	P
Calcium Carbonate (100%, <200 °F)	E	E	E	E	E	G	G	E	E	E	E	G
Calcium Chloride (<50%)	E	E	E	E	G ^{1,2}	G	E	E	E	E	E	E
Calcium Chloride (>50%)	E	-	E	G	G ^{1,2}	G ^{1,2}	E	E	F	G	E	G
Calcium Sulfate (sat.)	E	E	E	E	G	G	G	E	E	E	E	G
Carbon Dioxide (gas)	E	E	E	E	E	E	E	E	E	G	E	-
Carbonic Acid (100%, <500 °F)	E	E	E	E	E	E	E	E	G	E	E	E
Carbon Tetrachloride (dry-wet)	E	E	E	E	G	E	E	E	F	G	E	E
Cellulose Acetate (100%, <100 °F)	E	E	E	G	E	G	E	E	P	P	E	E
Cellulose Nitrate (100%, <200 °F)	E	E	E	G	G	G	G	E	-	-	E	-
Chloric Acid (<20%)	P	P	E	P	P	P	E	E	P	P	E	-
Chlorinated water (sat.)	P	G	E	F	P ^{1,2}	F	E	E	P	E	E	P
Chlorine Gas (dry)	G	G	E	G	F	G	G	E	P	G	E	P
Chlorine Gas (wet)	P	G	G	P	P ^{1,2}	G	F	E	P	P	E	-
Chlorine Gas (liq. anhydrous)	F	G	E	-	P	G	G	E	P	G	E	-
Chloroform (80-100%, <200 °F)	E	E	E	E	G	E	G	E	P	G	E	P
Citric Acid (<50%, <200 °F)	E	E	E	G	E	G	E	E	G	G	E	F
Citric Acid (>50%, <200 °F)	P	E	E	G	P	G	E	E	G	E	E	F
Crude Oil (Sour)	E	E	E	-	G	E	E	-	G	G	E	P

Technical Data Sheet

Online Only 00816-0100-3045, Rev CA
May 2003

Corrosion and Its Effects

Process Fluid	Flange/Adapter				Isolating Diaphragm				Wetted O-Rings			
	316 SST	Monel	Hast. C	Ni. Pl. C.S.	316L SST	Monel 400	Hast. C-276	Tantalum	Buna-N	Viton	Teflon	Eth. Prop.
Ethylene Dichloride (100%, <200 °F)	E	E	E	G	G ^{1,2}	G	G	E	P	G	E	P
Ferric Chloride (<10%)	P	F	E	P	P ^{1,2}	P	E	E	G	G	E	F
Ferric Chloride (<40%, hot)	P	P	G	P	P ^{1,2}	P	F	E	G	G	E	F
Freon (gas, wet)	E	E	E	F	G	E	E	E	G	P	E	P
Fruit Juices	E	E	-	-	E	G	-	-	G	E	E	E
Glycerol (0-100%, <200 °F)*	E	E	E	G	E	E	E	E	E	E	E	E
Green Liquor (NaOH)	E	E	E	E	E ¹	E	E	E	P	G	E	-
Green Liquor (Sulfate, <200 °F)	E	E	E	E	G	G	G	-	G	E	E	E
Hydrochloric Acid (<1%)	P	G	G	G	P	G	G	E	F	E	E	G
Hydrochloric Acid (>2%, RT-Hot)*	P	P	F	P	P	P	P	E	P	E	E	F
Hydrofluoric Acid (<50%)*	P	E	E	G	P	G	G	P	P	E	E	F
Hydrofluoric Acid (>50%)*	P	E	G	F	P	G	G	P	P	G	E	F
Hydrogen Chloride (anhydrous, <500 °F)	G	E	E	E	F	G	E	E	G	E	E	-
Hydrogen Chloride (wet)	F	F	F	F	P	P	-	E	P	E	E	-
Hydrogen Fluoride (dry, <500 °F)	G	E	E	E	F	G	G	P	P	E	E	-
Hydrogen Gas (<500 °F)	E	E	E	E	E	E	E	E	F	G	E	G
Hydrogen Peroxide	E	F	E	F	G	P	E	E ¹	P	E	E	F
Hydrogen Sulfide (dry, <200 °F)	E	E	E	G	E ¹	G	G	E	E	E	E	E
Hydrogen Sulfide (wet, <200 °F)	G	F	E	G	G ^{1,2}	P	E	E	P	E	E	G
Isopropanol (<200 °F)	E	E	E	E	E	E	E	E	-	-	-	-
Methanol	E	E	E	E	G	G	E	E	E	F	E	-
Natural Gas (liq.)	E	E	E	E	E	E	E	E	E	E	E	P
Nitric Acid (20%)	E	P	G	P	E	P	P	E	P	E	E	P
Nitric Acid (20%, 200 °F)	E	P	P	P	G	P	P	E	P	G	E	P
Nitric Acid (65%, boil.)	G	P	P	P	P	P	P	E	P	F	E	P
Nitric Acid (conc., hot)	P	P	P	P	P	P	P	E	P	P	E	P
Nitric Acid (fuming)	E	P	G	P	E	P	G	E	P	F	E	P
Nitrous Oxide	G	P	G	P	G	P	G	E	P	E	E	-
Oxygen Gas	E	E	E	E	E	E	E	E	G	E	E	E
Phosgene (RT to HOT)	G	E	E	E	G	E	G	-	P	P	E	-
Phosphoric Acid (<50%)*	E	F/E	-/E	F/G	E	P/E	-/E	-/E	F	E	E	G
Phosphoric Acid (>50%)*	G	P/E	-/E	P	G	P/E	-/E	-/E	F	E	E	G
Phosphoric Acid (<10%, boil.)*	F	P/G	-/G	P	P/G	P/G	-/G	-/E	P	E	E	G
Phosphoric Acid (85%, boil.)*	P/F	P/G	-/F	P	P/F	P/G	-/F	-/E	P	E	E	G
Polyethylene (100%, <200 °F)	E	E	E	E	E	E	E	E	-	-	-	-
Polyvinylchloride	E	E	-	G	E	G	-	-	P	E	E	G
Potassium Chloride (<40%, <200 °F)	E	E	E	G	E	G	E	E	P	E	E	G
Potassium Nitrate (<200 °F)	E	E	E	E	G	G	G	-	E	E	E	E
Propane (100%, <200 °F)	E	E	E	E	E	E	E	E	E	E	E	P
Propylene Dichloride (100%)	E	E	E	E	G	G	G	-	-	-	-	-
Propylene Oxide (<200 °F)	E	-	-	-	E	-	-	-	P	P	E	E
Sewage	E	E	E	E	E	E	G	E	E	E	E	G
Sodium Chloride (<40%, <200 °F)	E	E	E	F	G	E	E	E	E	E	E	G
Sodium Hydroxide (50%)	E	E	E	E	E ¹	E	E	P	F	G	E	-
Sodium Hydrox. (<40%, <150 °F)	E	E	E	E	E ¹	E	G	P	P	F	E	G
Sodium Hydrox. (40-75%, <150 °F)	E	E	E	E	G ¹	E	G	P	P		E	-
Sodium Hydroxide (molten)	F	F	P	G	P ¹	F	P	P	P	P	P	-
Steam (<500 °F)	E	E	E	E	E	E	E	E	P	F	E	P
Styrene	E	E	E	E	E	G	E	-	-	-	-	-

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Sulfur (molten, dry, 230 °F)	E	E	E	G	G	G	E	E	P	E	E	G
Sulfur Dioxide (dry)	E	P	G	P	G	P	F	E	P	G	E	E
Sulfur Dioxide (wet)	E	P	E	P	G	P	F	E	P	F	E	G
Sulfuric Acid (<2%)*	E/G	F/E	E	P	G	P/G	E	E	G	E	E	P
Sulfuric Acid (2–40%)*	F/P	E/G	E	G/P	P	E/G	E	E	F	E	E	P
Sulfuric Acid (conc.>95%)*	E	P	E	P	G	P	E	E	P	G	E	P
Sulfuric Acid (10%–conc., boil.)*	P	P/F	P	P	P	P	P	E	P	G	E	P
Trichloroethylene (80–100%)	E	E	E	G	E	E	G	–	P	E	E	P
Vinyl Chloride (100%)	E	E	E	E	G	E	E	–	P	–	E	E
Water (fresh & distilled)	E	E	E	E	E	E	E	E	G	E	E	–
Water (sea)	G	E	E	G	F ^{1,2}	E	E	E	G	E	E	–
Water (mine)	E	G	E	P	G ²	F	E	E	G	E	E	–
White Liquor	E	E	E	–	E	G	E	E	G	E	E	–
Xylene (100%, <200 °F)	E	E	E	E	E	E	E	E	P	E	E	P

Technical Data Sheet

Online Only 00816-0100-3045, Rev CA
May 2003

Corrosion and Its Effects

Corrosion and Its Effects

Technical Data Sheet
Online Only 00816-0100-3045, Rev CA
May 2003

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