

CORROSION TECHNOLOGY

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1. *Corrosion Protection Handbook*, Second Edition, Revised and Expanded, edited by Philip A. Schweitzer
2. *Corrosion Resistant Coatings Technology*, Ichiro Suzuki
3. *Corrosion Resistance of Elastomers*, Philip A. Schweitzer
4. *Corrosion Resistance Tables: Metals, Nonmetals, Coatings, Mortars, Plastics, Elastomers and Linings, and Fabrics, Third Edition, Revised and Expanded (Parts A and B)*, Philip A. Schweitzer
5. *Corrosion-Resistant Piping Systems*, Philip A. Schweitzer
6. *Corrosion Resistance of Zinc and Zinc Alloys*, Frank C. Porter

ADDITIONAL VOLUMES IN PREPARATION

Corrosion Resistance OF Zinc AND Zinc Alloys

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Organic and Inorganic Chemicals, Building Materials and Coatings, and Fuels

I. GENERAL

This chapter commences with advice on the cleaning of zinc surfaces. The major corrosion interests are then considered in five groups: (a) inorganic chemicals and their aqueous solutions, (b) organic materials and fuels, (c) concretes, cements, and plaster, (d) bitumen, and (e) other building materials.

Consideration must be given not only to the effect of corrosion on the zinc, but also to the possible effects of corrosion products in noncorrosion aspects; for example, solid corrosion products may prevent a valve from shutting. Also, corrosion that may be too slight to affect the zinc may significantly contaminate the chemical with which it is in contact or change the texture or appearance of a consumer product. This chapter consists largely of brief references to actual tests and an indication of the apparent suitability of the material for contact with zinc, plus lists of chemicals known to be stored satisfactorily in zinc-coated steel containers.

Many foods and drinks are not affected by contact with zinc but, in some cases, this property may give rise to unacceptably high levels of zinc. Long contact with zinc should be avoided with most acid foodstuffs. In general, zinc levels up to 50 ppm (50 mg/L) will not be harmful to human health, but many regulations set an unnecessarily low level for zinc. This subject is outside the scope of this book but is covered in *Zinc Handbook* (Porter, 1991).

Zinc-coated tanks and cylinders are widely used in oil refineries and other plants for storing oil and petroleum products, chlorine, carbon dioxide, and other industrial gases. Refrigerating plants and cooling equipment, as well as degreasing plants, are almost universally protected by a zinc coating. Zinc-coated steel is also used on structural steelwork around chemical plants, where it is exposed to high humidity and a variety of chemical fumes. Galvanized steel is used extensively for roofing and siding on buildings that house pulp and paper processing operations. Other uses of zinc-coated steel in the chemical industry include applications in floating-roof-type storage tanks for volatile liquids, and galvanized wire cloth and mesh belts for the movement of chemicals through various production stages. Galvanized steel containers are used to store strategic chemicals in outdoor locations. From these representative examples, it is apparent that zinc and zinc-coated steel are very useful in the chemical industry.

II. CLEANING OF ZINC SURFACES

Certain water-based solutions are used to clean zinc surfaces, notably to remove corrosion products from test specimens without removing uncorroded zinc. ASTM Standard Recommended Practice G1 calls for the use of ammonium hydroxide solution followed by boiling chromic acid/silver nitrate for cleaning zinc test panels after exposure. Noranda trials show the correction factors to be applied for metal lost in the cleaning procedure (Fig. 5.1). Swedish Standard (draft) SS 11 72 11, Accelerated Outdoor Test by Intermittent Spraying of a Salt Solution (Scab Test), recommends using 200 g of CrO_3 in distilled water to make 1000 mL for 1 minute at 80°C and warns that chloride contamination of the chromic acid can cause zinc corrosion.

When wet storage staining has occurred, the objects should be arranged so that their surfaces dry rapidly. The attack will then cease and, with a free supply of air to the surfaces, the normal protective layer of corrosion products will form, provided the reaction has not consumed too much zinc (i.e., that not more than 10–15 μm of zinc coating has been consumed). The white corrosion products are gradually washed off, and the surface of the coating takes on the normal appearance of an exposed hot dip galvanized object.

A guideline for users appears in Swedish standard SMS 2950:

The special form of corrosion known as wet storage stain (white rust) that sometimes appears on hot dip galvanized objects after a short period of storage shall not be regarded as sufficient cause for not granting approval, unless a special agreement has been reached that wet storage stain shall not be allowed.

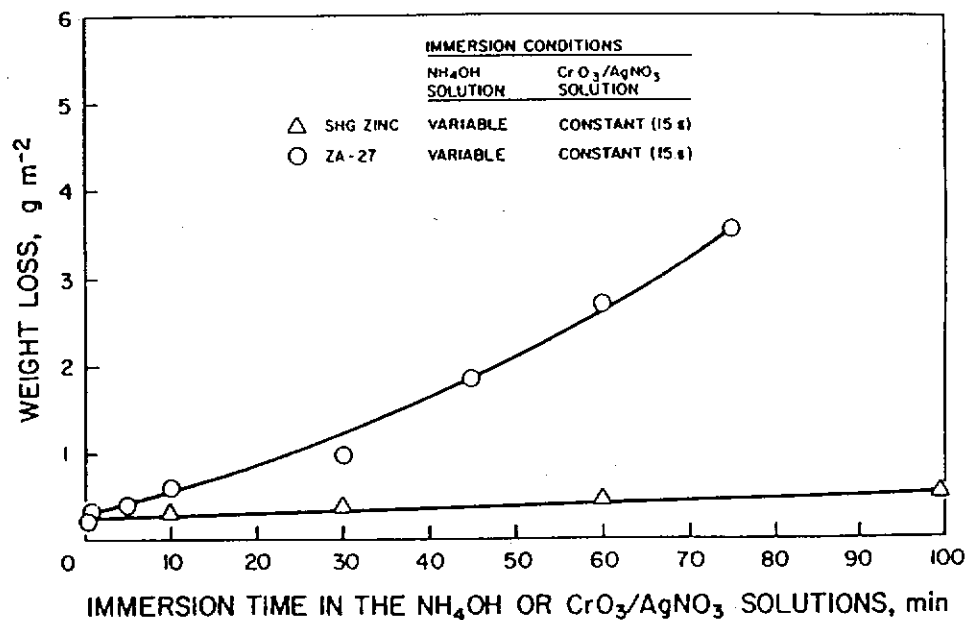


Fig. 5.1 Base metal loss of zinc and of ZA 27 when cleaned to ASTM G1 procedure (150mL/L NH_4OH s.g. 0.90 followed by boiling 50 g/L CrO_3 + 10 g/L AgNO_3) (Noranda, 1991).

If desired, white corrosion products that have already formed can be partially removed by brushing with a stiff bristle brush. They can be removed completely by washing with 10% acetic acid, which must be followed by very thorough rinsing with water. Also recommended for removal of white zinc corrosion products is a paste consisting of 100 parts by weight of "Champagne chalk" (a fine white powder from northern France) and 20–40 parts by weight of a 10% caustic soda solution in water. After using the paste to rub off the corrosion products, rinse in water and dry.

Another method is to use a dilute solution of sodium tartrate and ammonium carbonate in water, to which chalk is added. With a sponge soaked in this solution, the white corrosion products can be easily removed. The original bright, metallic lustrous surface cannot be restored by these treatments, however.

A. General

Mechanical methods (wire brushing, steel wool, abrasives) of cleaning rolled zinc are rarely acceptable. Areas cleaned by such methods tend to contrast

with adjacent untreated zinc and may take a long time to weather to a uniform color.

B. Water Staining

Mild staining can be removed by swabbing—repeated, if necessary, with ammonia (“strong” household ammonia) followed by rinsing with water. The following solution is more effective; the composition is not critical:

Ingredient	Amount
Ammonia (0.880)	19 mL
Ammonium chloride	6 g
Ammonium carbonate	6 g
Water (tap)	71 mL

Swabbing, like the mechanical methods, should be used only in the open, or in well-ventilated conditions, and protective goggles should be used.

C. Rust Staining

Water draining onto zinc from rusting steelwork (e.g., scaffolding) often causes conspicuous and permanent brown staining.

The remedy is to swab with a cold water solution of commercial quality oxalic acid solution (or alternatively use a proprietary solution for the removal of scale from pots and pans) followed by rinsing with water. Oxalic acid is toxic; rubber gloves and goggles are recommended.

D. Cement and Mortar Stains

Portland cement mortar droppings tend to adhere strongly to zinc and when fully hardened are often difficult to remove completely without damaging the metal.

After gross deposits have been removed as far as practicable, use oxalic acid as for rust stains. Hydrochloric (muriatic) acid and proprietary mixtures based on it are sometimes used, but this approach is not recommended because the action on zinc is too vigorous and it is difficult to rinse off residues.

Test samples of metal that have been embedded in concretes, and so on, can be divested of much of the adherent material by gentle heating—the adherent material will crack off.

E. Finger Marking

Polished zinc surfaces, such as organ pipes, finger-mark very easily when handled; such marks may be hardly visible initially, taking hours or days to “develop,” but once evident, they remain conspicuous even after the metal has tarnished. To avoid finger marking on zinc surfaces, the objects are sprayed (before handling) with a clear light-fast acrylate or methacrylate varnish (dry film thickness 10–15 μm).

The marks may be enhanced by clear lacquer finishes. If this happens, any lacquer finish must be stripped off and the marks treated as under Section II. B. Local repolishing may be necessary. Finger marking can be avoided by wearing fabric gloves and can also be suppressed by the sparing application of white vaseline (laboratory chemical grade), rubbed on with a clean, soft cloth.

F. Bitumen-Based Products (asphalt, etc.)

Contamination from bitumen-based products arises mainly from accidental spillage on building sites. The remedy is to clean off the surface as soon as possible with wooden scrapers. Then swab repeatedly with clean cloths and a solvent such as paint thinner (white spirit) or xylene/toluene (solvent naphtha). Avoid “spreading,” and do not apply heat.

G. Conventional Paints

If still wet, clean off conventional paints with appropriate paint thinners. Hardened paint should be removed with a nonalkaline organic paint stripper. Burning off or the use of steel scrapers is not advisable.

H. Staining by Beer, Wines, and Spirits

Zinc countertops are occasionally used in bars and cafeterias. Particularly when the metal covering is new, it may develop local stain “rings” under glasses containing wine or spirits.

The remedy is to treat with a mixture of ammonia, ammonium chloride, and ammonium carbonate mixture as described in Section II. B.; polishing or the use of abrasives is not recommended.

Usually, a soft gray matte finish is desired, and periodic wiping with a beer-moistened cloth (in England draft bitter has been found most effective) helps to achieve this effect by developing a stain-resistant skin.

I. Detergents and Cleansers

Mildly alkaline solutions of ordinary laundry soaps develop a protective coating on zinc and its alloys. They are satisfactory for both warm and cold applications. Detergent solutions are more corrosive; however, the better grades include inhibitors, which reduce corrosion to allow reasonably satisfactory service for zinc alloys. Strong alkalis (e.g., hypochlorite bleach solutions) or acid solutions (e.g., Harpic, which contains trisodium hydrogen disulfate) are to be avoided.

Table 5.1 gives results for five series of immersion trials designed to show the short-term and long-term effects of both simple chemicals and commercial solutions. Although the corrosion rates are calculated per year (for consistency with other tables), it must be remembered that often the contact time will be in hours or even minutes per year; hence, quite high corrosion rates may be acceptable. Some tests were made on zinc sheet and some on hot dip galvanized material. The results should be of the same order, so this detail is normally omitted from the tables in this chapter. When the original source shows significant differences in the two materials, it is anticipated that the dissimilarities are due to surface films (e.g., chromating) being left in place unwittingly. Trials in the United Kingdom were made by BNF and by Imperial Smelting (unpublished) at room temperature, at 70°C, and at 100°C on commercial detergents in use in Britain in 1959. Corrosion was significant at the higher temperatures, suggesting that for long life of die-cast components in washing machines, a protective coating is desirable.

I. Trichlorethylene

Normal trichlorethylene degreasing has no effect on zinc or zinc-aluminum alloys, provided immersion in solution that has become degraded or contaminated is avoided.

III. INORGANIC CHEMICALS

In the presence of moisture such as rain or condensation, or in solution, many chemicals react with zinc. Corrosion is serious if the reaction of the chemical with zinc forms acidic products. Mixtures of chemicals can sometimes be more corrosive than the sum of their effects taken separately but, when such mixtures come from natural sources, there are often unsuspected inhibitors present, which give a net beneficial effect.

A short immersion trial is desirable for water-based solutions. Linear extrapolation of the results will usually indicate the worst possibility, since the attack often reduces with time.

Table 5.1 Corrosion Data for Zinc and Zinc Coatings with Detergents, Cleaners, Soaps, Synthetic Detergents (Syndets), etc.

Materials	Time (days unless otherwise indicated)	Temperature (°C)	Corrosion rates		Remarks	Refs.
			mg/m ² /year	µm/year		
			Letter code for references cited in the table:			
			I	International Nickel Co. (direct information)		
			K	Stupel and Koch (1959)		
			L	Bukowiecki (1958)		
			M	Bablik and Belohlavy (1957)		
			P	Bacon and Nutting (1952)		
Detergents and Cleaners						
Calcium chloride						I
20% solution	10	33	125	17	Dairy cleaning	I
20% solution	10	33	82	11	Dairy cleaning	I
20% solution + silicate	10	35	92	13	Dairy cleaning	I
20% solution + 0.05% Ca(OH) ₂	10	35	95	13	Dairy cleaning	I
20% solution + 0.17% Na ₂ Cr ₂ O ₇	10	35	80	11	Dairy cleaning	I
Lime mix						I
200 g/L of 66.5% Ca(OH) ₂ + 32.5% MgO	5	21	270	38	Dairy cleaning	I
Sodium carbonate						I
sodium carbonate-zinc sheet	5 h	66	1,425	200	Dairy cleaning	I
sodium carbonate-HDG sheet	5 h	66	1,350	190	Dairy cleaning	I
Sodium hydroxide						I
0.5% solution	5 h	66	3,250	450	Dairy cleaning	I
0.5% solution	5	21	171	24	Dairy cleaning	I
0.5% solution-HDG sheet	5 h	66	7,450	1,040	Dairy cleaning	I
0.5% solution-HDG sheet	5	21	440	61	Dairy cleaning	I

Table 5.1 Continued

Materials	Time (days unless otherwise indicated)	Temperature (°C)	Corrosion rates		Remarks	Refs.
			mg/m ² /year	µm/year		
			Letter code for references cited in the table:			
	I	=	International Nickel Co. (direct information)			
	K	=	Stupel and Koch (1959)			
	L	=	Bukowiecki (1958)			
	M	=	Bablik and Belohlavy (1957)			
	P	=	Bacon and Nutting (1952)			
Sodium hypochlorite						
6 g/L, 236 ppm available Cl ⁻	5	21	190	110	Dairy cleaning	I
6 g/L, 236 ppm available Cl ⁻	5	21	752	105	Dairy cleaning	I
Diversol						
7 g/L, 236 ppm available Cl ⁻	5	21	175	25	Dairy cleaning	I
7 g/L, 236 ppm available Cl ⁻	5	21	Gained weight		Dairy cleaning	I
4 g/L, 137 ppm available Cl ⁻	5	21	215	30	Dairy cleaning	I
4 g/L, 137 ppm available Cl ⁻	5	21	266	37	Dairy cleaning	I
Chloramine T, 0.6 g/L, 222 ppm available Cl ⁻	5	21	617	86	Dairy cleaning	I
Chloramine T, 0.6 g/L, 222 ppm available Cl ⁻	5	21	0	0	Dairy cleaning	I
Trisodium phosphate						
0.16% solution	5 h	66	1,059	150	Dairy cleaning	I
0.16% solution	5 h	66	47	7	Dairy cleaning	I
0.50% solution	5 h	66	876	120	Dairy cleaning	I
0.50% solution	5 h	66	Gained weight		Dairy cleaning	I
Carbon tetrachloride-benzol						
90%-10% mixture	40	RT	1,522	210	Dry cleaning	I
90%-10% mixture	38	140	Very high		Dry cleaning	I
Perchloroethylene						
vapor	64	127	4,300	600	Dry cleaning	I
liquid	64	151	14,874	2,080	Dry cleaning	I
Syndet components						
sodium tripolyphosphate 0.08%	7 h	95	6,883	965	Individual component of syndet at concentration present in detergent	M
tetrasodium pyrophosphate 0.085%	7 h	95	4,856	680		M
sodium perborate 0.064%	7 h	95	976	137		M
sodium carbonate 0.18%	7 h	95	625	87		M
sodium sulfate 0.12%	7 h	95	250	35		M
sodium chloride 0.004%	7 h	95	488	68		M
sodium metasilicate 0.045%	7 h	95	650	91		M
lauryl alcohol sulfonate 0.18%	7 h	95	538	75		M
lauric acid ethanolamide 0.015%	7 h	90	187	26		M
sodium tripolyphosphate 0.15%	12 h	90	36,534	5,090		Solution also contained 0.1% sodium perborate; solution renewed every hour
sodium tripolyphosphate 0.50%	12 h	90	49,640	6,950	L	
tetrasodium pyrophosphate 0.15%	12 h	90	32,193	4,510	L	
sodium metaphosphate 0.15%	12 h	90	35,551	4,980	L	
ordinary soap 0.3%	12 h	90	4,672	655	L	
lauryl sulfate 0.05%	12 h	90	Gain	Gain	L	
sodium carbonate, tech calcined 0.1%	12 h	90	2,409	340	L	
sodium metasilicate · 5H ₂ O 0.03%	12 h	90	438	61	L	
sodium sulfate cryst 0.05%	12 h	90	4,818	675	L	
sodium trisulfate 0.15%	12 h	90	8,249	1,155	L	
sodium carbonate 0.1%	12 h	90	1,022	143	Perborate-free solutions	L
sodium metasilicate · 5H ₂ O 0.03%	12 h	90	Gain	Gain		L
ordinary soap, 0.03%	12 h	90	4,745	665		
Tetrasodium pyrophosphate						
0.1%	20 min	95	3,940	560	Effect of solution concentration and duration of immersion	M
0.1%	20 min	95	27,070	3,760		M
0.1%	80 min	95	10,840	1,525		M
0.1%	7 h	95	4,850	685		M

Table 5.1 Continued

Materials	Time (days unless otherwise indicated)	Temperature (°C)	Corrosion rates		Remarks	Refs.	
			g/m ² /5 cycles	μm/year			
Letter code for references cited in the table:							
I	=	International Nickel Co. (direct information)					
K	=	Stupel and Koch (1959)					
L	=	Bukowiecki (1958)					
M	=	Bablik and Belohlavý (1957)					
P	=	Bacon and Nutting (1952)					
Tetrasodium pyrophosphate							
0.5 g/L in 0 g water		bp	6.0	(1,965)	5 cycles, each 30 min at boiling + 15 min cooling; solution renewed after each cycle g/m ² /5 cycles × 328 = μm/year Aeration and agitation from boiling	K	
0.5 g/L in 21 g water		bp	1.2	(391)		K	
0.5 g/L in 21 g water + 1 g/L perborate		bp	1.5	(493)		K	
1.0 g/L in 0 g water		bp	11.2	(3,665)		K	
1.0 g/L in 21 g water		bp	4.7	(1,540)		K	
1.0 g/L in 21 g water + 1 g/L perborate		bp	5.1	(1,670)		K	
2.0 g/L in 0 g water		bp	25.8	(8,460)		K	
2.0 g/L in 21 g water		bp	19.0	(6,450)		K	
2.0 g/L in 21 g water + 1 g/L perborate		bp	21.2	(6,935)		K	
3.0 g/L in 0 g water		bp	34.5	(11,300)		K	
3.0 g/L in 21 g water		bp	27.2	(8,915)		K	
3.0 g/L in 21 g water + 1 g/L perborate		bp	32.8	(10,745)		K	
Sodium tripolyphosphate							
0.01%	20 min	95	2,630	380		Effect of solution concentration and duration of immersion	M
0.05-1%	20 min	95	31,270	4,400	M		
0.08%	7 h	95	6,880	965	M		
0.5 g/L in 0 g water		bp	5.4	(1,770)	5 cycles, each 30 min at boiling + 15 min cooling; solution renewed after each cycle g/m ² /5 cycles × 328 = μm/year Aeration and agitation from boiling	K	
0.5 g/L in 21 g water		bp	2.8	(920)		K	
0.5 g/L in 21 g water + 1 g/L perborate		bp	3.7	(1,210)		K	
1.0 g/L in 0 g water		bp	14.8	(4,850)		K	
1.0 g/L in 21 g water		bp	8.5	(2,800)		K	
1.0 g/L in 21 g water + 1 g/L perborate		bp	11.4	(3,730)		K	
2.0 g/L in 0 g water		bp	36.9	(12,100)		K	
2.0 g/L in 21 g water		bp	24.9	(8,150)		K	
2.0 g/L in 21 g water + 1 g/L perborate		bp	29.7	(9,730)		K	
3.0 g/L in 0 g water		bp	46.2	(15,140)		K	
3.0 g/L in 21 g water		bp	32.6	(10,700)		K	
3.0 g/L in 21 g water + 1 g/L perborate		bp	39.8	(13,030)		K	
Sodium metaphosphate							
0.5 g/L in 0 g water		bp	5.9	(1,930)		5 cycles, each 30 min at boiling + 15 min cooling; solution renewed after each cycle Aeration and agitation from boiling	K
0.5 g/L in 21 g water		bp	3.7	(1,210)	K		
0.5 g/L in 21 g water + 1 g/L perborate		bp	4.8	(1,570)	K		
1.0 g/L in 0 g water		bp	17.1	(5,610)	K		
1.0 g/L in 21 g water		bp	9.9	(3,250)	K		
1.0 g/L in 21 g water + 1 g/L perborate		bp	15.9	(5,210)	K		
2.0 g/L in 0 g water		bp	32.9	(10,770)	K		
2.0 g/L in 21 g water		bp	28.1	(9,200)	K		
2.0 g/L in 21 g water + 1 g/L perborate		bp	33.1	(10,850)	K		

Table 5.1 Continued

Materials	Time (days unless otherwise indicated)	Temperature (°C)	Corrosion rates		Remarks	Refs.
			g/m ² /5 cycles	μm/year		
3.0 g/L in 0 g water		bp	49.0	(16,050)	5 cycles, each 30 min at boiling + 15 min cooling; solution renewed after each cycle Aeration and agitation from boiling	K
3.0 g/L in 21 g water		bp	37.4	(12,250)		K
3.0 g/L in 21 g water + 1 g/L perborate		bp	47.4	(15,550)		K
Tetrasodium pyrophosphate			mg/m ² /year			
0.06% solution	6 h	80	8,570	1,200		P
0.15% solution of mixture: 40% tetrasodium pyrophosphate + 30% trisodium phosphate · 12H ₂ O + 30% sodium metasilicate · 5H ₂ O	6 h	80	65,300	9,150		P
0.15% solution of mixture: 31.2% sodium hexametaphosphate + 24.7% trisodium phosphate · 12H ₂ O + 39.2% sodium metasilicate · 5H ₂ O + 4.5% sodium carbonate	6 h	80	20,000	2,800		P
Commercial Soaps and Syndets						
Syndet 1						
0.2% solution (Fab)	1 week	RT	235	33		I
0.2% solution (Fab)	7 h	60	18	<2		I
Syndet 2						
0.2% solution (Mytron)	1 week	RT	890	125		I
0.2% solution (Mytron)	7 h	60	57	8		I
0.2% solution + sodium silicate	1 week	RT	1,215	170		I
Syndet 3						
0.2% solution (OS)	1 week	RT	870	122		I
Syndet 4						
0.2% solution (Tide)	1 week	RT	400	56		I
0.2% solution (Tide)	7 h	60	71	10		I
Syndet 5 containing phosphates						
0.5% solution	20 min	95	51,500	7,215	pH 10.20 5 consecutive 20 min cycles on same piece	M
0.5% solution	80 min	95	16,850	2,360		M
0.5% solution	4 h	95	9,250	1,295		M
1.0% solution	20 min	95	89,350	12,520		M
0.5% solution		95	3,000	415		M
0.5% solution		95	3,050	430		M
0.5% solution		95	4,535	655		M
0.5% solution		95	4,600	650		M
0.5% solution		95	5,060	710		M
0.5% solution		95				M
Syndet 6						
0.4% solution	80 min	95	13,600	1,905	pH 9.89	M
Soap 1						
0.8% solution, pH 10.65	80 min	95	4,355	610	5 consecutive 20 min cycles on same piece	M
0.8% solution, pH 10.65		95	1,050			M
0.8% solution, pH 10.65		95	685			M
0.8% solution, pH 10.65		95	370			M
0.8% solution, pH 10.65		95	210			M
0.8% solution, pH 10.65		95	105			M

Table 5.1 Continued

Materials	Time (days unless otherwise indicated)	Temperature (°C)	Corrosion rates		Remarks	Refs.
			mg/m ² /year	µm/year		
			g/m ² /5 cycles			
Letter code for references cited in the table:						
I	=	International Nickel Co. (direct information)				
K	=	Stupel and Koch (1959)				
L	=	Bukowiecki (1958)				
M	=	Bablik and Belohlavy (1957)				
P	=	Bacon and Nutting (1952)				
Soap 2						
0.8% solution, pH 10.73	80 min	95	1,450	203		
0.8% solution, pH 10.73	4 h	95	490	69		M
0.5% solution	20 min	95	4,470	635		M
2.0% solution	20 min	95	6,310	890		M
Syndet 7 (U.S.)			g/m ² /5 cycles			
in 0 g water		bp	49.0	(16,050)	5 cycles, each 30 min at boiling + 15 min cooling; solution renewed after each cycle.	K
in 12.5 g water		bp	24.8	(8,130)		K
Syndet 8 (German)					Aeration and agitation from boiling	
in 0 g water		bp	7.9	(2,590)		K
in 12.5 g water		bp	13.8	(4,520)	K	
Syndet 9 (Swiss)					5 cycles, each 30 min at boiling + 15 min cooling; solution renewed after each cycle.	
in 0 g water		bp	7.8	(2,540)		K
in 12.5 g water		bp	14.1	(4,620)	K	
Syndet 10					Aeration and agitation from boiling	
in soft water		bp	58.9	(19,250)		K
+ 1% acid orthophosphate		bp	54.2	(17,730)	K	
+ 5% acid orthophosphate		bp	47.8	(15,650)	K	
+ 10% acid orthophosphate		bp	31.0	(10,160)	K	
Syndet 11					5 cycles, each 30 min at boiling + 15 min cooling; solution renewed after each cycle.	
in soft water (silicates; no orthophosphate)		bp	34.5	(11,330)		K
+ 1% acid orthophosphate		bp	28.2	(9,250)		K
+ 5% acid orthophosphate		bp	17.9	(5,870)		K
+ 10% acid orthophosphate		bp	8.7	(2,845)	K	
Syndet 12					g/m ² /5 cycles × 328 = µm/year Aeration and agitation from boiling	
in soft water		bp	22.4	(7,340)		K
+ 1% acid orthophosphate		bp	20.4	(6,680)		K
+ 5% acid orthophosphate		bp	19.6	(6,430)		K
+ 10% acid orthophosphate		bp	17.3	(5,660)	K	
Hard water soap 3 (U.S.)						
in 0 g water		bp	7.9	(2,590)		K
in 12.5 g water		bp	13.2	(4,320)	K	
Hard water soap 4 (Swiss)						
in 0 g water		bp	2.2	(720)		K
in 12.5 g water		bp	6.6	(2,160)	K	
Laboratory-Prepared Soap Mixtures and Syndets ^a						
Syndet I					5 cycles, each 30 min at boiling + 15 min cooling; solution renewed after each cycle. Aeration and agitation from boiling	
6 g/L in 0 g water		bp	40.2	(13,160)		K
6 g/L in 21 g water		bp	28.5	(9,350)		K
6 g/L in 42 g water		bp	12.1	(3,960)		K
6 g/L + 0.3 g/L sodium metasilicate 0 g H ₂ O		bp	36.4	(1,200)		K
0.3 g/L sodium disilicate 0 g H ₂ O		bp	32.9	(1,080)		K
0.3 g/L sodium trisilicate 0 g H ₂ O		bp	27.6	(9,040)		K
1.8 g/L sodium trisilicate 0 g H ₂ O		bp	18.3	(6,000)		K
0.3 g/L monoammonium phosphate 0 g H ₂ O		bp	22.2	(7,260)		K
0.3 g/L monoammonium phosphate 21 g H ₂ O		bp	14.6	(4,780)		K

Table 5.1 Continued

Materials	Time (days unless otherwise indicated)	Temperature (°C)	Corrosion rates		Remarks	Refs.	
			g/m ² /5 cycles	μm/year			
Letter code for references cited in the table:							
I	=	International Nickel Co. (direct information)					
K	=	Stupel and Koch (1959)					
L	=	Bukowiecki (1958)					
M	=	Bablik and Belohlavy (1957)					
P	=	Bacon and Nutting (1952)					
0.18 g/L sodium nitrate 0 g H ₂ O		bp	24.1	(7,900)	5 cycles, each 30 min at boiling + 15 min cooling; solution renewed after each cycle. Aeration and agitation from boiling	K	
0.3 g/L magnesium lactate 0 g H ₂ O		bp	19.3	(6,325)		K	
0.3 g/L magnesium lactate 21 g H ₂ O		bp	21.0	(6,880)		K	
0.3 g/L calcium chloride 0 g H ₂ O		bp	16.0	(5,230)		K	
0.36 g/L sodium thiosulfate		bp	16.8	(5,510)		K	
0.3 g/L sodium aluminate 0 g H ₂ O		bp	21.7	(7,110)		K	
0.3 g/L sodium perborate 0 g H ₂ O		bp	56.2	(18,400)		K	
0.3 g/L sodium perborate 21 g H ₂ O		bp	34.7	(11,380)		K	
Syndet I, 6 g/L + magnesium silicate 0.18 g/L + 0 g/L perborate - 0 g H ₂ O		bp	51.9	(17,000)		K	
2 g/L perborate - 0 g H ₂ O		bp	55.8	(18,300)		K	
4 g/L perborate - 0 g H ₂ O		bp	64.8	(21,200)		K	
6 g/L perborate - 0 g H ₂ O		bp	75.1	(24,600)		K	
8 g/L perborate - 0 g H ₂ O		bp	79.0	(26,000)		K	
10 g/L perborate - 0 g H ₂ O		bp	81.2	(26,700)		K	
12 g/L perborate - 0 g H ₂ O		bp	82.0	(26,900)		K	
13 g/L perborate - 0 g H ₂ O		bp	81.9	(26,900)		K	
15 g/L perborate - 0 g H ₂ O		bp	80.4	(26,400)		K	
20 g/L perborate - 0 g H ₂ O		bp	63.7	(20,850)		K	
Syndet II ^a							L
6 g/L solution	12 h	20	5,800	810	Solution renewed every hour—HDG + Vigorous aeration and agitation here	L	
6 g/L solution	12 h	40	13,200	1,850		L	
6 g/L solution	12 h	65	27,800	3,890		L	
6 g/L solution	12 h	90	57,300	8,030		L	
6 g/L solution	12 h	90	59,500	8,330		L	
6 g/L solution	12 h	90	49,100	6,880	Solutions renewed every hour—zinc Solutions renewed every hour—HDG Vigorous aeration and agitation	L	
without perborate, 5 g/L	12 h	90	5,250	735		L	
without perborate, 5 g/L	12 h	90	13,200	1,850		L	
Soap detergent I						L	
9 g/L	12 h	90	3,785	530	HDG—solutions renewed every hour	L	
9 g/L	12 h	90	1,165	163	Zinc—solutions renewed every hour	L	
8 g/L	12 h	90	1,380	193	HDG—solutions renewed every hour	L	
Soap detergent II						L	
9 g/L	12 h	90	12,350	1,730	HDG—solutions renewed every hour	L	
9 g/L	12 h	90	4,530	635	Zinc—solutions renewed every hour	L	
8 g/L	12 h	90	6,000	840	HDG—solutions renewed every hour	L	

^aCompositions of laboratory syndets and soaps:

Syndet I: sodium tripolyphosphate, 50%; sodium sulfate, 19%; dodecylbenzylsulfonate, 10%; sodium perborate · (4H₂O), 8%; lauryl sulfate, 5%; sodium metasilicate, 5%; sodium chloride, 1%; sodium salt of EDTA, 0.5%; carboxymethyl cellulose, 0.5%; water, 1%.

Syndet II: lauryl sulfate, 10%; dodecylbenzylsulfonate, 17%; sodium tripolyphosphate, 30%; tetrasodium pyrophosphate, 5%; waterglass (powder), 6%; magnesium silicate, 2%; carboxymethylcellulose, 1%; sodium sulfate, 13%; sodium perborate, 16%.

Soap detergent I: ordinary soap, 40%; soda, 25%; trisodium phosphate, 11%; tetrasodium pyrophosphate, 5%; waterglass (powder), 6%; magnesium silicate, 2%; sodium perborate, 11%.

Soap detergent II: ordinary soap, 35%; soda, 21%; trisodium phosphate, 5%; sodium tripolyphosphate, 20%; waterglass (powder), 6%; magnesium silicate, 2%; sodium perborate, 11%.