**Corrosion resistance of Nickel based alloys in alkali environments**



**About Manufacturer**

Heanjia Super-Metals founded in 1984, has been serving the industries such as aerospace, oil and gas, communication, nuclear, aviation, medical and others by supplying nickel based superalloys. These superalloys are made as per ASTM standards, following the goal of meeting the stringent needs of demanding industries. We are located in America and China. Earlier the alloys made by following the traditional techniques were less corrosion resistant. With the passage of time and introduction of modern methods to save cost and reduce material quantity, the applications include severe corrosive conditions which need high performance alloys. Therefore we manufacture original nickel and nickel alloys that are excellent in performing in the high temperature corrosive conditions for the prolong periods.

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**Alloys Tested**

* **Nickel**
* **Inconel Alloy 600**
* **Nimonic Alloy 75**
* **Monel 400**
* **Monel K500**
* **CuNi alloy 90/10 UNS 706**
* **CuNi Alloy 70/30 UNS 715**
* **Incoloy 800**
* **Stainless steel 316**
* **Stainless Steel 316l**
* **Stainless steel 310**
* **Stainless steel 330**
* **Incoloy 825**
* **Hastelloy C276**
* **Inconel 625**

**Introduction to Alkali Media**

**Caustic Soda**

Caustic soda or sodium hydroxide is a commonly employed alkaline material. It is completely produced as a side product while the production of chlorine in America. A variety of alloys are chosen to handle caustic soda depending on their strength, resistance to stress corrosion cracking, concentration, temperature, corrosion rates and cost. Studies have shown that Nickel and its alloys are the recommended materials for dealing with caustic solutions in the various applications and procedures. Nickel can be employed preferably at all magnitudes and temperatures of this alkaline.

**Role of Nickel: Influence of temperature, content and carbon %**

Nickel successfully resists the attack by caustic soda at the different times and regions. Only the high magnitudes of caustics close to the boiling point affect the corrosion resistance rate that is also only neat 1 mpy (mills per year). For caustic content exceeding 75% and in molten caustic soda, Nickel is the second metal after silver that provides excellent corrosion resistance. For use in temperatures above 316oC or 600oF, Nickel 201 is recommended to control the feasibility of graphite precipitation in grain boundaries that tends to reduce the metal’s ductility. Nickel 201 is commonly employed in the production of tubular evaporators for regular vacuums at temperatures about 404oC or 760of in 50 to 73% caustic content.

Nickel 201 is a successful container material for handling liquefied caustic soda at temperature limits 580oC or 1076oF.

**Nickel-Chromium Alloys**

Inconel 600, a nickel-chromium alloy offers similar corrosion resistance as of nickel in the caustic soda environments. In 600 is preferred for use in apparatus for the making anhydrous caustic in presence of sulfur bearing fuels as it excellently resists sulfidation even better than Nickel. In few conditions, In alloy 600 is attacked by stress corrosion cracking in the strong alkaline conditions at the elevated temperatures from 190oC to 450oC.

**Nickel-Copper Alloys**

Monel 400, a nickel-copper alloy offers great resistance in caustic soda conditions but its corrosion rate is significant in caustic soda above 75% in anhydrous condition. Its protective properties are lower than nickel at temperature exceeding the atmospheric boiling point. However its performance is lower than Nickel, but the corrosion rates are very nominal.

Monel 400 and Monel K-500 can be attacked by stress corrosion cracking (SCC) in the extensive exposure periods at high stresses with elevated temperatures and contents of caustic soda. In the cold processed and annealed form, alloy 400 is resistant to SCC. Similar is with Monel K500. Therefore for using Alloy 400 in caustic at the high temperatures, it should be stress relieved from 538 to 566oC or 1000oF to 1050oF or anneal from 760oC to 816oC or 1400of to 1500oF for one to three hours to obtain high strength.

**Copper-Nickel Alloys**

The corrosion resistance strength of copper-nickel alloys in caustic soda solutions depends on the concentration of nickel in the alloy. Cu Ni alloy 715 containing 70% copper and 30% nickel, offers outstanding resistance to dilute concentrations of caustic soda at low temperatures and has significant corrosion resistance properties in caustic soda solutions about 73% at the boiling temperature. Alloy 715 has been lucratively employed as evaporator tubes for concentration up to 50% where copper attack by caustic soda could be controlled.

Cu-Ni alloy 706 containing copper 90% and nickel 10% offers considerable resistance to caustic solutions however its use is more limited than alloy 715. In the severe caustic solution applications in the presence of sulfur, Cu Ni alloy 715 resists the corrosion in specific conditions.

**Iron-Nickel-Chromium Alloys**

Incoloy 800 and Inconel 600 have similar resistance in caustic soda solutions. Although, alloy 800 is more inclined to SCC than In 600. Therefore Alloy 800 is recommended for use after stress annealing to obtain higher strength in caustic soda conditions at the high temperatures.

**Austenitic Chromium-Nickel Stainless Steels**

Austenitic chromium-nickel stainless steels have good corrosion resistance in boiling caustic soda about 10% concentrations. In the high content solutions at the elevated temperatures, the corrosion rates are irregular. SS 304 offers better corrosion resistance than SS 316 in caustic soda solutions.

Chromium-nickel stainless steels are sensitive to stress corrosion cracking in caustic soda at the high temperatures. Many cases of stress corrosion cracking of austenitic stainless steels are resulted by alkalies. Annealed steel 304 is more resistant to SCC in boiling caustic soda than sensitized steel 304.

**Iron-Nickel-Chromium-Copper-Molybdenum Alloys and nickel-chromium-copper-molybdenum alloys**

Incoloy 825 and other nickel based alloys containing iron, chromium, copper and molybdenum offer suitable corrosion resistance. Austenitic stainless steels containing nickel and chromium like SS 304 and Inconel alloy 600 offer good resistance to caustic soda solutions. These offer superior resistance to stainless steel 304 in concentrated solutions exceeding 95oC or 205oF. For using these alloys in combination with nickel and high nickel alloys in the concentrated caustic soda environments at the high temperatures, preference should be given to unlike alloys to avoid deleterious galvanic effects.

**Nickel-Molybdenum or Molybdenum-chromium-nickel-iron alloys**

The alloys like Hastelloy B, Hastelloy C276 and Inconel 625 have not been employed on a wide scale in the caustic soda media. Hastelloy B can be used in caustic media up to 50% at boiling point and the temperature for Alloy C276 is lower than for alloy B. Hastelloy C and Inconel 625 are both attacked by stress corrosion after seven days in 90% caustic soda at 300oC or 572oF.

**Corrosion By Caustic Potash (KOH)**

Caustic potash is made while the electrolysis of potassium chloride. KOH is commonly used in 45 to 50% and 85 to 90% concentrations on the industrial scale. At concentration above 50% caustic potash exhibits higher boiling point than caustic soda of the same content. Therefore it is not concentrated more than 90% due to involvement of elevated temperatures.

Nickel 200 and Inconel 600 are ideally used for applications in hot caustic potash. In the extensive environments, few nickel based alloys are prone to stress corrosion cracking in caustic potash solutions. Although the attack on alloy 600, alloy 400 and alloy k500 is not vigorous as that happens with caustic soda.

**Ammonia and Ammonium Hydroxide**

Many nickel based alloys excluding the nickel-copper alloys and pure nickel, offer resistance to the whole concentrations of ammonium hydroxide up to boiling temperatures.

In the nickel based alloys, austenitic stainless steels are commonly used in ammonia and ammonium hydroxide solutions. Austenitic stainless steels have outstanding resistance to whole magnitudes of ammonia and ammonium hydroxide to the boiling temperature.

SS 304 is resistant to intergranular corrosion in 28% ammonium hydroxide at room temperature. Although, this resistance doesn’t last in the high temperatures in the commercial media. Significant magnitudes of Stainless steel 316/316l are employed in the ammonia soda procedure in the generation of soda ash symbolized as Na2CO3.

Nickel is resistant to anhydrous ammonia, however it is resistant to ammonium hydroxide solutions in contents up to 1% only. Nickel-Copper alloys like Monel 400 offer suitable resistance to anhydrous ammonia and are superior resistant to ammonium hydroxide solutions than pure nickel.

**Alkaline solutions of Sodium and Potassium salts**

The salts like sodium sulfide, sodium carbonate, sodium silicates, trisodium phosphate and various others produce alkaline water solutions. These salt solutions can be used with the materials as for caustic soda. The low temperature dilute solutions are not highly attacking to carbon steels and these may be treated as corrosion preventers, however in strong solutions at the elevated temperatures, nickel or high nickel alloys are often required.

Monel 400 and austenitic stainless steels are great for use in phosphate hydrations. Nickel and high nickel alloys provide great corrosion resistance in sodium sulfide solutions. In 10% sodium sulfide, the corrosion rates are very nominal. The vigorous corrosive conditions occur in hot, concentrated solutions.

Nickel 200 and Monel 400 are suitable for use in 25 to 60% sodium sulfide solutions.

Inconel 600 is significant for applications involving direct fired pans of concentrated sodium sulfide from 25% to 60%. For the application temperatures about 150oC to 177oC or 300of to 350of, Inconel 600 offers suitable service for 8 years.

**Role of Nickel based alloys in Industrial Applications of alkalines**

**Production of caustic soda**

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Nickel and Nickel alloys provide successful performance in caustic soda production units. For example, in one unit, Nickel centrifugal pumps were employed 27 years ago, but still they are operating in handling 50% caustic soda. Nickel 200, Nickel 201, Inconel 600, Monel 400 and their components are standard used in the parts of evaporators, heat exchanger tubing, valves, pumps, fitting and others, in handling the concentrated caustic soda.

In the regular vacuum content and manufacturing anhydrous caustic soda, Nickel 201 offers outstanding performance as evaporator tubes, tube sheets and shells, receiving tanks and pipes.

Inconel 600 has been widely employed in the production of anhydrous caustic soda and is a recommended material of construction where the heating is done in any media in which the sulfur compounds are available. Nickel Inconel 600 is initially stress relieved or annealed before using in this application.

**Production of Caustic Potash**

Nickel and nickel alloys are used in manufacturing caustic potash in the same manner as used in manufacturing caustic soda. The difference lies in the boiling temperature which caustic potash possesses at content above 50%. Cathodic protection is provided to low carbon Nickel 201 due to introduction of high temperature to the equipment that is chosen for manufacturing caustic potash at 90% contents and more.

**Storage and moving Caustic Soda**

Nickel and nickel clad steel barrels are employed while moving caustic soda in small magnitudes. Generally, nickel plated steel tanks and pipes are also used. Incoloy alloy 825 and Inconel 600 are also selected for carrying 50% to 73% caustic solutions and ammonia base fertilizers or jet fuel. Nickel 200, Monel 400 and Inconel 600 are also used in pumping in handling 50% caustic soda. Nickel 200 heat exchangers, pumps and pipes are used in handling 73% caustic products.

**Soap Production**

Soaps contain alkalis, fatty acids and fatty oils. Caustic potash is used to produce liquid soap. In the specific high grade soaps, pure caustics are used in corrosion resistance apparatus. Nickel 200, Monel 400, SS 304 and SS 316 are used for heating coils, kettle covers and different accessory equipments. Alloy 400 and Nickel 200 are employed for acid and caustic treating tanks as these are resistant in such conditions. Austenitic chromium-nickel stainless steel and Inconel 600 are also employed but pitting is a trouble in some conditions. SS 316 is used as a hydrolyzing tower maintained at 232oC to 260oC or 450oF to 500oF and 600 psi and 700 psi.

**Pulp and Paper industry**

Hundreds of thousand tons of caustic soda is used in pulp and paper industry, basically in extraction of alkali- soluble impurities in multistage bleaching. In the following parts, nickel based alloys are commonly used in an advantageous manner.

Digester: Batch kind Kraft digesters are made of carbon steel with a permitted attack of one inch. But with the increased severity of service conditions in the advanced pulping techniques, the service life of digesters was significantly lowered. Weld overlays using Stainless steel 310 offer longer life than carbon steel in batch digesters. Stainless steel and many nickel based alloys offer excellent corrosion resistance performance in these equipments.

In the United States, there is a large count of digesters that are working on the wooden chips. These are made of stainless steel 316l. The highly attacking regions are on upper and bottom portion in the place of blow valve. Internal accessories are often made from stainless steel 316l. Making digesters with clad SS 316l would permit significantly thin material and reduced maintenance expenditures.

Liquor Heaters

The heat exchanger tubes are utilized to heat the digester liquor before pouring it into batch and continuous digesters. Use of stainless steel 304 is proven in this application. Moreover Inconel 600 offers superior performance as exchanger tubes to SS 304 while resisting the stress corrosion cracking induced by chlorides.

**Aluminum industry**

Caustic soda is also extensively used by aluminum industry in the extraction of hydrated alumina from bauxite during the Bayer process. Monel 400 tubes have been commonly used for digester preheaters and insert ferrules to prevent inlet corrosion in the other steel preheater tubing. In the modern methods ores with large boehmite content are used that need higher operation pressure and temperature limits which indicate the use of nickel and nickel clad steel for this purpose.

**Caustic Fusions**

Nickel 200 and 201 are the significant materials for use in construction vessels for the caustic fusion of organic materials. For temperatures above 316oC or 600of, low carbon grade nickel 201 is recommended. For the processes including sulfur compounds at temperatures above 250oC to 300oC or 482 to 572oF, use of Inconel 600 is preferred over nickel.

**Petroleum refining**

Caustic soda, caustic potash or sodium carbonates are utilized in the petroleum refining process for neutralization of acid and elimination of unnecessary agents like hydrogen sulfide and mercaptans. The magnitudes of aqueous solution vary from 2 to 50%.

In the various applications involving small temperature and content limits, the corrosion rates are nominal that steels can be suitably employed. But for vigorous corrosive conditions, Nickel 200, Monel 400 or Inconel 600 alloys are employed. Commonly Monel 400 is employed as it withstands contaminants that exist in the process.

In the reproduction of caustic solutions, Monel 400 is a crucial part of the system where steels cannot be used. These parts are regenerator boiler, preheaters and piping for handling hot caustic solutions and lower sections of the towers.

Considering the suitable corrosion resistance to caustic alkalis comprising of hydrogen sulfide and mercaptans, **Inconel 600** is also significant in evaporator tubing or other components of regenerator systems. Alloy 600, instead Nickel 200 or alloy 400, is employed in this application where metal temperature varies up to 300oC or 572oF. At such temperature limits Nickel 200 and Monel 400 are attacked by sulfur.

A caustic stripper in Louisiana refinery, made of Monel 400, attained no significant metal loss after 4.5 years of operation of handling 45% caustic soda at temperatures about 143oC to 149oC or 290of to 300of. It can even provide service for another 15 years.

In a refinery located at Texas, mercaptains are discarded through Dualayer process that includes dual layers of immiscible solvents. The initial layer consists of water solution of caustic potash and potassium cresylate, discards the mercaptans. Second and beneath layer is also a water solution of caustic potash for preserving the magnitude of above layer. Monel 400 was employed in stripper preheater, reboiler and stripping tower trays in cast form. It is also used in lining the tower in stress relieved condition. This system provides service for 20 years.

**Caustic Descaling**

Various procedures include liquefied caustic soda for commercial application for descaling of different metals and alloys, specifically stainless steels. Few procedures include the inclusion of caustic of reducing materials to decrease the metallic oxides which later flake off after water cooling. Nickel 201 is employed in sodium hydride generators. Alloy 201 and Inconel 600 are employed for enclosing of electric heating elements in caustic baths. Nickel alloy 600 is chosen for gas fired heater tubing in few conditions. Nickel 201 is employed when the caustic baths are used at the elevated temperatures up to 621oC or 1150oF.

**Test data**

**Chemical composition of nickel alloys used in corrosion tests in caustic based conditions**

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Metal/Alloy | Nickel | Iron | Chromium | Molybdenum | Copper | Carbon | Silicon | Manganese | | | Others |
| wrought | | | | | | | | | | | |
| Nickel 200 | 99.5 % | .15 % | - | - | .05 % | .06 % | .05 % | .25 % | | - | |
| Nickel 201 | 99.5 % | .15 % | - | - | .05 % | .01 % | .05 % | .20 % | | - | |
| Duranickel 301 | 94 | .15 % | - | - | .15 % | .55 % | .25 % | .25 % | | Al 4.5 %, TI 0.5 % | |
| Nickel-chromium alloys | | | | | | | | | | | |
| Inconel 600 | 76 % | 7.2 % | 15.8 % | - | .10 % | .04 % | .20 % | .20 % | | - | |
| Nimonic 75 | 77.4 | .5 % | 20.5 % | - | - | .10 % | - | - | | Ti .35 %, Al 0.15 % | |
| Nickel-copper alloys | | | | | | | | | | | |
| Monel 400 | 66 % | 1.35 % | - | - | 31.5 % | .12 % | .15 % | .90 % | | - | |
| Monel K500 | 65 % | 1 % | - | - | 29.5 % | .15 % | .15 % | .60 % | | Al 2.8 %, Ti 0.5 % | |
| Copper-nickel alloys | | | | | | | | | | | |
| UNS 706 | 10 | 1.25 % | - | - | 88 % | - | - | .3 % | | Pb .05 %, Zn 1 % | |
| UNS 710 | 20 % | .75 % | - | - | 78 % | - | - | .4 % | | Pb .05 % | |
| UNS 715 | 30 % | .55 % | - | - | 67 % | - | - | .5 % | | Pb .05 % | |
| Iron-nickel-chromium alloys | | | | | | | | | | | |
| Incoloy 800 | 32 % | 46 % | 20.5 % | - | .30 % | .04 % | .35 % | .75 % | | - | |
| Stainless steels | | | | | | | | | | | |
| SS 202 | 5 % | 67 % | 18 % | - | - | .15 % | 1 % | 8.7 % | | N 0.25 % | |
| SS 302 | 9 % | 70.5 % | 18 % | - | - | .15 % | .5 % | 1.5 % | | - | |
| SS 304 | 9.5 % | 70 % | 18 % | - | - | .08 % | .5 % | 1.5 % | | - | |
| SS 304l | 10 % | 69 % | 18 % | - | - | .03 % | .5 % | 1.3 % | | - | |
| SS 316 | 13 % | 65 % | 17 % | 2 % | - | .08 % | .5 % | 1.7 % | | - | |
| SS 316l | 13 % | 65 % | 17 % | 2 % | - | .03 % | .5 % | 1.8 % | | - | |
| SS 309 | 13.5 % | 60.5 % | 23 % | - | - | .20 % | 1 % | 2 % | | - | |
| SS 310 | 20 % | 52 % | 25 % | - | - | .25 % | 1 % | 2 % | | - | |
| SS 330 | 35 % | 47 % | 15 % | - | - | .25 % | 1 % | 2 % | | - | |
| SS 347 | 11 % | 68 % | 18 % | - | - | .08 % | 1 % | 2 % | | Cb + Ta 10%, C min. | |
| SS 430 | - | Bal. | 17 % | - | - | .12 % | - | - | | - | |
| Nickel based iron-chromium-molybdenum alloys | | | | | | | | | | | |
| Incoloy 825 | 41.8 % | 30 % | 21.5 % | 3 % | 1.8 % | .03 % | .35 % | .65 % | Al 0.5 %, Ti 0.9 % | | |
| Hastelloy G | 45 % | 19.5 % | 22.2 % | 6.5 % | 2 % | .03 % | .35 % | 1.3 % | W 0.5 %, Cb+ Ta 2.12 %, Co 2.5 % | | |
| Hastelloy C | 54 % | 5 % | 15.5 % | 16 % | - | .08 % | 1 % | 1 % | Co 2.5 %, W 4 %, V 4% | | |
| Hastelloy C276 | 54 % | 5 % | 15.5 % | 16 % | - | .02 % | .05 % | 1 % | Co 2.5 %, W 4 %, V 0.4 % | | |
| Inconel 625 | 60 % | 5 % | 21.5 % | 9 % | - | .10 % | .5 % | .5 % | Cb – Ta 3.65 % | | |
| Nickel-Molybdenum alloy | | | | | | | | | | | |
| Hastelloy b | 61 % | 5 % | 1 % | 28 % | - | .05 % | - | - | Co 2.5 %, V 0.2 to 0.4 %, P 0.025 % | | |

**Comparison of corrosiveness of diaphragm cell vs. mercury cell caustic**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Material** | **Corrodent** | **Temperature** | | | | | | | | | **Corrosion rate, mpy** | | | |
| Nickel 200 | 50% NaOH- diaphragm cell | 1 | | 2 | | 3 | | 4 | | | 1 | 2 | 3 | 4 |
| 35 oC | 95 of | 29 oC | 85 of | 88 oC | 190 of | 54 oC | 130 of | | <0.1 | <0.1 | <0.1 | <0.1 |
| Nickel 200 | 50% NaOH- diaphragm cell | 40 oC | 104 of | - | - | - | - | Ambient | | | <0.1 |  | <0.1 |  |
| Nickel 200 | 50% NaOH- mercury cell | 38 oC | 100 of | 105 oC | 221 of | 82 oC | 180 of | 60 oC | 140 of | | <0.1 | <0.1 | 1 | <0.1 |
| Nickel 200 | 50% NaOH- mercury cell | 37 oC | 98 of | 45 oC | 113 of | - | - | Ambient | | | <0.1 | <0.1 | <0.1 | <0.1 |
| Nickel 200 | 50% NaOH- mercury cell | - | - | Ambient | | - | - | Ambient | | | - | <0.1 | - | <0.1 |
| Nickel 200 | 73% NaOH-diaphragm cell | 119 oC | 246 of | - | - | 99 oC | 210 of | - | | - | <0.1 | - | 0.2 | - |
| Nickel 200 | 73% NaOH-diaphragm cell | 125 oC | 257 of | - | - | - | - | - | | - | 0.2 | - | 0.2 | - |
| Nickel 200 | 73% NaOH-diaphragm cell | 114 oC | 236 of | - | - | - | - | - | | - | 0.3 | - | - | - |
| Inconel 600 | 50% NaOH- diaphragm cell | 35 oC | 95 of | 29 oC | 85 of | 88 oC | 190 of | 54 oC | | 130 of | <0.1 | <0.1 | <0.1 | <0.1 |
| Inconel 600 | 50% NaOH- diaphragm cell | 40 oC | 104 of | - | - | - | - | Ambient | | | <0.1 | - | - | <0.1 |
| Inconel 600 | 50% NaOH- mercury cell | 38 oC | 100 of | 105 oC | 221 of | 82 oC | 180 of | 60 oC | | 140 of | <0.1 | <0.1 | <0.1 | <0.1 |
| Inconel 600 | 50% NaOH- mercury cell | 37 oC | 98 of | 45 oC | 113 of | - | - | Ambient | | | <0.1 | <0.1 | - | <0.1 |
| Inconel 600 | 50% NaOH- mercury cell | - | - | Ambient | | - | - | Ambient | | | - | <0.1 |  | <0.1 |
| Inconel 600 | 73% NaOH- Diaphragm cell | 119 oC | 246 of | - | - | 99 oC | 210 of | - | | - | <0.1 |  | 0.2 |  |
| Inconel 600 | 73% NaOH- Diaphragm cell | 125 oC | 257 of | - | - | - | - | - | | - | 0.3 |  |  |  |
| Inconel 600 | 73% NaOH- mercury cell | 114 oC | 236 of | - | - | - | - | - | | - | 0.2 | - | - | - |
| Monel 400 | 50% NaOH- diaphragm cell | 35 oC | 95 of | 29 oC | 85 of | 88 oC | 190 of | 54 oC | | 130 of | <0.1 | <0.1 | <0.1 | <0.1 |
| Monel 400 | 50% NaOH- diaphragm cell | 40 oC | 104 of | - | - | - | - | Ambient | | <0.1 of | - | - | - | <0.1 |
| Monel 400 | 50% NaOH- mercury cell | 38 oC | 100 of | 105 oC | 221 of | 82 oC | 180 of | 60 oC | | 140 of | <0.1 | 0.1 |  | <0.1 |
| Monel 400 | 50% NaOH- mercury cell | 37 oC | 98 of | 45 oC | 113 of | - | - | Ambient | | - | <0.1 | - | - | <0.1 |
| Monel 400 | 50% NaOH- mercury cell | - | - | Ambient | | - | - | Ambient | | - | <0.1 | - | - | <0.1 |
| Monel 400 | 73% NaOH- Diaphragm cell | 119 oC | 246 of | - | - | 99 oC | 210 of | - | | - | <0.1 | - | 0.8 | - |
| Monel 400 | 73% NaOH- Diaphragm cell | 125 oC | 257 of | - | - | - | - | - | | - | 0.4 | - | - | - |
| Monel 400 | 73% NaOH- mercury cell | 114 oC | 236 of | - | - | - | - | - | | - | 0.5 | - | - | - |
| Incoloy 800 | 50% NaOH- diaphragm cell | 35 oC | 95 of | 29 oC | 85 of | 88 oC | 190 of | 54 oC | | 130 of | <0.1 | <0.1 | <0.1 | <0.1 |
| Incoloy 800 | 50% NaOH- diaphragm cell | 40 oC | 104 of | - | - | - | - | Ambient | | | <0.1 | - | - | <0.1 |
| Incoloy 800 | 50% NaOH- mercury cell | 38 oC | 100 of | 105 oC | 221 of | 82 oC | 180 of | 60 oC | | 140 of | <0.1 | <0.1 | <0.1 | <0.1 |
| Incoloy 800 | 50% NaOH- mercury cell | 37 oC | 98 of | 45 oC | 113 of | - | - | Ambient | | | <0.1 | <0.1 | - | <0.1 |
| Incoloy 800 | 50% NaOH- mercury cell | - | - | Ambient | | - | - | Ambient | | | - | <0.1 | - | <0.1 |
| Incoloy 800 | 73% NaOH- Diaphragm cell | 119 oC | 246 of | - | - | 99 oC | 210 of | - | | - | 0.1 | - | 4.1 | - |
| Incoloy 800 | 73% NaOH- Diaphragm cell | 125 oC | 257 of | - | - | - | - | - | | - | 0.5 | - | - | - |
| Incoloy 800 | 73% NaOH- mercury cell | 114 oC | 236 of | - | - | - | - | - | | - | 0.3 | - | - | - |
| SS 316 | 50% NaOH- diaphragm cell | 35 oC | 95 of | 29 oC | 85 of | 88 oC | 190 of | 54 oC | | 130 of | <0.1 | <0.1 | 3.3 | <0.1 |
| SS 316 | 50% NaOH- diaphragm cell | 40 oC | 104 of | - | - | - | - | Ambient | | | 0.2 | - | - | <0.1 |
| SS 316 | 50% NaOH- mercury cell | 38 oC | 100 of | 105 oC | 221 of | 82 oC | 180 of | 60 oC | | 140 of | <0.1 | <0.1 | 0.2 | <0.1 |
| SS 316 | 50% NaOH- mercury cell | 37 oC | 98 of | 45 oC | 113 of | - | - | Ambient | | | <0.1 | 0.1 | - | <0.1 |
| SS 316 | 50% NaOH- mercury cell | - | - | Ambient | | - | - | Ambient | | |  | <0.1 | - | <0.1 |
| SS 316 | 73% NaOH- Diaphragm cell | 119 oC | 246 of | - | - | 99 oC | 210 of | - | | - | 6 | - | - | - |
| SS 316 | 73% NaOH- Diaphragm cell | 125 oC | 257 of | - | - | - | - | - | | - | 13.1 | - | - | - |
| SS 316 | 73% NaOH- mercury cell | 114 oC | 236 of | - | - | - | - | - | | - | 10 | - | - | - |
| SS 304 | 50% NaOH- diaphragm cell | 35 oC | 95 of | 29 oC | 85 of | 88 oC | 190 of | 54 oC | | 130 of | <0.1 | <0.1 | 1.1 | <0.1 |
| SS 304 | 50% NaOH- diaphragm cell | 40 oC | 104 of | - | - | - | - | Ambient | | | <0.1 | - | - | <0.1 |
| SS 304 | 50% NaOH- mercury cell | 38 oC | 100 of | 105 oC | 221 of | 82 oC | 180 of | 60 oC | | 140 of | <0.1 | 0.1 | 0.3 | <0.1 |
| SS 304 | 50% NaOH- mercury cell | 37 oC | 98 of | 45 oC | 113 of | - | - | ambient | | | <0.1 | <0.1 | - | 0.4 |
| SS 304 | 50% NaOH- mercury cell | - | - | Ambient | | - | - | Ambient | | | - | <0.1 | - | <0.1 |
| SS 304 | 73% NaOH- Diaphragm cell | 119 oC | 246 of | - | - | 99 oC | 210 of | - | | - | 15 | - | 13 | - |
| SS 304 | 73% NaOH- Diaphragm cell | 125 oC | 257 of | - | - | - | - | - | | - | 19.4 | - | - | - |
| SS 304 | 73% NaOH- mercury cell | 114 oC | 236 of | - | - | - | - | - | | - | 15 | - | - | - |
| Mild Steel | 50% NaOH- diaphragm cell | 35 oC | 95 of | 29 oC | 85 of | 88 oC | 190 of | 54 oC | | 130 of | 1.4 | 1.4 | 20 | 2.1 |
| Mild Steel | 50% NaOH- diaphragm cell | 40 oC | 104 of | - | - | - | - | ambient | | | 1.5 | - | - | 3.2 |
| Mild Steel | 50% NaOH- mercury cell | 38 oC | 100 of | 105 oC | 221 of | 82 oC | 180 of | 60 oC | | 140 of | 0.6 | 3 | 1.8 | 1.2 |
| Mild Steel | 50% NaOH- mercury cell | 37 oC | 98 of | 45 oC | 113 of | - | - | ambient | | | 1.4 | 2 | - | 2.9 |
| Mild Steel | 50% NaOH- mercury cell | - | - | Ambient | | - | - | Ambient | | | - | 5.1 | - | 1.9 |
| Mild Steel | 73% NaOH- Diaphragm cell | 119 oC | 246 of | - | - | 99 oC | 210 of | - | | - | 59 | - | 5.7 | - |
| Mild Steel | 73% NaOH- Diaphragm cell | 125 oC | 257 of | - | - | - | - | - | | - | >38 | - | - | - |
| Mild Steel | 73% NaOH- mercury cell | 114 oC | 236 of | - | - | - | - | - | | - | 71 | - | - | - |

**Corrosion of Hastelloy B and Hastelloy C in caustic soda solutions**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| NaOH content % | temperature | | Corrosion rate, mpy | |
| oC | oF | Hastelloy B | Hastelloy C |
| 5 % | Room | Room | Nil | Nil |
| 5 % | 66 oC | 150 oF | Nil | Nil |
| 5 % | 102 oC | 215 oF | Nil | Nil |
| 10 % | Room | Room | Nil | Nil |
| 10 % | 103 oC | 217 oF | <2 mpy | 2.20 mpy |
| 10 % | 121 oC | 250 oF | 2.20 mpy | - |
| 20 % | 107 oC | 225 oF | <2 mpy | 2.20 mpy |
| 25 % | Room | Room | Nil | Nil |
| 30 % | 166 oC | 240 oF | <2 mpy | 2.20 mpy |
| 40 % | Room | Room | Nil | Nil |
| 40 % | 128 oC | 261 oF | <2 mpy | 2.20 mpy |
| 50 % | Room | Room | Nil | Nil |
| 50 % | 66 oC | 150 oF | Nil | Nil |
| 50 % | 144 oC | 291 oF | <2 mpy | 2.20 mpy |
| 50 % | 400 oC | 750 oF | - | 152 mpy |
| 60 % | 165 oC | 328 oF | 2.20 mpy | 2.20 mpy |
| 70 % | 191 oC | 375 oF | 2.20 mpy | 2.20 mpy |

**Corrosion of copper-nickel alloys by caustic soda solutions**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| NaOH cont % | Cu-Ni alloy | Alloy composition | | temperature | | Test time | Corrosion rate, mpy | Remarks |
| 5 % | - | 60 | 40 | 15 to 20 oC | 59 to 68of | 21 days | Nil | Lab test in glass bottle |
| 11 % | - | 60 | 40 | Hot temperature | | 25 | 0.5 | Diaphragm cell liquor coupons in distributor box |
| 5 % | UNS 715 | 70 | 30 | 15 to 20 | 59 to 68 | 21 | Nil | Lab test in glass bottle |
| 11 % | 70 | 30 | Hot temperature | | 25 | 4.3 | Diaphragm cell liquor |
| 50 % | 70 | 30 | 95 | 203 | 67 | 0.8 | Velocity 1.8 ft/sec salt saturated |
| 50 % | 70 | 30 | 65 | 149 | 30 | Nil | In storage tank |
| 73 % | 70 | 30 | 105 | 221 | 118 | 1.2 |  |
| 60 to 75 % | 70 | 30 | 150-175 | 302 - 347 | 0.5 | 4.4 | In evaporator content from 60 to 75% |
| 60 to 100 % | 70 | 30 | 150-260 | 302 - 500 | 2 | 21 | In evaporator content 60% to anhydrous |
| 100 % | 70 | 30 | 400 – 410 | 752 0 770 | 1 | 70 | In anhydrous salt |
| 5 % | CA 710 | 80 | 20 | 15 to 20 | 59 to 68 | 21 | Nil | Lab test in glass bottle |
| 60 to 75 % | 80 | 20 | 150 to 175 | 302 to 347 | 0.5 | 8.1 | In evaporator content from 60 to 75% |
| 60 to 100 % | 80 | 20 | 150 to 260 | 302 to 500 | 2 | 28 | In evaporator content 60% anhydrous |
| 100 % | 80 | 20 | 400 to 410 | 752 to 770 | 1 | 90 | In anhydrous melt |
| 50 % | CA 706 | 90 | 10 | 95 | 203 | 67 | 1.8 | Velocity 1.8 ft/sec salt saturated |
| 73 % | 90 | 10 | 105 | 221 | 118 | 2 |

**Lab corrosion tests in caustic solutions at high temperatures**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| NaOH % | Temperature | | Time | Corrosion rate, mpy | |
| oC | oF | Hours | Nickel 200 | Monel 400 |
| 20 % | 110 oC | 262 oF | 15 Hours | Nil | - |
| 40 % | 110 oC | 262 oF | 15 Hours | Nil | - |
| 60 % | 110 oC | 262 oF | 15 Hours | Nil | - |
| 80 % | 110 oC | 262 oF | 15 Hours | Nil | - |
| 20 % | 115 oC | 272 oF | 19 Hours | Nil | - |
| 40 % | 115 oC | 272 oF | 19 Hours | Nil | - |
| 60 % | 115 oC | 272 oF | 19 Hours | Nil | - |
| 80 % | 115 oC | 272 oF | 19 Hours | Nil | - |
| 20 % | 162 oC | 355 oF | 19 Hours | Nil | - |
| 40 % | 162 oC | 355 oF | 19 Hours | Nil | - |
| 60 % | 162 oC | 355 oF | 19 Hours | Nil | - |
| 80 % | 162 oC | 355 oF | 19 Hours | Nil | - |
| 20 % | 149 oC | 332 oF | 19 Hours | - | Nil |
| 40 % | 149 oC | 332 oF | 19 Hours | - | 3 mpy |
| 60 % | 149 oC | 332 oF | 19 Hours | - | 1 mpy |
| 20 % | 132 oC | 270 oF | 19 Hours | - | - |
| 40 % | 132 oC | 270 oF | 19 Hours | - | - |
| 60 % | 132 oC | 270 oF | 19 Hours | - | - |
| 80 % | 132 oC | 270 oF | 19 Hours | - | - |
| 20 % | 171 oC | 340 oF | 19 Hours | - | - |
| 40 % | 171 oC | 340 oF | 19 Hours | - | - |
| 60 % | 171 oC | 340 oF | 19 Hours | - | - |
| 80 % | 171 oC | 340 oF | 19 Hours | - | - |
| 20 % | 156 oC | 345 oF | 20 Hours | - | - |
| 40 % | 156 oC | 345 oF | 20 Hours | - | - |
| 60 % | 156 oC | 345 oF | 20 Hours | - | - |
| 80 % | 156 oC | 345 oF | 20 Hours | -- | - |
| 20 % | 127 oC | 293 oF | 15 Hours |  | - |
| 40 % | 127 oC | 293 oF | 15 Hours | - | - |
| 60 % | 127 oC | 293 oF | 15 Hours | -- | - |
| 80 % | 127 oC | 293 oF | 15 Hours | - | - |
| 20 % | 150 oC | 334 oF | 18 Hours | - | - |
| 40 % | 150 oC | 334 oF | 18 Hours | - | - |
| 60 % | 152 oC | 336 oF | 19 Hours | - | - |
| 20 % | 183 oC | 394 oF | 15 Hours | - | - |
| 60 % | 183 oC | 394 oF | 15 Hours | - | - |
| 80 % | 183 oC | 394 oF | 15 Hours | - | - |

**Corrosion rates for Nickel and High nickel alloys in caustic soda solutions**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| NaOH wt | Temperature | | Aeration | Agitation | Time | Remarks | Corrosion rate, mills per year | | |
| oC | oF | Hours | Nickel 200 | Monel 400 | Inconel 600 |
| 0.7 % | 30 oC | 86 oF | None | None | 27 hrs | Cleaned, dried daily for 30 days | 0.01 | 0.01 | nil |
| 4 % | 30 oC | 86 oF | None | None | 1 & 2 hrs | Average tests run at 8 separate labs | 0.05 | 0.16 | - |
| 4 % | 30 oC | 86 oF | Air agitated | Air agitated | 1 & 2 hrs | Average tests run at 8 separate labs | 0.05 | 0.21 | - |
| 5 to 10 % | 21 to 32 oC | 70 to 90 oF | Extensive | Filling tank | 124 hrs | Storage tank | 0.15 | 0.31 | 0.05 |
| 14 % | 88 oC | 190 oF | None | None | 90 hrs | Multiple effect evaporator | 0.02 | 0.05 | 0.03 |
| 22 % | 50 to 60 oC | 120 to 140 oF | None | Filling tank | 133 hrs | Storage tank immersed 95% of time | Nil | 0.01 | 0.01 |
| 34 % | 65 oC | 150 oF | High | Nominal | 37 hrs | Storage tank in which air was bubbled from bottom | 0.03 | - | 0.03 |
| 30 to 50 % | 81 oC | 178 oF | None | None | 16 hrs | Single effect evaporator, average rates | 0.09 | 0.19 | - |
| 49 to 51 % | 55 to 75 oC | 131 to 167 oF | None | Filling tank | 30 hrs | Storage tank fully immersed | 0.02 | 0.03 | 0.02 |
| 50 % | 55 to 61 oC | 131 to 142 oF | None | Filling tank | 135 hrs | Storage tank | 0.02 | 0.02 | 0.02 |
| 50 % | 60 to 70 oC | 140 to 158 oF | Medium | 100 gpm flow from pump | 393 hrs | Distribution piping, at pump discharge | 0.07 | 0.10 | 0.03 |
| 50 % | 150 oC | 302 oF | none | None | 14 hrs | Lab test on tubing, | - | - | 0.25 |
| 72 to 73 % | 116 oC | 273 oF | None | Filling tank | 183 hrs | Storage tank | 0.3 | 0.7 | 0.4 |
| 72 % | 121 oC | 282 oF | Medium | Filling tank | 119 hrs | Storage tank | 0.1 | 0.3 | 0.1 |
| 73 % | 95 to 100 oC | 203 to 212 oF | none | Filling tank | 111 hrs | Test tank, simulating action of tank car | 0.13 | 0.16 | 0.14 |
| 73 % | 100 to 120 oC | 212 to 248 oF | none | Filling tank | 52 hrs | Storage tank materials immerse 95% of period | 0.05 | 0.04 | 0.06 |
| 73 % | 104 to 116 oC | 244 to 251 oF | None | Filling tank | 126 hrs | Storage tank coupons fully immersed | 0.02 | 0.10 | 0.01 |
| 74 % | 130 oC | 266 oF | Not stated | Movement of tank car | 7 to 9 days | Coupons in railroad tank | 0.3 | 0.4 | - |
| 75 % | 135 oC | 271 oF | Not stated | Filling tank | 35 hrs | Storage tnak among evaporator and finishing pots. Ammonia soda process | 1.6 | 1.7 | 1.3 |
| 60 % anhydrous | 150 to 260 oC | 302 to 500 oF | None | None | 2 hrs | Content in caustic evaporator | 3.9 | 13.4 | - |

**Plant Corrosion Test in a Sulfate Process, Alkaline, Wood Pulp Digester**

Temp: 177oC or 350oF, test time 586 days.

Aeration: None.

Agitation: Violent boiling during cook.

Top--Vapors in the top of the digester. rare splashing of chips, pulp and cooking

liquors. Bottom-Liquid and slurry on bottom screen of digester.

|  |  |  |  |
| --- | --- | --- | --- |
| Material | Condition | Corrosion rate, mills per year | |
| Inconel 600 | Plate, as received | .02 mpy | .21 mpy |
| Carpenter alloy 20 | Welded | .03 mpy | .09 mpy |
| Inconel 600 | Welded | .03 mpy | .23 mpy |
| Incoloy 825 | Plate, as received | .03 mpy | .09 mpy |
| Incoloy 825 | Welded | .03 mpy | - |
| Stainless steel 316 | Plate, as received | .04 mpy | .15 mpy |
| Stainless steel 316l | Plate, as received | .05 mpy | - |
| Stainless steel 316l | Welded | .06 mpy | .17 mpy |
| Stainless steel 316 | Welded | .06 mpy | .15 mpy |

**Test in storage tank for 73% caustic soda**

Temp: 116oC or 240oF

Test time- 183 days

Non aerated, no agitation excluding filling of tank

|  |  |
| --- | --- |
| Alloy/Metal | Corrosion rate, mpy |
| Nickel 200 | 0.3 mpy |
| Inconel 600 | 0.4 mpy |
| Monel 400 | 0.7 mpy |
| Zirconium | 1.4 mpy |
| Titanium | 4.7 mpy |
| Mild steel | Damaged |