PROPERTIES OF THE REACTIVE METALS

TITAN®

METAL FINISHING

A Division of TITAN Metal Industries, Inc

APPLICATIONS OF TITANIUM

TITANIUM AS A METAL

Many Titanium alloys have been developed for aerospace applications where mechanical properties are the primary consideration. The main issue with industrial applications is typically corrosion resistance.

Commercially pure industrial grades of titanium are listed by ASTM grade in Table 1. Titanium Grade 2 represents the vast majority of the titanium used for industrial applications where corrosion resistance is the main concern.

The corrosion resistance of titanium is due to a stable, protective, strongly adherent oxide film layer. This film forms instantly when a fresh surface is exposed to air or moisture. A 12–16 angstroms thick oxide film is immediately formed on clean titanium when it is exposed to air. It continues to grow slowly, reaching 50 angstroms after 70 days, and 80–90 angstroms after 545 days. The film growth is accelerated under strong oxidizing conditions. The oxide film is very stable and is only attacked by a few substances—most notably, hydrofluoric acid. The titanium oxide film is capable of healing itself instantly in the presence of moisture or oxygen.

Anhydrous conditions should be avoided since the protective film may not be regenerated in the absence of oxygen.

TABLE 1

ASTM GRADE	UNS DESIGNATION	NOMINAL COMPOSITION	YIELD STRENGTH, PSI
1	R50250	Commercially Pure	25,000
2	R50400	Commercially Pure	40,000
3	R50550	Commercially Pure	55,000
4	R50700	Commercially Pure	70,000

Several titanium alloys have been developed with small amounts of palladium or ruthenium which have significance in industrial applications. Even though titanium has excellent corrosion resistance to a wide variety of corrosive media, it is limited in very hot brine and under acidic or reducing conditions as occur in crevices. The addition of palladium or ruthenium improves the corrosion resistance of the alloy under these conditions and extends the service temperatures in sea water and brine service. The presence of a small amount of these noble metals does not change the mechanical properties of the titanium. Palladium- and ruthenium-stabilized industrial grades of titanium are represented by the following ASTM grades in Table 2.

TABLE 2

ASTM GRADE	UNS DESIGNATION	NOMINAL COMPOSITION
7	R52400	Grade 2 + .15% Pd
11	R52250	Grade 1 + .15% Pd
16	R52402	Grade 2 + .05% Pd
17	R52252	Grade 1 + .05% Pd
26	R52404	Grade 2 + .10% Ru
27	R52254	Grade 1 + .10% Ru

The availability of lean palladium and ruthenium grades of titanium is still low, but with ASME code approval and increasing potential applications, the supply will increase to meet demand.

INDUSTRIAL APPLICATIONS

Titanium has found its niche in many industrial applications where corrosion resistance is required. Below we have listed some of the common applications of titanium in corrosion resistant service:

- Chlorine Chemicals
- Hydrochloric Acid
- Phosphoric Acid
- Sea Water
- Sulfuric Acid
- Nitric Acid

CHLORINE CHEMICALS

The corrosion resistance of titanium in chlorine gas and chlorine containing solutions is the basis for a large amount of titanium installations.

Titanium is widely used in chloro-alkali cells as anodes, cathodes, bleaching equipment for pulp and paper, heat exchangers, piping, vessels, and pumps for the manufacture of other intermediate organic chemicals. See Table 3 for the corrosion resistance of unalloyed titanium in aerated chloride solutions.

TABLE 3

MEDIA	CONCENTRATION (%)	TEMPERATURE (°F)	CORROSION RATE (mpy)
Aluminum Chloride	5 – 10	140	.12
	10	212	.09
	10	302	1.3
	20	300	630
	25	68	.04
	25	212	258
	40	250	4300
Ammonium Chloride	All	68 – 212	<0.5
Barium Chloride	5 – 25	212	<0.01
Calcium Chloride	5	212	.02
	10	212	0.3
	20	212	0.6
	55	220	.02
	60	300	<0.01
	62	310	2 – 16
	73	350	84
Cupric Chloride	1 – 20	212	<0.5
	40	Boiling	0.2
Cuprous Chloride	1 – 20	212	<0.5
Ferric Chloride	1 – 20	70	Nil
	1 – 40	Boiling	<0.5
	50	Boiling	.16
	50	302	<0.7
Lithium Chloride	50	300	Nil
Magnesium Chloride	5	212	.03
	20	212	0.4
	50	390	0.2
Manganous Chloride	5 – 20	212	Nil
Mercuric Chloride	1	212	.01
	5	212	.42
	10	212	.04
	55	215	Nil
Nickel Chloride	5 – 20	212	0.14
Potassium Chloride	Saturated	70	Nil
	Saturated	140	<0.01

TABLE 3 (CONTINUED)

MEDIA	CONCENTRATION (%)	TEMPERATURE (°F)	CORROSION RATE (mpy)
Stannous Chloride	Saturated	70	Nil
Sodium Chloride	3	Boiling	.01
	29	230	.01
	Saturated	70	Nil
	Saturated	Boiling	Nil
Zinc Chloride	20	220	Nil
	50	302	Nil
	75	392	24
	80	392	8000

FRESH AND SEA WATER

Titanium resists all forms of corrosive attack in fresh and sea water to temperatures of 500°F (260°C). Titanium tubing has been used in surface condensers successfully for more than 15 years in polluted sea water with no sign of corrosion. Titanium has provided over thirty years of trouble-free sea water service for the chemical, oil refining and desalination industries.

NITRIC ACID

Titanium is resistant to highly oxidizing acids over a wide range of temperatures and concentrations. Titanium has been extensively used in the handling and production of nitric acid. Titanium offers excellent resistance over a full concentration range at temperatures below boiling. Table 4 shows titanium's resistance to nitric acid vapors produced by boiling 70% azeotrope.

TABLE 4

ASTM DESIGNATION	CORROSION RATE (mpy)
Titanium Grade 2	2.0
Titanium Grade 12	0.8
Titanium Grade 7	.08

RED FUMING NITRIC ACID

Although titanium has an excellent corrosion resistance to nitric acid over a wide range of temperatures and concentrations, it should not be used in applications with red fuming nitric acid. A dangerous pyrophoric reaction product can be produced.

PHOSPHORIC ACID

Unalloyed titanium is resistant to phosphoric acid up to 30% concentration at room temperature. The resistance extends to about 10% pure acid at 140°F. Table 5 shows unalloyed titanium's resistance to phosphoric acid.

TABLE 5

MEDIA	CONCENTRATION (%)	TEMPERATURE (°C)	CORROSION RATE (mpy)
Phosphoric Acid	2	100	5
	10	50	5
	20	30	5
	30	20	5

HYDROCHLORIC ACID

Titanium has useful corrosion resistance in dilute hydrochloric acid applications. Small amounts of multivalent metal ions in solution can effectively inhibit corrosion.

TABLE 6

HCL CONCENTRATION (%)	$FeCl_3$ ADDED	TEMP. (°F)	TITANIUM GRADE 2	TITANIUM GRADE 7
1		Room	Nil	0.1
2		Room	Nil	0.2
3		Room	0.5	0.4
5		Room	0.2	0.6
8		Room	0.2	0.1
1		Boiling	85	0.8
2		Boiling	280	1.8
3		Boiling	550	2.7
5		Boiling	840	10
8		Boiling	>2000	24.0
3	2 g/l	200	0.2	0.1
4	2 g/l	200	0.4	0.3

SULFURIC ACID

Titanium is corrosion resistant to sulfuric acid only at low temperatures and concentrations such as 20% acid at 32°F and 5% acid at room temperature. Like hydrochloric acid, small amounts of multivalent metal ions in solution can effectively inhibit corrosion as illustrated in Table 7.

TABLE 7

H_2SO_4 CONCENTRATION (%)	INHIBITOR ADDED	TEMP. (°F)	TITANIUM GRADE 2
20	None	210	>2400
20	2.5 g/l Copper Sulfate	210	<2
20	16 g/l Ferric Ion	Boiling	5

ORGANIC ACIDS

Unalloyed titanium generally has good resistance to many organic acids such as those shown in Table 8.

TABLE 8

MEDIA	CONCENTRATION (%)	TEMPERATURE (°C)	CORROSION RATE (mpy)
Acetic Acid	5 / 25 / 75 / 99.5	100	Nil
Citric Acid	50	100	<.01
Citric (Aerated)	50	100	<5
Citric (Nonaerated)	50	Boiling	14
Formic (Aerated)	10 / 25 / 50 / 90	100	<5
Formic (Nonaerated)	10 / 25 / 50 / 90	Boiling	>50
Lactic Acid	10	60	.12
	10	100	1.88
	85	100	.33
Lactic (Nonaerated)	10	Boiling	.55
	25	Boiling	1.09
	85	Boiling	.40
Oxalic Acid	1	35	5.96
	1	60	177
	25	100	1945
Stearic Acid	100	182	<5
Tartaric Acid	50	100	0.2
Tannic Acid	25	100	Nil

Information courtesy of Titanium Metals Corp. & RTI International Metals, Inc.

APPLICATIONS OF ZIRCONIUM

One of the major applications for zirconium is as a corrosion resistant material of construction in the chemical processing industry. Zirconium exhibits excellent resistance to corrosive attack in most organic and inorganic acids, salt solutions, strong alkalis, and some molten salts. In certain applications, the unique corrosion resistance of zirconium can extend its useful life beyond that of the remainder of the plant. Consequently, maintenance costs are reduced and downtime is minimized. Furthermore, an increasingly important advantage is that zirconium appears to be non-toxic and bio-compatible. Some of the more important areas in the chemical processing industry where zirconium is being used include reboilers, evaporators, tanks, packings, trays, reactor vessels, pumps, valves and piping.

Zirconium is commonly used for corrosion resistance when dealing with the following chemicals:

- Nitric Acid
- Formic Acid
- Sulfuric Acid
- Hydrochloric Acid
- Acetic Acid
- Melamine

NITRIC ACID

Nitric acid is one of the most widely used acids in the Chemical Processing Industry. It is a key raw material in the production of ammonium nitrate for fertilizer, and is also utilized in a variety of manufacturing processes, including the production of industrial explosives, dyes, plastics, synthetic fibers, metal pickling and the recovery of uranium.

Most nitric acid is produced by the oxidation of ammonia with air over platinum catalysts. The resulting nitric acid is further oxidized into nitrogen oxide and then absorbed into water to form HNO3. This process produces acid of up to 70% concentration, with higher concentration acid produced by distilling the dilute acid with a dehydrating agent. Stainless steel has long been used in nitric acid applications; however, it has developed certain serious problems over the years and is subject to several limitations. The superior corrosion resistance of zirconium can overcome some of these limitations, making it an ideal replacement material in many specific nitric acid environments.

Corrosion Resistance of Zirconium in Nitric Acid

		CORROSION RATE (mpy)			
		LIQUID PHASE		VAPOR PHASE	
NITRIC ACID %	IMPURITY	NON WELDED	WELDED	NON WELDED	WELDED
30 / 50 / 70	0.1 or 1% $FeCl_3$	<2.5	<2.5	<2.5	<2.5
30 / 50 / 70	0.2 or 1% seawater	<2.5	<2.5	<2.5	<2.5
30 / 50 / 70	0.1% NaCl	<2.5	<2.5	<2.5	<2.5
30	1% NaCl	<2.5	<2.5	<2.5	<2.5
50	1% NaCl	<2.5	<2.5	12.7	35.6
70	1% NaCl	<2.5	<2.5	<2.5	<2.5
0	Saturated Cl_2	<2.5	102	<2.5	91.4
30	Saturated Cl_2	<2.5	<2.5	<2.5	<2.5
50	Saturated Cl_2	<2.5	<2.5	<2.5	<2.5
70	Saturated Cl_2	<2.5	<2.5	<2.5	<2.5
30 / 50 / 70	1% Fe	<2.5	<2.5	<2.5	<2.5
30 / 50 / 70	1.45% 304 S.S.	<2.5	<2.5	<2.5	<2.5

SULFURIC ACID

Sulfuric acid is undoubtedly the most important raw material in the chemical and pharmaceutical industry today. This fact is not unique to the United States, but is true on a worldwide basis. One can often look to the production and/or use of sulfuric acid as an indication of the industrial activity of a nation. Few chemicals are manufactured without sulfuric acid being involved. It is a strong dibasic acid and can be a reducing acid, an oxidizing acid, and/or a dehydrating agent.

In the chemical industry, sulfuric acid has many diverse applications. The largest quantities are used to manufacture phosphate and nitrogen based fertilizers. The petrochemical sector utilizes sulfuric acid in alkylation and paraffin refining. The inorganic branch of the chemical industry uses sulfuric acid in the production of chromic and hydrofluoric acids, aluminum sulfate and sodium sulfate. The organic arm employs sulfuric acid in the manufacture of explosives, soaps, detergents, dyes, isocyanates, plastics, pharmaceuticals, etc. Everywhere one turns today, we encounter products which use sulfuric acid in their manufacturing process.

Many chemical plants use sulfuric acid in one or more process steps and this generally results in severe corrosion problems. Each process has unique minor constituents that can change the way metals corrode. Zirconium has been used very successfully in many sulfuric acid applications. The advantage of zirconium is that corrosion rate will be very small if properly applied and equipment life of over 20 years is expected. Since there is no corrosion maintenance, repair, downtime and replacement costs do not exist and will quickly pay back for the slightly higher initial cost.

Corrosion Resistance of Zirconium Vs. Other Materials in Sulfuric Acid

		CORROSION RATE (mpy)				
CONCENTRATION (%)	TEMP. (°C)	Zr 702	310L S.S.	316L S.S.	Alloy B-2	Alloy C-276
10	102*	<0.1	45	574	<1	7.0
30	108*	<0.1	1,137	5,000	2	55
55	132*	0.1	350,000	10,000	1.89	295
55	168	19.6	—	—	37	212
2	225	<0.1	—	—	14.9	39.7
5	232	0.1	—	—	110	153
10	225	0.1	—	—	1,023	661

*Boiling point **Heat treating of zirconium weldments may be required for sulfuric acid.

ACETIC ACID

Acetic acid is one of the basic components in a wide range of organic materials including acetate esters, acetic anhydride, terephthalic acid, aspirin and other pharmaceuticals. Zirconium is considered the most corrosion resistant material in virtually all acetic acid solutions. The few exceptions include acetic acid containing cupric ions, free chlorine and solutions with insufficient moisture to allow zirconium to reform its protective oxide surface layer. Under highly stressed conditions, >650-ppm water is required in acetic acid to prevent stress corrosion cracking. If water addition is not practical, stress relieving may be considered.

Corrosion Resistance of Zirconium in Acetic Acid

MEDIA	CONCENTRATION (%)	TEMPERATURE (°C)	CORROSION RATE (mpy)
Acetic Acid (amhydride)	99	Room – boiling	<1
Acetic Acid	5 – 99.5	35 – boiling	<1
Acetic Acid	99	200	<1
Acetic Acid (glacial)	99.7	Boiling	<1
Acetic Acid (glacial) + 0.5% methanol	99	200	<1
Acetic Acid (glacial) + 0.5% methanol + 200 ppm $FeCl_3$ + 1% H_2O	98	200	<1
Acetic Acid (glacial) + 200 ppm $FeCl_3$	99	200	<1
Acetic Acid + 0.5% methanol + 200 ppm $FeCl_3$ + 5% H_2O	94	200	<1
Acetic Acid + 1% I^-(KI) + 100 ppm Fe^{+3}($Fe_2(SO_4)_3$)	99	200	<1
Acetic Acid + 10% methanol	90	200	<1
Acetic Acid + 10% methanol + 200 ppm $FeCl_3$ + 1% H_2O	88	200	<1
Acetic Acid + 10% methanol + 200 ppm $FeCl_3$ + 5% H_2O	84	200	<1
Acetic Acid + 10% methanol + 1000 ppm copper Acetate	89	89	<1 pit
Acetic Acid + 10% methanol + 1000 ppm Cupric Chloride	89	89	<1 pit
Acetic Acid + 10% methanol + copper metal	89	89	<1 pit
Acetic Acid + 1000 ppm copper Acetate	99	115	<1 pit
Acetic Acid + 1000 ppm copper metal	89	115	<1 pit
Acetic Acid + 1000 ppm Cupric Chloride	89	115	<1 pit
Acetic Acid + 2% HI	80	100	<1
Acetic Acid + 2% HI	98	150	<1
Acetic Acid + 2% HI + 1% methanol + 500 ppm formic acid	80	150	<1
Acetic Acid + 2% HI + 1000 ppm copper Acetate	97	115	<1 pit
Acetic Acid + 2% HI + 1000 ppm copper metal	97	115	<1 pit
Acetic Acid + 2% HI + 200 ppm Cl^-(NaCl)	80	100	<1
Acetic Acid + 2% HI + 200 ppm Fe^{+3}($FeCl_3$)	80	100	<1
Acetic Acid + 2% HI + 200 ppm Fe^{+3}($Fe_2(SO_4)_3$)	80	100	<1
Acetic Acid + 2% HI + 1% methanol + 500 ppm formic acid + 100 ppm copper	80	150	<1
Acetic Acid + 2% I^-(KI)	98	150	<1
Acetic Acid + 48% HBr	50	115	<1
Acetic Acid + 50% Acetic Anhydride	50	Boiling	<1
Acetic Acid + 50 ppm I^-(KI)	100	160,200	<1
Acetic Acid + HCl bubble	98	21	<1 pit
Acetic Acid + HCl bubble + chlorine bubble (liquid & vapor)	98	102	>50
Acetic Acid + Saturated, gaseous HCl and Cl_2	100	Boiling	>200
Acetic Acid + Saturated, gaseous HCl and Cl_2	100	40	<1
Acetic Acid + 1% acetyl chloride	99	Boiling	>50
Acetic Acid + 0.1% acetyl chloride	99	Boiling	wg
Acetic Acid + 200 ppm acetyl chloride	99	Boiling	wg

FORMIC ACID

More corrosive than acetic acid, formic acid is used in the production of pharmaceuticals, dyes and artificial flavors. The leather, textile, rubber, and pulp and paper industries also use formic acid in their process.

Corrosion Resistance of Zirconium in Formic Acid

MEDIA	CONCENTRATION (%)	TEMPERATURE (°C)	CORROSION RATE (mpy)
Formic Acid	10 – 98	35 – boiling	<1
Formic Acid (aerated)	10 – 90	Room – 100	<1
Formic Acid + 5% sulfuric acid	50, 70, 93	Boiling	<1
Formic Acid + 5% hydrochloric acid	50, 70, 85	Boiling	<1
Formic Acid + 1% Cupric Chloride	50, 70, 96	Boiling	<1
Formic Acid + 1% iron powder	50, 70, 98	Boiling	<1
Formic Acid + 5% HI	50, 70, 90	Boiling	<1
Formic Acid + 2% hydrogen peroxide	50	80	<1
Formic Acid + 4% hydrogen peroxide	50	80	<1

Corrosion Resistance of Zirconium in Various Media

MEDIA	CONCENTRATION (%)	TEMPERATURE (°C)	CORROSION RATE (mpy)
Acetaldehyde	100	Boiling	<2
Acetyl Chloride	100	25	>200
Aniline Hydrochloride	5, 20	35 – 100	<1
Aniline Hydrochloride	5, 20	100	<2
Bromochloromethane	100	100	<2
Dichloroacetic Acid	100	Boiling	<20
Ethylene Dichloride	100	Boiling	<5
Formaldehyde	6 – 37	Boiling	<1
Formaldehyde	0 – 70	Room – 100	<2
Formalin	100	98	<1
Hydroxyacetic Acid	70	205	<1
Methanol + 0.1% KI + 0.1% formic acid	99.8	65	Nil
Melamine	100	260	<1
Melamine	100	427	<1
Methanol + 1% KI	99	200	<1
Oxalic Acid	0 – 100	100	<1
Oxalic Acid + 52% sulfuric acid	4	82	<1
Oxalic Acid + 52% sulfuric acid + 3% nitric acid + 2.5% ferrous sulfate	4	82	Gained Weight
Phenol	Saturated	Room	<5
Phenol + 11% hydrochloric acid	60	70	<1
Phenol + 27% hydrochloric acid	7.2	100	<1
Sodium Formate	0 – 80	100	<2
Sodium Phenolsulfonate	100	185	<1
Tannic Acid	25	35 – 100	<1
Tartaric Acid	10 – 50	35 – 100	<1
Tetrachloroethane	100	Boiling	<5
Trichloroethylene	99	Boiling	<5
Urea	50	Boiling	<1
Urea Reactor Mixture— 45% urea, 17% ammonia, 15% carbon dioxide, 10% water	Mixture	193	<1

APPLICATIONS OF TANTALUM

THE OBVIOUS CHOICE

Tantalum is a refractory metal with a melting point of 5425˚F (2996˚C). It is a tough, ductile metal which can be formed into almost any shape. It is used in corrosion resistant applications for environments no other metal can withstand. The major limitation of Tantalum is its reactivity with oxygen and nitrogen in the air at temperatures above 300˚C.

CORROSION RESISTANCE

Tantalum is the most corrosion resistant metal in common use today. The presence of a naturally occurring oxide film on the surface of Tantalum is the reason for its extreme corrosion resistant properties. It is inert to practically all organic and inorganic compounds. Its corrosion resistance is very similar to glass as both are unsuitable for use in hydrofluoric acid and strong hot alkali applications. For this reason Tantalum is often used with glass lined steel reactors as patches, dip tubes, piping and overhead condensers. Tantalum is inert to sulfuric and hydrochloric acid in all concentrations below 300˚F. Attack up to 400˚F is not significant and is in common use up to 500˚F. Tantalum is not attacked by nitric acid in concentrations up to 98% and temperatures up to at least 212˚F. Tantalum has proven itself to be totally inert in many applications. Some heat exchanger installations have been in continuous use for over 40 years in multi-product research environments without so much as a gasket change.

WIDE RANGE OF APPLICATIONS

The corrosion resistance, heat transfer properties and workability of Tantalum make it a perfect construction material for a wide range of equipment and applications. Tantalum is used in heat exchangers, condensers, columns, reactors, helical coils, pipe spools, valve linings and a variety of other components exposed to extremely corrosive fluids. It can be fabricated into most TEMA design shell and tube heat exchangers and bayonet heaters for chemical, petrochemical and pharmaceutical applications.

CORROSION RESISTANCE OF TANTALUM (MILS PER YEAR)

MEDIA	CONCENTRATION	TEMPERATURE	NB	TA	TI	ZR
Acetic Acid	50%	Boiling	Nil	Nil	Nil	Nil
Bromine	Dry	200˚F	Nil	Nil	Nil	Nil
Chlorine	Wet	220˚F	Nil	Nil	Nil	10
Chromic Acid	50%	Boiling	1	Nil	>5	5
HCL	5%	200˚F	1	Nil	100	Nil
HCL	30%	200˚F	5	Nil	100	Nil
Nitric Acid	65%	Boiling	Nil	Nil	1	1
Nitric Acid	99%	Boiling	Nil	Nil	5	1
Sodium Hydroxide	10%	Room	Nil[1]	Nil[1]	Nil	Nil
Sulfuric Acid	40%	Boiling	Nil	Nil	5	3
Sulfuric Acid	98%	400˚F	5	Nil	50	200

[1] *Note: Material may become embrittled due to hydrogen attack.*

Tantalum can be clad to carbon steel to form a bimetallic material of construction. The Tantalum is used as a corrosion barrier while the substrate is used to contain pressure and stress. The corrosion resistance of Tantalum together with the low cost and high strength of carbon steel can often be the most economical choice for high pressure equipment.

Tantalum is the material to consider in any application where corrosion is a factor and the long-term benefits of reduced downtime, increased life expectancy and profitability is important. For many applications, Tantalum is the only reasonable choice.

TANTALUM OUTPERFORMS OTHER MATERIALS

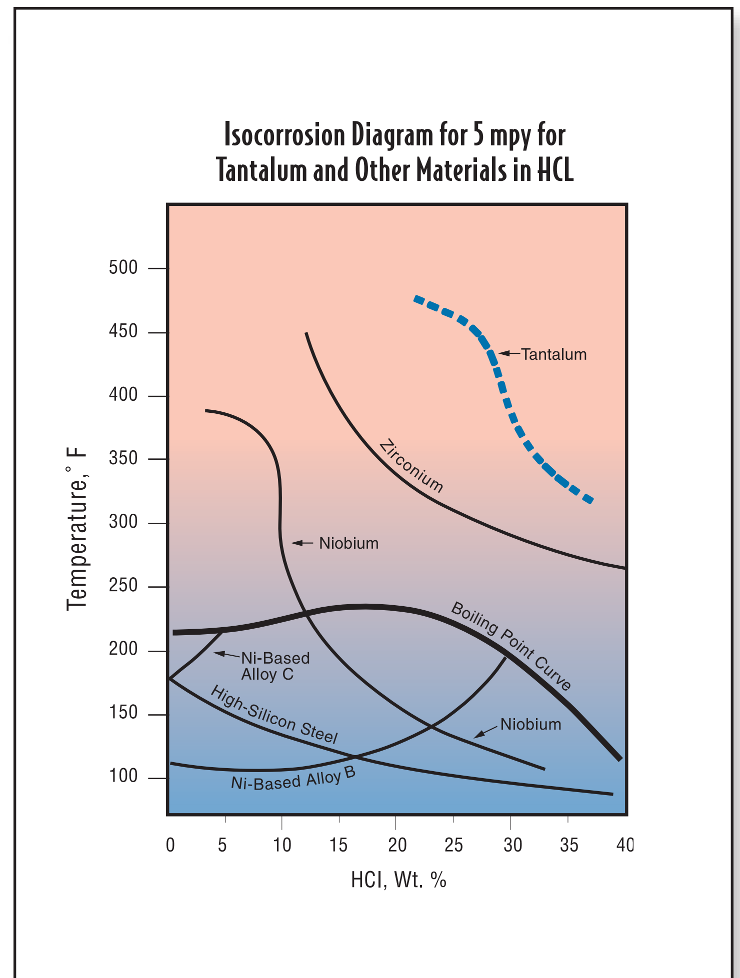
Today's global economy means increased competition. The control of cost including manufacturing efficiency, plant equipment costs and maintenance are paramount to survival. Chemical producers have recognized that increasing pressure and temperature increases efficiency in many applications. This also increases corrosion problems which Tantalum can handle.

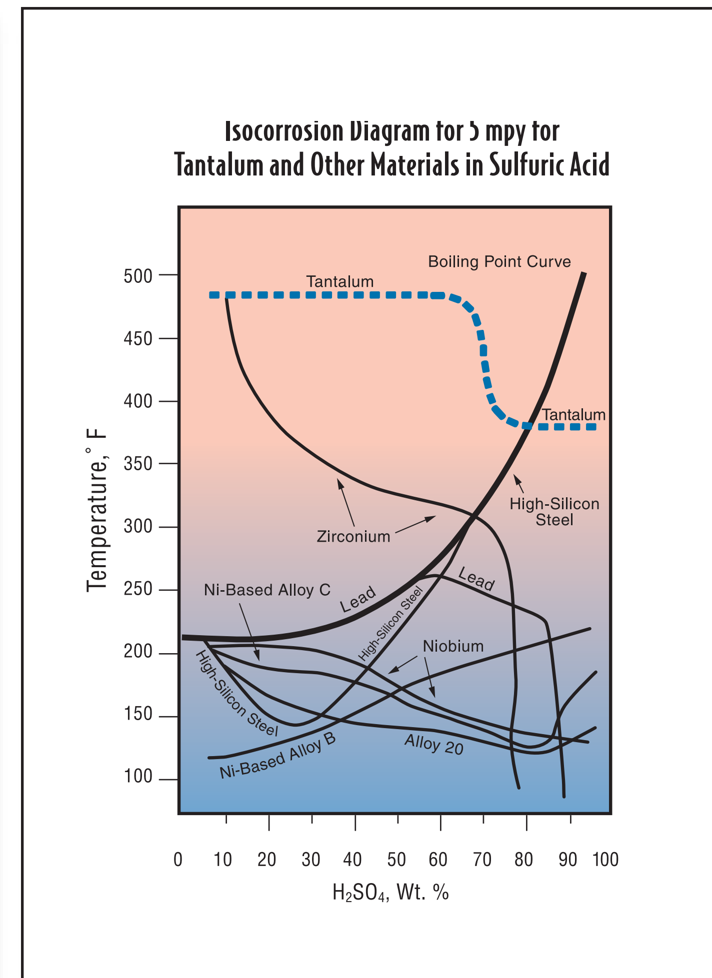
The largest cost of all is often maintenance and downtime. Industries from steel pickling to pharmaceutical have recognized that to stay competitive you first have to stay in production. It is no coincidence that the world's best, most progressive, and most profitable steel pickling and pharmaceutical companies standardize on Tantalum equipment to solve their corrosion problems.

The relatively high initial cost of Tantalum equipment is offset by its extremely low corrosion and long lifetime. Life cycle costs and manufacturing efficiencies need to be evaluated for a globally competitive manufacturing facility. Tantalum process equipment meets all these challenges.

PRICE AND AVAILABILITY

Tantalum is always found in nature in its oxide form. This oxide is very difficult to break which gives Tantalum its extraordinary corrosion resistance. However, to make pure Tantalum metal, the oxide must be broken. The process by which this is done is complicated and costly, and is the reason why Tantalum is more expensive than most metals. It is not because Tantalum is rare like Gold or Silver. The Tantalum industry has recently completed a large amount of capital spending, increasing supply by 30% to 40%. This will insure a stable price and delivery situation for many years to come.





ATOMIC & CRYSTALLOGRAPHIC

	TITANIUM	ZIRCONIUM	TANTALUM
Atomic Number	22	40	73
Atomic Weight	47.90	91.22	180.95
Atomic Volume	10.64cm^3/g-atom	10.9cm^3/g-atom	10.9cm^3/g-atom
Lattice Type	Body Center Cubic	Body Center Cubic	Body Center Cubic

MASS

	TITANIUM	ZIRCONIUM	TANTALUM
Density at 20°C (68°F)	4.51g/cm^3 0.163 lb/in^3	6.51g/cm^3 0.235 lb/in^3	16.6g/cm^3 0.600 lb/in^3

THERMAL

	TITANIUM	ZIRCONIUM	TANTALUM
Melting Point	1660°C 3320°F	1852°C 3665°F	2996°C 5425°F
Boiling Point	3285°C 5945°F	4377°C 7910°F	5425°C 9800°F
Specific Heat at 0°C	0.52 J/gK	0.27 J/gK	0.14 J/gK
Average Linear Coefficient of Expansion at 25°C (77°F)	8.64 cm/cm/°C × 10^{-6} 4.8 in/in/°F × 10^{-6}	5.89cm/cm/°C × 10^{-6} 3.3 in/in/°F × 10^{-6}	6.6cm/cm/°C × 10^{-6} 3.7 in/in/°F × 10^{-6}

THERMAL CONDUCTIVITY

	TITANIUM	ZIRCONIUM	TANTALUM
20°C (68°F)	219 Watts/cmK 12.6 BTU/hr-ft°F	.22 Watts/m-K 13 BTU/hr-ft°F	.13 Cal/cm-sec°C 36 BTU/hr-ft°F

MECHANICAL PROPERTIES OF TITANIUM GRADES 2, 7, 16, 26

Tensile Strength (Minimum)	345 Mpa — 50,000 PSI
Yield Strength (Minimum)	276 Mpa — 40,000 PSI
Modulus of Elasticity (Tension)	103 Gpa — 15,000,000 PSI
Nominal Hardness	98 Hrb

MECHANICAL PROPERTIES OF ZIRCONIUM 702

Tensile Strength (Annealed)	379 Mpa — 55,000 PSI
Yield Strength (Annealed)	207 Mpa — 30,000 PSI
Modulus of Elasticity (ASTM MIN)	
20°C (68°F)	99.2 Gpa — 14,400,000 PSI
260°C (500°F)	75.2 Gpa — 10,900,000 PSI
Nominal Hardness	78 Hrb

MECHANICAL PROPERTIES OF TANTALUM + 2% TUNGSTEN

Tensile Strength (Annealed)	275.8 Mpa — 40,000 PSI
Yield Strength (Annealed)	206.8 Mpa — 30,000 PSI
Modulus of Elasticity (Tension)	185 Gpa — 27,000,000 PSI)
Nominal Hardness	51 Hrb

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