# ALLOY C-276

ALLOY C-276 (UNS N10276/W.Nr. 2.4819) is known for its corrosion resistance in a wide range of aggressive media. The high molybdenum content imparts resistance to localized corrosion such as pitting. The low carbon minimizes carbide precipitation during welding to maintain resistance to intergranular attack in heat affected zones of welded joints. It is used in chemical processing, pollution control, pulp and paper production, industrial and municipal waste treatment and the recovery of “sour” natural gas. Applications in air pollution control include stack liners, ducts, dampers, scrubbers, stack-gas re-heaters, fans and fan housings. In chemical processing, the alloy is used for components including heat exchangers, reaction vessels, evaporators and transfer piping.

**Corrosion Resistance**
ALLOY C-276 is resistant to general corrosion, stress corrosion cracking, pitting and crevice corrosion in a broad range of severe environments. Its resistance to carbide precipitation during welding maintains corrosion resistance in the heat affected zones of welded joints.
It has exceptional resistance to sulfuric acid and hydrochloric acid. It resists many of the most severe media encountered in chemical processing, including reducing and oxidizing acids, highly oxidizing, neutral, and acid chlorides, solvents, formic and acetic acids, acetic anhydride, wet chlorine gas, hypochlorites, and chlorine solutions. It has excellent resistance to phosphoric acid. At all temperatures below the boiling point and at concentrations lower than 65 wt %, tests have shown corrosion rates of less than 5 mpy (0.13 mm/y).
ALLOY C-276 exhibits excellent resistance to corrosion by seawater especially under crevice conditions which induce attack in other commonly used materials such as 316 stainless steel, ALLOY 400, and ALLOY 625.

The performance of ALLOY C-276 in a severe test for susceptibility to intergranular attack (ASTM G 28) is shown below in Table 8. The base corrosion rates listed are representative of typical production material. Rates significantly higher than these indicate susceptibility to intergranular attack. This test is designed to verify mill production only and not to compare alloys for use in applications such as flue gas desulfurization.

**Corrosion Resistance Flue Gas Desulfurization**
ALLOY C-276 is useful for flue gas desulfurization (FGD) systems to control air pollution from electric power plants. The alloy is used for various applications including scrubbers, ducting and stack liners.
Scrubber liquors and gas condensates generally contain chlorides and the chloride level often determines the corrosion behaviour of the materials.
ALLOY C-276 has been shown to withstand higher chloride content than other alloys before the onset of localized corrosion in a simulated scrubber environment.

**Corrosion Resistance Oilfield Applications**
ALLOY C-276 is one of the premier materials for recovery and handling of “sour” natural gas, which contains hydrogen sulfide and usually carbon dioxide and chlorides. The gas can be extremely corrosive to carbon and alloy steels, and may cause brittle failure of many alloys by sulfide stress cracking (hydrogen embrittlement) or stress corrosion cracking.
The high levels of nickel, chromium, and molybdenum in ALLOY C-276 make the alloy resistant to sour environments even at high temperatures in deep wells. The alloy is used for tubing and a variety of other downhole and surface components.

**Heat Treatments**
Hot forming should be between 1600 and 2250°F (870 and 1230°C), with all heavy forming above 2000°F (1090°C). ALLOY C-276 is normally annealed at 2100-2150°F (1150-1175°C) and rapidly cooled such as by water quenching.

**Welding**
ALLOY C-276 has good weldability and can be used as welded for most applications.

Table 1 - Limiting Chemical Composition, %

| | |
|---|---|
| Nickel | Balance |
| Molybdenum | 15.0-17.0 |
| Chromium | 14.5-16.5 |
| Iron | 4.0-7.0 |
| Tungsten | 3.0-4.5 |
| Cobalt | 2.5 max. |
| Manganese | 1.0 max. |
| Carbon | 0.01 max. |
| Vanadium | 0.35 max. |
| Phosphorus | 0.04 max. |
| Sulfur | 0.03 max. |
| Silicon | 0.08 max. |

Table 2 - Physical Properties

| Temp | Thermal Conductivity | Coeff. of Expansion[a] | Electrical Resistivity | Young's Modulus |
|---|---|---|---|---|
| °F | Btu•in./ft$^2$•h°F | $10^{-6}$ in/in•°F | ohm•cmil/ft | $10^3$ ksi |
| -270 | 50 | - | - | - |
| -100 | 60 | - | 0 | - |
| 0 | 65 | - | - | - |
| 77 | - | - | 739.2 | 29.8 |
| 100 | 71 | - | - | - |
| 200 | 77 | 6.8 | 743.8 | 29.5 |
| 400 | 90 | 7.0 | 749.3 | 28.6 |
| 600 | 104 | 7.2 | 757.7 | 27.8 |
| 800 | 117 | 7.4 | 760.3 | 26.7 |
| 1000 | 132 | 7.5 | 772.5 | 25.7 |
| 1200 | 145 | 7.7 | 781.5 | 24.8 |
| 1400 | 159 | 8.1 | 773.9 | 23.5 |
| 1600 | 173 | 8.5 | 768.3 | 22.0 |
| 1800 | 185 | - | 766.2 | 20.6 |
| 2000 | 195 | - | 757.7 | 19.1 |
| °C | W/m•°C | µm/m•°C | µΩ•cm | GPa |
| -168 | 7.2 | - | - | - |
| -73 | 8.7 | - | - | - |
| 20 | 9.8 | - | - | - |
| 25 | - | - | 122.9 | 205 |
| 100 | 11.2 | 12.2 | 123.7 | 203 |
| 200 | 12.8 | 12.4 | 124.5 | 198 |
| 300 | 14.7 | 12.9 | 125.7 | 192 |
| 400 | 16.4 | 13.2 | 126.0 | 186 |
| 500 | 18.2 | 13.5 | 127.7 | 180 |
| 600 | 20.0 | 13.6 | 129.9 | 178 |
| 700 | 21.9 | 14.1 | 129.7 | 167 |
| 800 | 23.7 | 14.8 | 128.2 | 159 |
| 900 | 25.4 | - | 127.4 | 150 |
| 1000 | 27.0 | - | 127.1 | 141 |
| 1100 | 28.3 | - | - | - |

[a]Mean coefficient of linear expansion between 77°F (25°C) and temperature shown.

Table 3 - Physical Constants

| | | |
|---|---|---|
| Density, lb/in$^3$ | | 0.321 |
| | g/cm$^3$ | 8.89 |
| Melting Range, °F | | 2415-2500 |
| | °C | 1325-1370 |
| Thermal Conductivity, Btu•in/ft$^2$•h•°F | | 67.9 |
| | W/m•°C | 9.8 |
| Specific Heat, Btu•lb•°F | | 0.102 |
| | J/kg•°C | 427 |
| Young's Modulus, $10^3$ ksi | | 29.8 |
| | GPa | 205 |
| Shear Modulus, $10^3$ ksi | | 11.4 |
| | GPa | 79 |
| Permeability at 200 oersted (15.9 kA/m) | | 1.0002 |
| Poisson's Ratio | | 0.307 |

Table 4 - Elevated Temperature Dynamic Modulus Properties

| Temperature | Young's Modulus | Shear Modulus | Poisson's Ratio |
|---|---|---|---|
| °F | $10^3$ ksi | $10^3$ ksi | |
| 70 | 31.30 | 11.81 | 0.33 |
| 100 | 31.18 | 11.75 | 0.33 |
| 200 | 30.77 | 11.57 | 0.33 |
| 300 | 30.35 | 11.40 | 0.33 |
| 400 | 29.92 | 11.23 | 0.33 |
| 500 | 29.42 | 11.05 | 0.33 |

**Table 5** - Corrosion Rates in Acid Solutions[a]

| Solution | Temperature | | Corrosion Rate, mpy (mm/a) | | | |
|---|---|---|---|---|---|---|
| | °F | °C | alloy C-276 | alloy 22 | alloy 625 | alloy 686 |
| 10% $H_2SO_4$ | Boiling | Boiling | 20 (0.51) | 22 (0.56) | 17 (0.43) | 3 (0.08) |
| 20% $H_2SO_4$ | 176 | 80 | 3 (0.08) | 1 (0.03) | 1 (0.03) | - |
| 40% $H_2SO_4$ | 176 | 80 | 5 (0.13) | 10 (0.25) | 5 (0.13) | - |
| 80% $H_2SO_4$ | 176 | 80 | 4 (0.10) | 9 (0.23) | 6 (0.15) | 4 (0.10) |
| 95% $H_2SO_4$ | 122 | 50 | 0.1 (0.003) | - | 48 (1.2) | - |
| 5% $H_2SO_4$ + 0.1% HCl | Boiling | Boiling | 22 (0.56) | 24 (0.61) | - | - |
| 10% $H_2SO_4$ + 1% HCl | Boiling | Boiling | 70 (1.78) | 201 (5.11) | 465 (11.68) | - |
| 10% $H_2SO_4$ + 2% HCl | Boiling | Boiling | 138 (3.51) | 281 (7.14) | - | 132 (3.35) |
| 10% $H_2SO_4$ + 2% HCl | 122 | 50 | 0.2 (0.005) | 0.1 (0.003) | 0.1 (0.003) | 0 (0) |
| 10% $H_2SO_4$ + 5% HCl | Boiling | Boiling | 256 (6.50) | 456 (11.58) | - | - |
| 40% $H_2SO_4$ + 10% HCl | 176 | 80 | 26 (0.66) | 32 (0.81) | - | - |
| 2% HCl | Boiling | Boiling | 43 (1.09) | 52 (1.32) | - | 6 (0.15) |
| 5% HCl | 140 | 60 | 10 (0.25) | - | 46 (1.17) | 1.2 (0.30) |
| 20% HCl | 212 | 100 | 154 (3.91) | 269 (6.83) | 385 (9.78) | - |
| 5% HCl + 2% HF | 158 | 70 | 18 (0.46) | 40 (1.02) | 102 (2.59) | - |
| 85% $H_3PO_4$ | Boiling | Boiling | 10 (0.25) | 13 (0.33) | >180 (>4.57) | 16 (0.41) |
| 10% $HNO_3$ + 3% HF | Boiling | Boiling | 95 (2.41) | 23 (0.61) | 28 (0.71) | - |

[a]168 h tests.

**Table 6** - Corrosion Rates in Hydrochloric, Phosphoric and Acetic Acids[a]

| Solution | Temperature | | Corrosion Rate, mpy (mm/a) | | | | |
|---|---|---|---|---|---|---|---|
| | °F | °C | alloy C-276 | alloy 25-6MO | alloy 27-7MO | alloy 22 | alloy 686 |
| 0.2% HCl | Boiling | Boiling | 0.60 (0.02) | <0.1 (<0.003) | 1.3 (0.03) | <0.1 (<0.003) | 0.20 (0.005) |
| 1% HCl | Boiling | Boiling | 6.5 (0.17) | 119 (3.02) | <0.1 (<0.003) | 2.7 (0.07) | 2.0 (0.05) |
| | 194 | 90 | 3.5 (0.09) | 37.0 (0.94) | <0.1 (<0.003) | - | - |
| | 158 | 70 | 0.74 (0.02) | 0.02 (<0.001) | <0.1 (<0.003) | - | - |
| 5% HCl | 158 | 70 | 13.2 (0.34) | 142 (3.61) | 150 (3.8) | 18.8 (0.48) | 9.8 (0.25) |
| | 122 | 50 | 0.5 (0.01) | 43.4 (1.10) | 5 (0.13) | 1 (0.03) | 0 (0) |
| 85% $H_3PO_4$ | Boiling | Boiling | 10.4 (0.26) | 114 (2.90) | 27 (0.69) | 13.0 (0.33) | 16.2 (0.41) |
| | 194 | 90 | 0.20 (0.005) | 10.6 (0.27) | <0.1 (<0.003) | 0.21 (0.005) | 0.18 (0.005) |
| 80% $CH_3COOH$ | Boiling | Boiling | 0.15 (0.004) | <0.1 (<0.003) | <1 (<0.03) | <0.1 (<0.003) | <0.1 (<0.003) |

[a]192 h tests.

**Table 7** - Corrosion Rates in Various Media[a]

| Solution | Temperature | | Corrosion Rate | |
|---|---|---|---|---|
| | °F | °C | mpy | mm/a |
| 10% $HNO_3$ | Boiling | Boiling | 15[b] | 0.38[b] |
| 10% $HNO_3$ + 2% HCl | 180 | 82 | 6.5 | 0.17 |
| 15% $HNO_3$ + 3% HF | 140 | 60 | 179 | 4.55 |
| 20% $HNO_3$ + 2% HF | 140 | 60 | 215 | 5.46 |
| 3% HF | 176 | 80 | 53 | 1.35 |
| 10% HF | 75 | 24 | 2 | 0.05 |
| 10% HF | 176 | 80 | 28 | 0.71 |
| Concentrated HF | 75 | 24 | 1 | 0.03 |
| Concentrated HF | 176 | 80 | 34 | 0.86 |
| 20% $H_3PO_4$ | Boiling | Boiling | <1 | <0.03 |
| 60% $H_3PO_4$ | Boiling | Boiling | 1 | 0.03 |
| 85% $H_3PO_4$ | 212 | 100 | <1 | <0.03 |
| 85% $H_3PO_4$ | Boiling | Boiling | 10 | 0.25 |
| 99.9% $CH_3COOH$ + 0.1% NaCl | Boiling | Boiling | <1 | <0.03 |
| 50% NaOH | Boiling | Boiling | 1 | 0.03 |
| 10% HBr | 176 | 80 | <1 | <0.03 |
| 10% HBr | Boiling | Boiling | <1 | <0.03 |
| 10% $NH_3Br$ | 176 | 80 | 0 | 0.00 |
| 10% $NH_3Br$ | Boiling | Boiling | 0 | 0.00 |

[a]Test duration of 168 h except as noted.
[b]Test duration of 24 h.

**Table 8** - ASTM G28 Tests for Intergranular Attack

| Alloy | Method A[a] Corrosion Rate | | Method B[b] Corrosion Rate | |
|---|---|---|---|---|
| | mpy | mm/a | mpy | mm/a |
| alloy C-276 | 175 | 4.45 | 30 | 0.76 |

[a]Boiling ferric sulfate/50% sulfuric acid.
[b]Boiling 23% $H_2SO_4$ + 1.2% HCl + 1% $FeCl_3$ + 1% $CuCl_2$.

**Table 9** - Critical Crevice and Critical Pitting Temperatures in an Acidified 6% Ferric Chloride Solution (ASTM G 48, Methods C & D)

| Alloy | Critical Crevice Temperature | | Critical Pitting Temperature | |
|---|---|---|---|---|
| | °C | °F | °C | °F |
| alloy 686 | >85 | >185 | >85 | >185 |
| alloy 22 | 75 | 167 | >85 | >185 |
| alloy C-276 | 50 | 122 | >85 | >185 |
| alloy 27-7MO | 45 | 122 | >85 | >185 |
| alloy 625 | 35 | 95 | >85 | >185 |
| alloy 25-6MO | 35 | 86 | 70 | 158 |
| alloy 825 | 5 | 41 | 30 | 86 |
| AISI Stainless Steel | <0 | <32 | 20 | 68 |

**Table 10** - Corrosion Rates[a] in Simulated FGD Mixed-Gas Condensate Solutions

| Solution | Temperature | | Corrosion Rate, mpy (mm/a) | | |
|---|---|---|---|---|---|
| | °F | °C | alloy C-276 | alloy 22 | alloy 625 |
| Solution 1[b] | 185 | 85 | 82 (2.08) | 20 (0.51) | 14 (0.36) |
| Solution 2[c] | 176 | 80 | 42 (1.07) | 50 (1.27) | 126 (3.20) |

[a]168 h test.
[b]60% $H_2SO_4$ + 0.5% HCl + 0.1% HF + 0.1% $HNO_3$.
[c]60% $H_2SO_4$ + 2.5% HCl + 0.2% HF + 0.5% fly ash.

**Table 11** - Maximum Pitting or Crevice Attack, mils (mm), in FGD Scrubber Slurry[a]

| Alloy | Quencher | Absorber | Absorber Outlet | Outlet Duct | Bypass Duct |
|---|---|---|---|---|---|
| AISI 316L | 22 (0.56) | 21 (0.53) | 35 (0.89)[b] | 35 (0.89)[b] | 12 (0.30) |
| AISI 317LM | 20 (0.51) | 22 (0.56) | 29 (0.74) | 33 (0.84) | 29 (0.74) |
| alloy 825 | 15 (0.38) | 33 (0.84) | 39 (0.99) | 50 (1.27)[b] | 10 (0.25) |
| alloy 625 | <2 (<0.05) | 10 (0.25) | 11 (0.28) | 7 (0.18) | nil |
| alloy C-276 | nil | nil | <2 (<0.05) | nil | nil |

[a]6-month exposure at 126°F (52°C), pH 5.5, 5000 ppm chlorides.
[b]Perforated.

**Table 12** - Maximum Pitting or Crevice Attack, mils (mm), in Scrubber Slurry[a]

| Alloy | Scrubber Bottom | Under Spray Nozzles | Scrubber Outlet | Hold Tank |
|---|---|---|---|---|
| AISI 316 | 5 (0.13) | 7 (0.18) | 49 (1.24)[b] | 2 (0.05) |
| alloy 825 | <2 (<0.05) | 1.2 (0.03) | 49 (1.24)[b] | nil |
| alloy 625 | nil | nil | 26 (0.66) | nil |
| alloy C-276 | nil | nil | nil | nil |

[a]3-month exposure at 120°F (49°C), pH 5.8-6.1, 10,000 ppm chlorides.
[b]Perforated.

**Table 13** - C-Ring Tests in NACE Solution[a]

| Material Condition | Simulated Well Age | Yield Strength (0.2% Offset) | | Hardness, Rockwell C | Duration, Days | Sulfide Stress Cracking |
|---|---|---|---|---|---|---|
| | | ksi | MPa | | | |
| Cold Worked | 600°F (315°C)/1000 h | 126.6 | 873 | 32 | 43 | No |
| Cold Worked | 600°F (315°C)/1000 h | 155.1 | 1069 | 38 | 43 | No |
| Cold Worked | 600°F (315°C)/1000 h | 166.8 | 1150 | 35 | 43 | No |
| Cold Worked | 600°F (315°C)/1000 h | 188.7 | 1301 | 43 | 43 | No |

[a]Room-temperature tests at 100% of yield strength in 5% NaCl plus 0.5% acetic acid saturated with $H_2S$. All specimens were coupled to carbon steel.

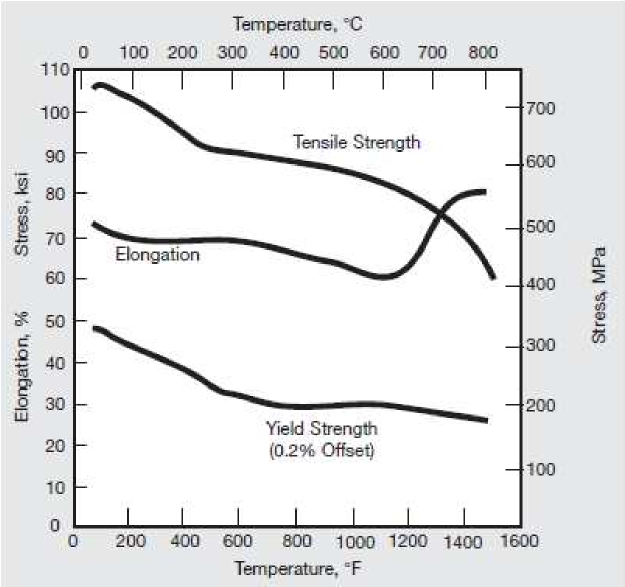


**Figure 1.** Tensile properties of annealed plate.

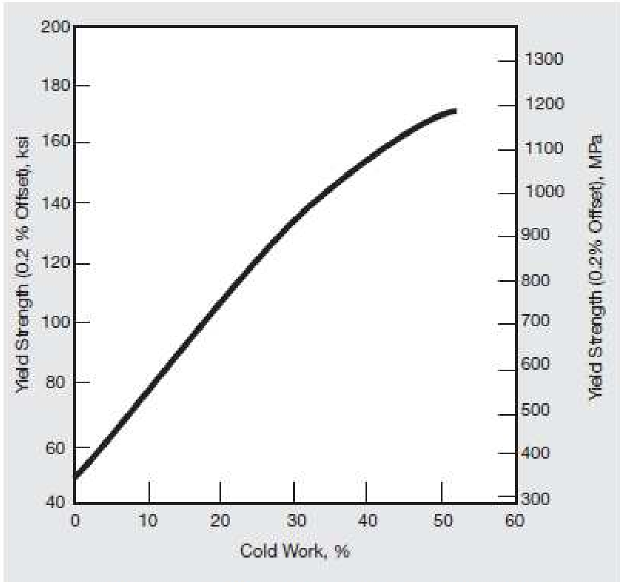


**Figure 2.** Effect of cold work on the yield strength of annealed plate.

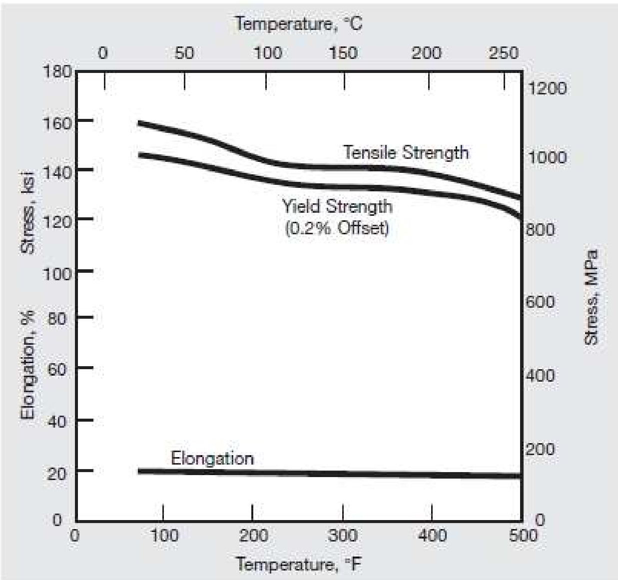


**Figure 3.** Tensile properties of 33.5% cold-worked tubing.

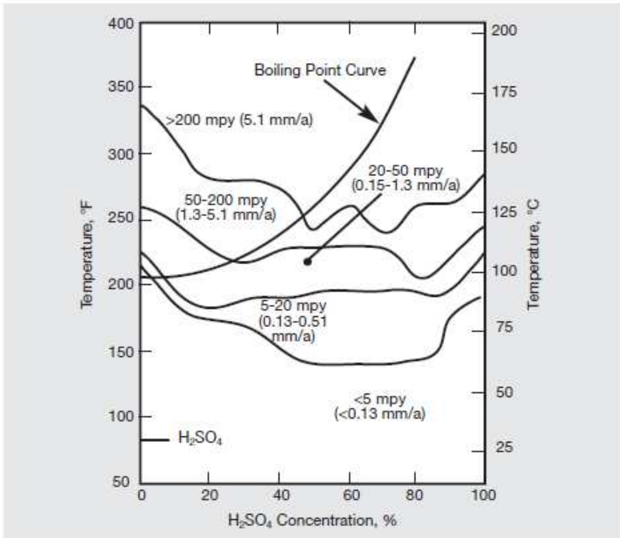


**Figure 4.** Corrosion rates in sulfuric acid.

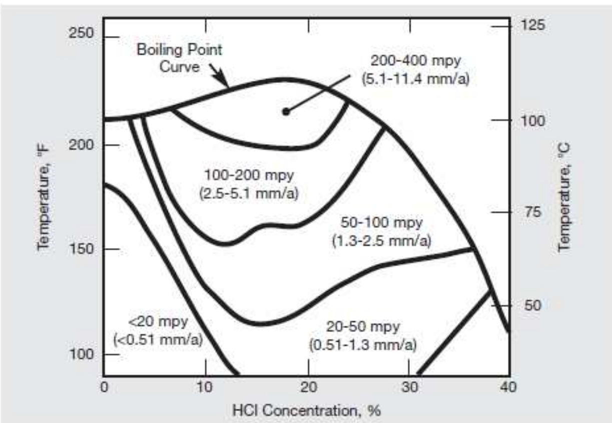


**Figure 5.** Corrosion rates in oxygen-saturated hydrochloric acid.

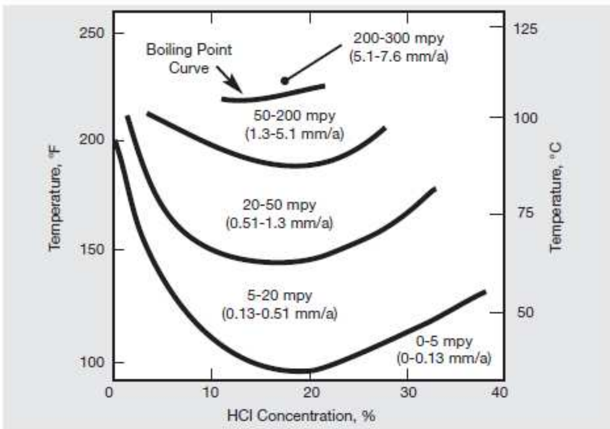


**Figure 6.** Corrosion rates in hydrochloric acid.

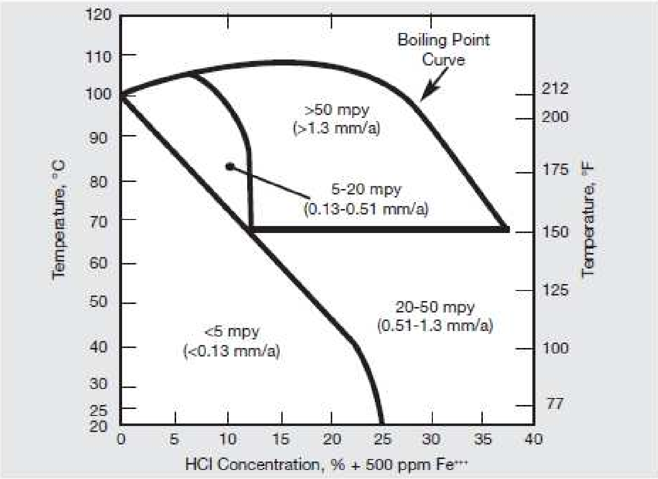


**Figure 7.** Corrosion rates in hydrochloric acid + 500 ppm $Fe^{+++}$

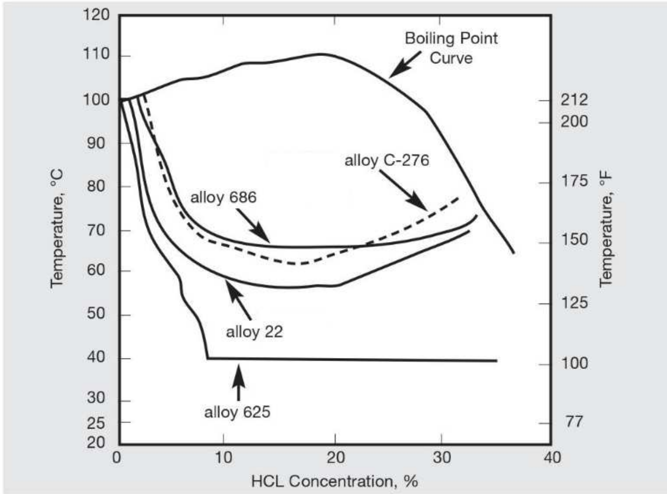


**Figure 8.** Corrosion resistance in hydrochloric acid. The isocorrosion curves show temperatures and concentrations above which the corrosion rate exceeds 0.5 mm/a (20 mpy).

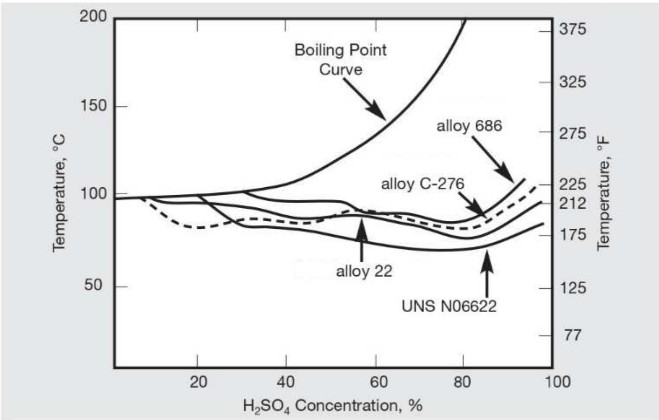


**Figure 9.** Comparative behavior of several nickel base alloys in sulfuric acid. The isocorrosion curves show temperatures and concentrations above which the corrosion rate exceeds 0.5 mm/a (20 mpy).

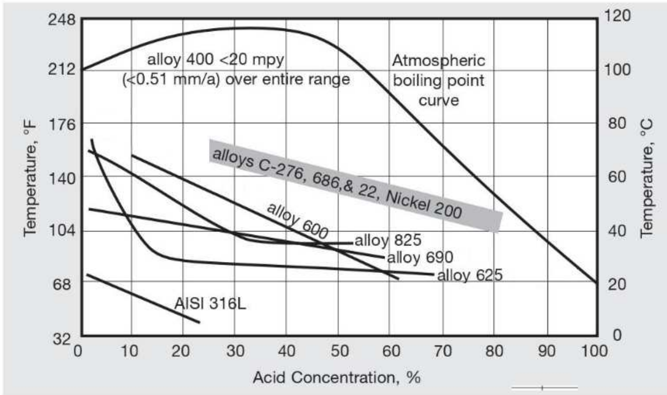


**Figure 10.** A summary iso-corrosion chart for 20 mpy (0.51 mm/a) data in hydrofluoric acid.