

Chapter 8

Engineering Applications of Electroless Nickel

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Engineering applications for electroless nickel can be found in virtually every industry. Various physical characteristics of electroless nickel coatings, such as hardness, wear resistance, coating uniformity, and corrosion resistance, as well as the ability to plate non-conductive surfaces make this a coating of choice for many engineering applications.

The as-plated hardness of electroless nickel-phosphorus coatings ranges from 500 to 650 VHN₁₀₀ although recent advances in proprietary formulations are generating an as-plated hardness of up to 700 VHN₁₀₀. Some electroless nickel-boron coatings have an as-plated hardness of 600 to 700 VHN₁₀₀. Increased hardness of chemically-deposited nickel can be achieved using elevated temperatures over a period of time. This heat treatment process encourages the separation of nickel phosphide (Ni₃P) or nickel boride (Ni₃B) (1). The resulting coating approaches, and in some cases surpasses, the hardness of hard chrome (1000 VHN₁₀₀ for Ni₃P and 1100 VHN₁₀₀ for Ni₃B). Consequently, electroless nickel is used as a barrier against wear and abrasion, specifically in applications where a uniform deposit is to be achieved without grinding. Even in severe wear situations, such as abrasion coupled with high temperatures (>500° C), where hard chrome is still the correct choice, electroless nickel plating can be used in conjunction with the hard chrome. The electroless nickel coating, under the chromium coating, is used to inhibit the corrosion of the base metal through the characteristic cracks of hard chrome plating.

Corrosion is one of the major problems facing engineers in industrial situations today. Its effects can range from a simple loss of appearance, which can lead to unsalable merchandise, on up to increased operating costs. Unfortunately, many metallic coatings used as barriers against corrosion have been inherently porous and therefore have provided poor protection for the base metal. In general, a high-phosphorus, low-stress electroless nickel coating largely eliminates the porosity problem.

Table 8.1 reviews the physical characteristics of electroless nickel. In addition to its engineering features, the unique ability to plate non-conductors such as glass, ceramics, plastics and graphite has made electroless nickel a very useful coating that can be regarded as a problem-solving finish offering a cost-effective alternative with equivalent performance to more expensive metal alloys.

Table 8.1
Properties of Electroless Nickel Coatings

**Data as a function
of phosphorus or boron content**

| Property | 5% B | 3% P | 5-6% P | 8-9% P |
|--|----------------------|---------------|----------------------|---------------|
| Density, gm/cm ^{3a} | 8.25 | 8.52 | 8.25 | 7.85-8.1 |
| Coefficient of thermal expansion, $\mu\text{m/m}/^\circ\text{C}^b$ | 12.1 | nd | nd | 13-14.5 |
| Electrical resistivity, $\mu\text{ohm-cm}^c$ | 89.1 | 30 | 72 | 50-110 |
| Thermal conductivity, cal/cm/sec/ $^\circ\text{C}^d$ | nd | nd | nd | 0.0105-0.0135 |
| Melting point, $^\circ\text{C}^e$ | 1080 | nd | nd | 890 |
| Magnetism, oersteds ^f | weakly ferromagnetic | ferromagnetic | weakly ferromagnetic | nonmagnetic |

^a The lower density of electroless nickel as compared to pure metallurgical nickel (8.91 g/cm³) is attributed to the presence of phosphorus or boron. Analysis has also shown minor levels of the following elements that may also affect density: H (0.0016%), N; (0.0005%), O; (0.0023%), and C (0.04%).

^b Values for electrodeposited nickel are from 14 to 17 $\mu\text{m/m}/^\circ\text{C}$. Heat treatment has been shown to decrease these values to an average of 10.8 $\mu\text{m/m}/^\circ\text{C}$.

^c Thinner films of 0.04 to 0.08 mils generated a resistivity of 55-60 $\mu\text{ohm-cm}$, as compared to 0.4 mils of the same 7-10% P coating, which exhibited resistivity of 30-55 $\mu\text{ohm-cm}$.

^d The same value for metallurgical nickel (99.94% purity) at 100° C is 0.198.

^e A 4.3% boron coating has also been reported with a 1350° C melting point. The melting point of the 8-9% P alloy corresponds to the melting point of nickel phosphide (Ni₃P₂).

^f Heat treatment of both Ni-B and Ni-P alloys has been shown to increase the coefficient of magnetism.

AEROSPACE APPLICATIONS

Electroless nickel has been used extensively over the years in the aerospace industry (2-5). All of the properties of electroless nickel are used to advantage in this industry. In aircraft engines, turbine or compressor blades are plated with electroless nickel as protection against the corrosive environment they are exposed to (6). The coating thickness in this application is generally 1 to 3 mils of high-P electroless nickel. When the blades are plated with electroless nickel, there is about 25 percent less loss of fatigue strength than when plated with hard chrome.

Aluminum is frequently used by engineers in aerospace applications because of its density and, consequently, its light weight. Electroless nickel coatings

compliment aluminum's inherent characteristics by adding hardness, wear resistance, corrosion protection, and solderability. Piston heads are a good example of the successful combination of aluminum and electroless nickel in the aerospace industry. The light weight of aluminum allows the piston to work more efficiently, while the electroless nickel provides wear resistance that extends the useful life of the piston. The main shafts of aircraft engines are plated with electroless nickel to provide good bearing surfaces. An additional advantage of electroless nickel is realized when rebuilding of the shafts is required during maintenance overhauls (10-12). The remaining electroless nickel can be stripped off and replated to the required thickness. This contrasts favorably with the more expensive machining required for chromium-plated shafts. The rear compressor hub sleeves and bearing liners of the TF30 jet engine are reconditioned and replated with electroless nickel at a cost savings of several thousand dollars over the purchase of new components. The components are made of a titanium alloy containing 6 percent vanadium and 4 percent aluminum. Two mils of electroless nickel are used as the finish.

In addition to engine-related applications, electroless nickel finds many other uses in the aerospace industry. The relatively low coefficient of friction of electroless nickel, coupled with its corrosion resistance, makes it useful in plating servo valves. Landing gear components are plated with 1 to 2 mils of electroless nickel to build up mismatched surfaces, as well as to provide corrosion resistance.

Metallic optics are becoming widely used in spaceborne systems. In these applications, a strong coating must be deposited over a light, strong metal such as beryllium or aluminum. Special high-phosphorus electroless nickel deposits have been polished to 9 Å (13), providing superior performance in space applications where high G forces are present and low inertia is required.

A deposit of 3 to 5 mils of electroless nickel is applied to the beryllium or aluminum substrate. The coating is controlled to produce a compressive strength of 7000 to 10,000 psi. After heat treatment, the coating has nearly zero stress, which provides a stable optical system for extended periods. The phosphorus content for these deposits is in the range of 12.2 to 12.7 percent, and the solutions must be free of stress-inducing elements. Boron-electroless nickel coatings are not suitable for this type of application because they tend to have high tensile stress.

Table 8.2 summarizes the major uses of electroless nickel in the aerospace industry.

AUTOMOTIVE APPLICATIONS

The automotive industry has been moving toward the use of alcohol/gasoline fuel mixtures. The use of alcohol, aside from some performance problems, also creates corrosion problems in the fuel systems. In Brazil, where ethanol is used as an auto fuel, zinc-die-cast-components, such as carburetors, are routinely plated with electroless nickel to prevent corrosion. Production of automobiles in

Table 8.2
Major Uses of Electroless Nickel
In the Aerospace Industry

| Component | Basis metal | Phosphorus, %* | Coating thickness, mils | Property of interest** |
|----------------------------|--------------------|-----------------------|--------------------------------|-------------------------------|
| Bearing journals | Al | L, M | 1-2 | WR, U |
| Servo valves | Steel | M, H | 1 | CR, LU, U |
| Compressor blades | Alloy steels | M, H | 1 | CR, WR |
| Hot zone hardware | Alloy steels | M, H | 1 | WR |
| Piston heads | Al | M, H | 1 | WR |
| Engine shafts | Steel | L, M | 1-2 | WR, Buildup |
| Hydraulic actuator splines | Steel | L, M | 1 | WR |
| Seal snaps & spacers | Steel | M, H | 0.5-1 | WR, CR |
| Landing gear components | Al | M, H | 1-2 | WR, Buildup |
| Struts | SS | M, H | 1-2 | WR, Buildup |
| Pitot tubes | Brass/SS | M, H | 0.5 | CR, WR |
| Gyro components | Steel | L, M | 0.5 | WR, LU |
| Engine mounts | Alloy steels | M, H | 1 | WR, CR |
| Oil nozzles | Steel | M, H | 1 | CR, U |
| Optics | Al | H | 3-5 | |

*Phosphorus content: H = 9 to 12; M = 5 to 8; L = 1 to 2.

**CR = corrosion resistance; WR = wear resistance; U = uniformity; LU = lubricity.

the U.S. should eventually be using electroless nickel on carburetors, fuel sending systems, and fuel pumps as ethanol and methanol gasoline mixtures gain wide acceptance and use.

Differential pinion ball shafts are plated with 1 mil of electroless nickel for wear resistance. Some automobile manufacturers use electroless nickel/teflon to plate shafts. The added lubricity of the teflon, coupled with the hardness of the electroless nickel, provide the added service life required for extended warranties.

The auto industry takes particular advantage of the uniformity of the electroless nickel deposit when it is used to plate components such as gears, heat sinks, and fuel injectors. Heat sinks, such as the one shown in Fig. 8.1 are easily plated with electroless nickel for heat protection, while it would be impossible to obtain good coverage on internal surfaces by plating electrolytically. Retaining tolerances of 10 to 20 μ in. on gears is easily accomplished

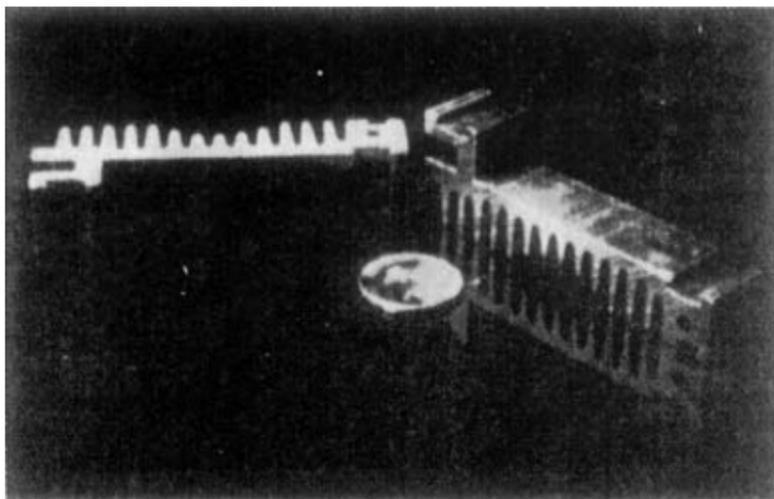


Fig. 8.1—Electroless nickel plated heat sink.

with electroless nickel, whereas electroplated nickel would require further processing to assure proper tolerances. Electroless nickel is also used on fuel injectors, providing important wear resistance against fuel flows, and to a certain extent, corrosion. The result of this wearing and corrosion over time can cause the widening of the injector orifice. As this widening occurs, the horsepower of the engine will increase beyond its design criteria, and therefore increase the warranty liability of the manufacturer. Electroless nickel prevents this wear and corrosion, thus considerably reducing warranty liability.

Table 8.3 summarizes the typical uses of electroless nickel in the automotive industry.

APPLICATIONS IN THE CHEMICAL PROCESSING INDUSTRY

Materials engineers in the chemical process industries are using electroless nickel to solve many unresolved corrosion problems. Use of electroless nickel also decreases the capital costs required for the construction of certain types of chemical plants. This results in more favorable economic conditions for producing chemicals more competitively. Potential gains also exist for improvement in product purity, environmental safeguards, safety of operations, and reliability in manufacturing and transportation of chemical products.

Table 8.3
Major Uses of Electroless Nickel
In the Automotive Industry

| Component | Basis metal | Phosphorus, %* | Coating thickness, mils | Property of interest** |
|--------------------------------------|--------------------|-----------------------|--------------------------------|-------------------------------|
| Heat sinks | Al | M, H | 0.4 | CR, S, U |
| Carburetor components | Steel | M, H | 0.6 | CR |
| Fuel injectors | Steel | M, H | 1.0 | CR, WR |
| Ball studs | Steel | M, H | 1.0 | WR |
| Dif. pinon ball shafts | Steel | M, H | 1.0 | WR |
| Disc brake pistons & pad holders | Steel | M, H | 1.0 | WR |
| Transmission thrust washers | Steel | M, H | 1.0 | WR |
| Synchromesh gears | Brass | M, H | 1.2 | WR |
| Knuckle pins | Steel | M, H | 1.0 | WR |
| Exhaust manifolds & pipes & mufflers | Steel | M, H | 1.0 | CR |
| Shock absorbers | Steel | M, H | 0.4 | CR, LU |
| Lock components | Steel | M, H | 0.4 | CR, WR, LU |
| Hose couplings | Steel | M, H | 0.2 | CR, WR |
| Gears & gear assemblies | Carburized | M, H | 1.0 | WR, Buildup |

*Phosphorus percent: H = 9 to 12; M = 5 to 8; L = 1 to 2.

**CR = corrosion resistance; WR = wear resistance; U = uniformity; LU = lubricity; S = solderability.

The capability to line large process size vessels was developed and patented in the 1950s. At that time, tank cars were being plated with electroless nickel for use in shipping caustic soda. Process controls were not developed sufficiently to produce a consistently good quality product; consequently, adhesion and porosity problems developed. Recent improvements in electroless nickel chemistry have shown the coating to be reliable in many chemical environments.

Steel valves of the ball, gate, plug, check, and butterfly types are widely employed in the chemical industry. Generally, a coating of 0.5 to 1 mil of high-P electroless nickel can more than double the life of such valves in corrosive environments. One exception is that of valves and other components used in caustic soda service. Corrosion data have shown that low-P (1 to 2 percent) electroless nickel provides superior performance to the higher-phosphorus nickels (14,15). The inherently higher hardness of the low-P electroless nickel, along with its tendency to form strongly adherent nickel oxide films, allows this coating to minimize corrosion rates in the caustic soda to about 0.1 mils/year. It is also possible that the solubility of phosphorus in caustic soda affects the corrosion rate of various phosphorus content coatings. Components in caustic soda service can be exposed to corrosion conditions such as 14 percent salt, 15 percent caustic soda at 285° F, and flow velocities of 5 to 10 ft/sec.

Electroless nickel does not perform well in highly acidic environments. Application in areas where hydrolysis of chemical compounds produces acids is also not recommended. For example, in a reactor where thionyl chloride is used as a chlorination agent, the release of hydrochloric acid would produce unacceptable corrosion rates in the electroless nickel coating.

Fasteners made of austenitic stainless steel undergo stress corrosion cracking in chlorine service as well as general corrosion and pitting. One to two mils of high-P electroless nickel over steel, using oversized nuts, provides a cost-effective solution to the problems encountered with stainless steel. In the production of low density polyethylene, 1 mil of high-P electroless nickel is plated over pressure-vessel-quality steel. This prevents unlined vessels from becoming contaminated and discolored by iron. The use of stainless steel was precluded because of its higher cost, roughly twice that of electroless nickel over steel.

Pumps used in mining sulfur undergo severe abrasion and corrosion of their impellers and housings, resulting in a service life of only days. A 1-mil coating of high-P electroless nickel increased the service life of the pumps to months.

Table 8.4 compares the corrosion rates of electroless nickel coatings in caustic soda with other commonly used materials. The low-P electroless nickel is comparable to the more expensive nickel 200, and performs better than stainless steel.

Table 8.5 compares the cost of alternative materials and coatings for 5/8 in. x 3-1/2 in. hex bolts with nuts. Again, the cost/performance of the electroless nickel-coated bolts provides the best overall value.

In Table 8.6, the cost of electroless nickel lined vessels is compared with FRP unlined steel and various lined steel tanks. Table 8.7 summarizes some of the typical applications of electroless nickel in the chemical process industries.

OIL AND GAS PRODUCTION

Oil and gas production is an important market for electroless nickel coatings. Typical environments encountered by tools and equipment used in oil and gas

Table 8.4
Comparison of the Corrosion Rates of Electroless Nickel Coatings
In Caustic Solutions with Other Commonly Used Materials*

| Corrodent | Nickel | EN coatings | | | Mild steel | 316 SS |
|---------------------------------|--------|-------------|------|------|------------|--------|
| | 200 | LP | MP | HP | | |
| 45% NaOH + 5% NaCl @ 40 ± 2° C | 2.5 | 0.3 | 0.3 | 0.8 | 35.6 | 6.4 |
| 45% NaOH + 5% NaCl @ 140 ± 2° C | 80.0 | 5.3 | 11.9 | F | nd | 27.9 |
| 35% NaOH @ 93 ± 2° C | 5.1 | 5.3 | 17.8 | 13.2 | 94.0 | 52.0 |
| 50% NaOH @ 93 ± 2° C | 5.1 | 6.1 | 4.8 | 9.4 | 533.4 | 83.8 |
| 73% NaOH @ 120 ± 2° C | 5.1 | 2.3 | 7.4 | F | 1448.0 | 332.7 |

*All corrosion rates in $\mu\text{m}/\text{year}$, 100 days exposure. nd = no data available; F = failure.

production includes brines, CO_2 , and H_2S at temperatures of up to 350 to 400° F. Sand and other grit can also be encountered, compounding the severe corrosion problems that can develop. Figure 8.2 is a schematic diagram of a typical oil well, indicating the various major components subject to corrosion and wear.

Tubulars used in oil and gas production are an excellent application for electroless nickel (17-19). The tubes are made of mild steel and if left unprotected, might last only a few months under severe conditions. Coated with 2 to 4 mils of high-P electroless nickel, corrosion rates are reduced to levels comparable with Hastelloy. Figures 8.3 and 8.4 compare corrosion rates of electroless nickel with several other tubular materials. When compared on a cost/performance basis, electroless nickel provides superior protection for tubular goods.

Figure 8.5 shows the components that are used with electrical submersible pumping equipment. Electroless nickel is widely used for protecting the various pumping components. Pump housings, impellers, and pump discharge barrels are plated with 1 to 3 mils of electroless nickel, depending on the corrosion environment encountered. Figure 8.6 shows another pumping system used for low volume producing wells. The sucker rod joint shown in the figure is an ideal electroless nickel application. The uniformity of the coating and the precision with which it can be applied will maintain the integrity of the threads. Tubing packers are used in the tubing string to seal off the space between the tubing and casing. The packers also help support the weight of the tubing string, and

Table 8.5
Economics of Electroless Nickel Coatings:
Cost Comparison for Corrosion Resistant
Bolting Applications for Use in the
Chemical Process Industry*

| Material | Cost each/\$ | Cost ratio |
|--|---------------------|-------------------|
| ASTM A307 Low carbon steel bolt | 0.44 | 1.0 |
| ASTM A193 B-7 Alloy steel bolt | 0.77 | 1.8 |
| ASTM A193 B-7 **Fluorocarbon coated | 1.41 | 3.2 |
| ASTM A320 B-7 ***EN coated | 0.99 | 2.3 |
| ASTM A320 L-7 Alloy steel bolt | 2.75 | 6.3 |
| ASTM A320 L-7 **Fluorocarbon coated | 3.16 | 7.2 |
| ASTM A320 L-7 ***EN coated | 2.97 | 6.8 |
| ASTM A193 B8M (316 SS) bolt | 3.09 | 7.0 |
| Nickel 200 | 17.80 | 40.5 |

*Based on 5/8-in. x 3-1/2-in. hex bolt with nut in 500 pieces quantity.

**20 to 25 μm proprietary coating not recommended for immersion.

***15 to 20 μm coating as-plated high phosphorus.

anchor it to prevent shifting. To prevent corrosion of packers, 1 to 2 mils of electroless nickel is employed.

At the surface, electroless nickel is widely used in the heat treater systems used to separate the water-oil mixtures produced from most wells. Large U-shaped tubes, used to heat the water-oil mixtures, are routinely coated with 1 to 3 mils of high-P electroless nickel to prevent corrosion. Valves and other fittings and fixtures used on the surface to collect and transfer the produced oil are also plated with electroless nickel. Table 8.8 summarizes the typical uses of electroless nickel in the oil and gas industry.

Table 8.6
Economics of Electroless Nickel Coatings:
Comparison of Standard Wall Vessels*

| Capacity, gal (m ³) | FRP | Mild steel | Steel- EN-lined 50 μm | 316 SS | Nickel 200 | Steel- glass- lined 1270 μm | Steel- teflon- lined 1000 μm |
|------------------------------------|------|---------------|--|-----------|---------------|---|--|
| 100 (0.32) | 1.0 | 1.2 | 1.6 | 1.7 | 4.5 | 5.5 | 7.0 |
| 200 (0.76) | 1.5 | 1.6 | 2.4 | 2.3 | 7.1 | 6.5 | 9.0 |
| 500 (1.9) | 2.0 | 2.0 | 3.4 | 3.0 | 9.0 | 10.5 | 13.3 |
| 1000 (3.8) | 3.0 | 2.9 | 5.5 | 4.1 | 14.0 | 13.0 | 18.7 |
| 5000 (18.9) | 5.0 | 4.5 | 10.6 | 8.0 | 30.0 | 35.7 | 42.5 |
| 10,000 (37.9) | 10.0 | 8.5 | 21.3 | 15.0 | 56.0 | 59.0 | 64.0 |
| 16,000 (60.0) | 16.0 | 12.0 | 32.1 | 22.0 | 78.0 | 81.0 | 75.3 |

*Vessels designed for use with liquid with 1.2 specific gravity. Each contains two nozzles (top and bottom), closed top and vented. Values are thousands of dollars.

FOOD PROCESSING INDUSTRY

The food processing industry offers a tremendous potential for the use of electroless nickel. There are, however, barriers to its widespread application (20-22). First and foremost, there has been a lack of regulatory standards for electroless nickel from the USDA and FDA. Generally, the agencies have approved the use of electroless nickel in a food contact application on a case-by-case basis. In the related area of food packaging, electroless nickel finds easy acceptance for its wear and corrosion resistance properties. In these applications, there is no direct contact of the electroless nickel with food. Typical applications include bearings, rollers, conveyors, hydraulics, and gears, and all components materials normally associated with materials handling.

There are some notable food contact applications. The processing conditions for meat products involve substances such as sodium chloride solution, nitrite,

Table 8.7
Applications of Electroless Nickel Plating
In the Chemical Industry

| Component | Basis metal | Phosphorus, percent* | Coating thickness, mils | Property of interest** |
|---|--------------------|-----------------------------|--------------------------------|--|
| Pressure vessels | Steel | H | 2.0 | CR |
| Reactors | Steel | H | 4.0 | CR, PP |
| Mixer shafts | Steel | L,M,H | 1.5 | CR |
| Pumps and impellers | Cast iron/steel | L,M,H | 3.0 | CR |
| Heat exchangers | Steel | H | 3.0 | CR, ER |
| Filters and components | Steel | H | 1.0 | CR, ER |
| Turbine blades and rotor assemblies | Steel | H | 3.0 | CR, ER |
| Compressor blades and impellers | Steel/Al | H | 5.0 | CR, ER |
| Spray nozzles | Brass/steel | H | 0.5 | CR, WR |
| Ball, gate, plug, check, and butterfly valves | Steel | L,M,H | 3.0 | CR, LU |
| Valves | SS | L,M,H | 1.0 | WR, GR, protection against stress and corrosion cracking |

*Phosphorus percent: H = 9 to 12; M = 5 to 8; L = 1 to 2.

**CR = corrosion resistance; WR = wear resistance; U = uniformity; LU = lubricity; PP = product purity; ER = erosion resistance; GR = galling resistance.

citric or acetic acid, natural wood smoke, acid-added liquid smoke, volatile organic acids, and others. The process temperature ranges from 60° C to 200° C, and the process air is usually laden with moisture. Under these conditions, corrosion or metal fatigue has been encountered in most of the processing equipment. Screws for extruding meat products are subject to abrasion and corrosion in service. Chromium plate has been a traditional coating for this application. Electroless nickel is a cost effective alternative to hard chrome because of its superior corrosion resistance and its ability to coat complex parts without the need for fixturing anodes to achieve a uniform deposit.

Coating dough kneaders used in the baking industry is an excellent application for electroless nickel contact applications. Dough kneaders are

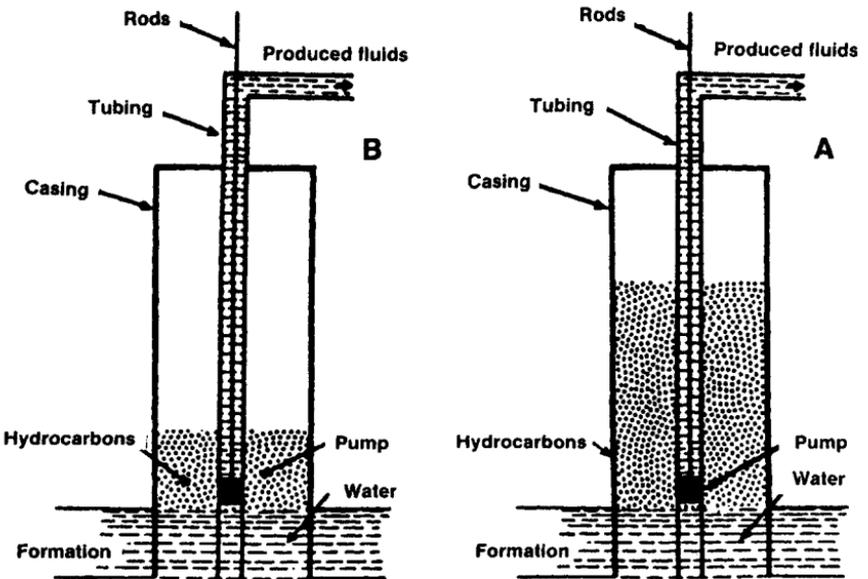
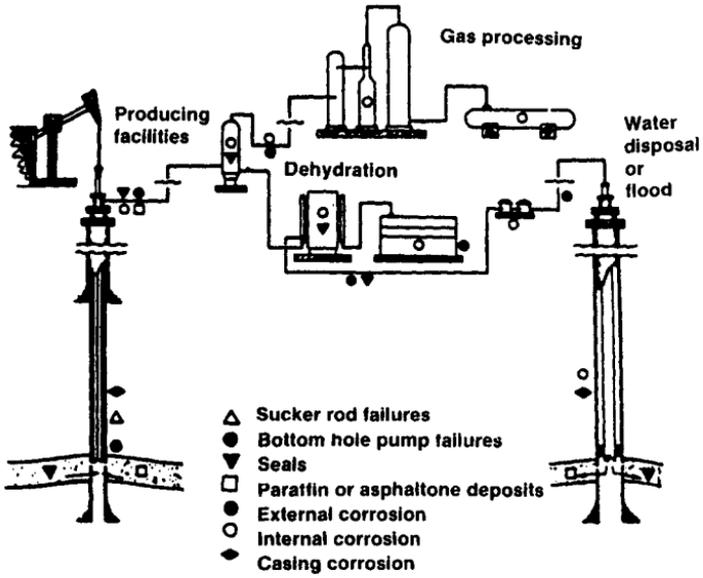


Fig. 8.2—Schematic diagram of a typical oil well, showing common corrosion sites.

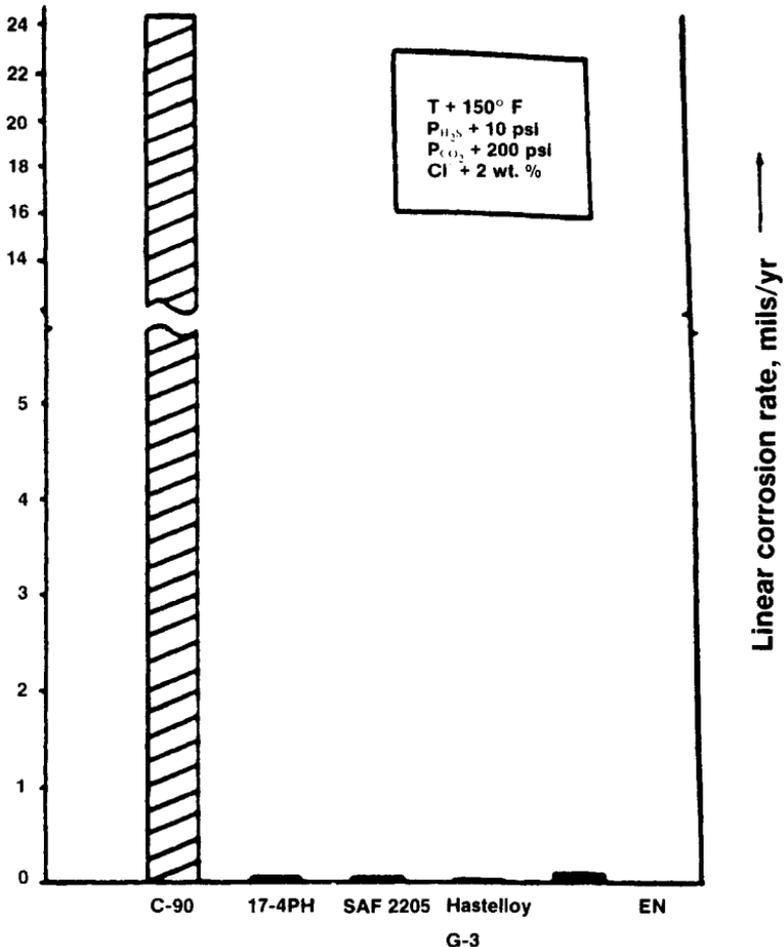


Fig. 8.3—Corrosion rates of various tubing materials used in oil and gas applications. Corrosion environment consists of mixed H₂S, CO₂, and Cl at temperature of 150° F.

rather convoluted components, so the uniformity of the electroless nickel coating is an advantage. The wear resistance, along with the excellent release properties of electroless nickel make it superior to hard chrome for this application.

MINING AND MATERIALS HANDLING APPLICATIONS

In the mining and associated materials handling industries, a wide range of operating conditions can be encountered that require surface finishes. In coal

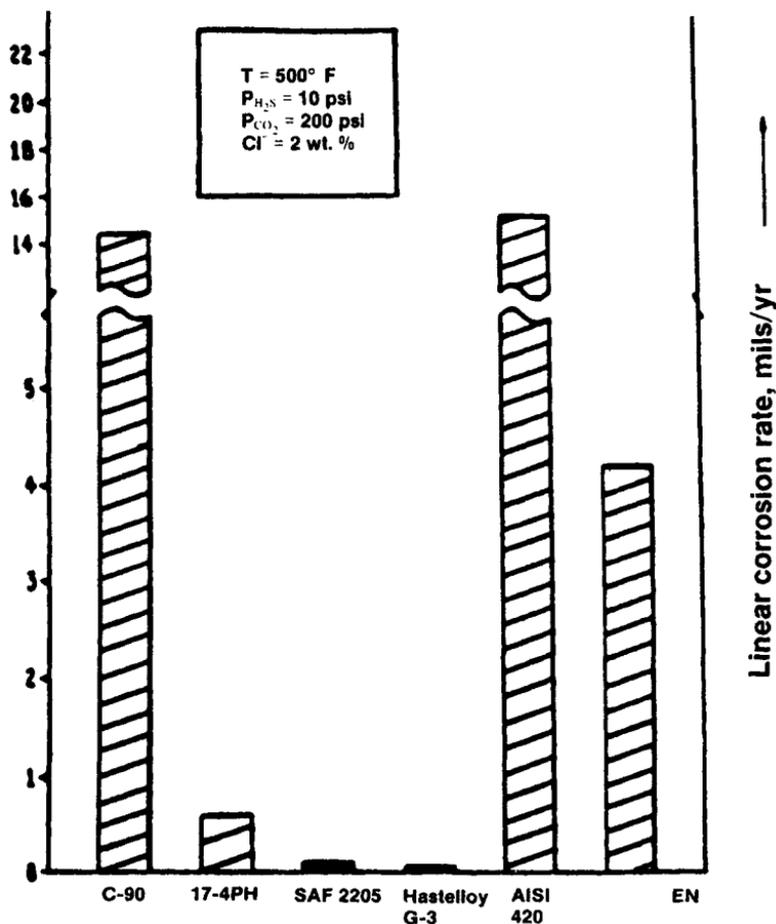


Fig. 8.4—Corrosion rates of various tubing materials used in oil and gas applications. Corrosion environment consists of mixed H_2S , CO_2 , and Cl^- at 500°F .

mining operations, below-ground mining components have to endure contact with brines and acid waters, high temperatures, and very abrasive conditions.

Hard chromium has been applied extensively in mining as a corrosion and wear resistant coating for the hydraulic cylinders used in roof support systems. Hard chromium deposits, however, are porous, as a result of their cracked structure. In service, these coatings developed significant corrosion, to the point where these cylinders can seize and fail to function. This problem is accentuated by the high pressures at which these cylinders operate (e.g., 6000 to 7000 psi), causing coating elongation to occur, which increases cracking of the highly

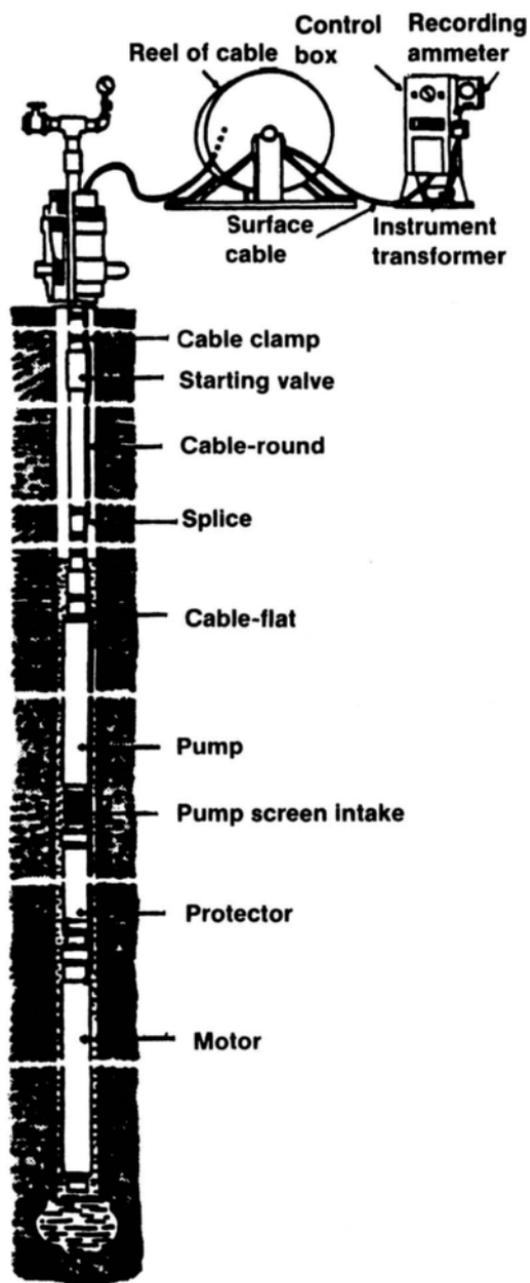


Fig. 8.5—Schematic diagram of submersible centrifugal pump. Electroless nickel plating on pump housing, blades and impellers provides excellent corrosion protection.

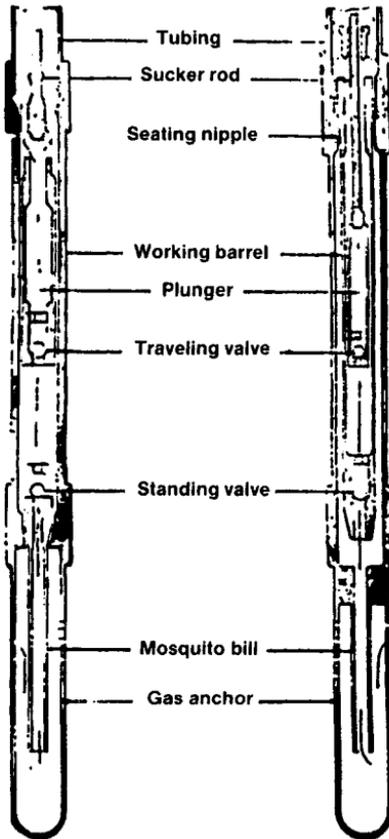
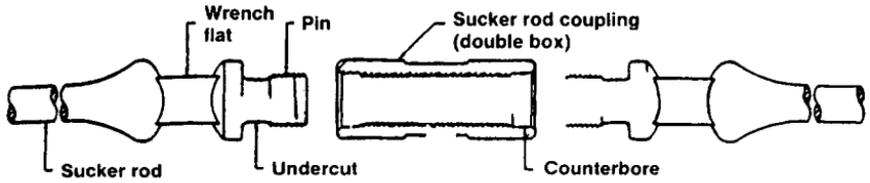


Fig. 8.6—Schematic diagram of pumping system for low-pressure wells. The sucker rod (inset) is plated with electroless nickel for corrosion protection.

Table 8.8
Applications of Electroless Nickel
In the Oil and Gas Industries

| Component | Basis metal | Phosphorus, percent* | Coating thickness, mils | Property of interest** |
|---------------------|--------------------|-----------------------------|--------------------------------|-------------------------------|
| Tubes | Steel | H | 2-4 | CR, WR, U |
| Pump housing | Steel | H | 2-3 | CR, WR |
| Sucker rods | Steel | H | 1-3 | CR, WR, U |
| Ball valves | Steel | H | 1-3 | CR, WR |
| Rod boxes | Steel | H | 1-3 | CR, WR, U |
| Packers | Steel | H | 1-3 | CR, WR |
| Mud pumps | Steel | H | 1-3 | CR, WR |
| Blow out preventors | Steel | H | 1-3 | CR, WR |
| Fire tubes | Steel | H | 1-3 | CR |

*Phosphorus percent. H = 9 to 12; M = 5 to 8; L = 1 to 2.

**CR = corrosion resistance; WR = wear resistance; U = uniformity.

stressed chromium deposits. A 1-mil coating of high-P electroless nickel with good compressive stress properties is used in this application. The electroless nickel deposits do not crack after elongation of the cylinder, and can withstand the corrosive and abrasive environments found in coal mines.

In certain open pit mineral mining operations, such as phosphate rock for use in fertilizers, high pressure pumps are used to suspend the mineral/soil mixtures as the first step in processing. Jetting pump heads also find wide use in mining operations. In this case, corrosion and erosion of materials is a problem. The corrosion resistance and hardness of electroless nickel is used over a steel substrate to prevent premature replacement of components.

Table 8.9 summarizes the typical mining and materials handling applications of electroless nickel.

MILITARY APPLICATIONS

The military presents numerous unique problems that were solved by the corrosion and wear resistant properties of electroless nickel, as well as taking advantages of other characteristics, such as its optical properties (13,23,24).

Table 8.9
Applications of Electroless Nickel Plating
In the Materials Handling and Mining Industries

| Component | Basis metal | Phosphorus, percent* | Coating thickness, mils | Property of interest** |
|--------------------------------|--------------------|-----------------------------|--------------------------------|-------------------------------|
| <i>Materials handling</i> | | | | |
| Hydraulic cylinders and shafts | Steel | H | 1.0 | CR, WR, LU |
| Extruders | Alloy steel | M, H | 3.0 | CR, WR |
| Link drive belts | Steel | M, H | 0.5 | CR, WR, LU |
| Gears and clutches | Steel | M, H | 1.0 | WR, buildup |
| <i>Mining</i> | | | | |
| Hydraulic systems | Steel | H | 2.4 | CR, AR |
| Jetting pump heads | Steel | L, M, H | 2.4 | CR, ER |
| Mine engine components | Steel/cast iron | M, H | 1.2 | CR, WR |
| Piping connections | Steel | M, H | 2.4 | CR |
| Framing hardware | Steel | M, H | 1.2 | CR |

*Phosphorus percent: H = 9 to 12; M = 5 to 8; L = 1 to 2.

**CR = corrosion resistance; WR = wear resistance; LU = lubricity; ER = erosion resistance; AR = abrasion resistance.

Catapult covers and tracks for aircraft carriers have recently been coated with electroless nickel. In this application, both wear and corrosion cause the failure of the catapult system within 6 to 12 months in the uncoated state. The catapult environment is very harsh. When the planes are launched, high temperature steam (450° F) is released and rushes by the track. At the same time, up to 1,000,000 lb of force is applied to the track, pulling down and putting pressure on the keyway. As the plane becomes airborne, the track is pulled up, creating additional wear. Salt water and corrosion products from the planes are always present and collect in the keyway, which is a galvanic cell between the dissimilar metals of the cover track.

Many other coatings were tried, with electroless nickel being the most effective in preventing the fretting wear and loss of keyway material through galvanic corrosion. The covers are first repaired and returned to size. After cleaning, a 1.2-mil coating of electrolytic glycolate nickel is applied, followed by a 4-mil coating of electroless nickel, and then 0.5 mils of cadmium, which is subsequently chromated. This combination of treatments provides fretting,

wear, and corrosion protection, and chloride in the aggressive marine environment.

After coating the catapult covers with electroless nickel and cadmium, the tracks and covers have a 14- to 18-year service life. This increase in life means that the carriers can remain operational for up to 5 years without having to return to base for a four-month-long overhaul.

Trunions for military vehicles have been plated with electroless nickel for many years. The trunions are located on the side of the vehicle and provide a bearing for the track splines. In this environment, salt and mud are always present and would cause rapid corrosion of the steel bearing surface if it were not protected.

The rear view mirrors of tanks are made of highly polished aluminum and plated with electroless nickel to provide a wear- and corrosion-resistant coating. This application requires that the reflectivity of the electroless nickel be 80 percent over the visible light spectrum. Electroless nickel easily meets these requirements. Aluminum radar wave guides are plated with 1 mil of electroless nickel to protect them against the elements either on land or at sea. Electroless nickel easily provides a uniform coating over the various shapes of the wave guides.

MISCELLANEOUS APPLICATIONS

Molds and Dyes

When electroplating complex molds, careful and complicated anode fixturing is required to achieve coverage in every recess of the mold. The time required for such anode fixturing, and the post-plating machining required to achieve uniformity, adds significantly to the cost. Plating molds in an electroless nickel bath provides the uniformity required, plus the inherent lubricity and excellent release properties that combine to make electroless nickel the most cost effective way to coat molds and dyes.

Foundry Tooling

Electroless nickel is successfully used to protect foundry tooling against pattern wear (25). Aluminum and cast iron tooling can be upgraded by applying 3 to 5 mils of a high-P electroless nickel coating, which increases the surface hardness of these metals and extends their useful life.

Printing Industry

In this industry, both printing rolls and press beds are plated with 1 to 2 mils of high-P electroless nickel (26). These components are generally made of steel or cast iron, and need to be protected from the corrosive inks. In the case of printing rolls, the uniformity of the electroless nickel coating eliminates the post-plating machining to achieve roundness.

Textiles

Wear is the single most important problem solved by electroless nickel in the textile industry. As literally hundreds of miles of thread pass through, around, and over components, wear becomes a significant maintenance problem. Steel thread feeds and guides are plated with 2 mils of heat-treated electroless nickel. Other electroless nickel-coated components include spinnettes, loom ratchets, and knitting needles.

Medical

Surgical staples have been plated with 0.1 to 0.2 mils of electroless nickel. Dental drills use hardened electroless nickel. Various hospital equipment moldings and rails are using electroless nickel in place of chrome or nickel-chrome coatings.

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