

Zinc is most useful in solutions with pH 5.5–12 and less useful in acidic or strongly alkaline chemical environments encountered, for example, in the chemical process industries. Corrosion of zinc increases rapidly in aqueous chemical solutions on either side of the pH 5.5–12 range. This rule should not be considered to be fixed, however, because many other factors, such as agitation, aeration, temperature, polarization, and, in some cases, the presence of inhibitors, may have considerable influence on the corrosion.

Zinc is widely used in contact with many milder chemical specialties such as detergents, agricultural chemicals, and similar materials. In most cases, zinc or zinc-coated steel comes in contact with chemicals during the handling, packaging, and storage of the commercial products.

Table 5.2 contains corrosion rate data for chemicals and chemical specialties assembled from various sources. Particular mention must be made of the compilation by Wiederholt (1976), which has been used extensively to supplement other data and some references quoted here are only given in full in that report. The chemicals and simple mixtures are listed alphabetically, with the main chemical of the mixture appearing first. The test conditions (temperature, duration, etc.) are also tabulated. There was very little uniformity in these values among the various investigations. For example, test temperatures ranged from room temperature to the boiling point and time of immersion from minutes to several months. The test procedures also included exposure to vapors and partial immersion or total immersion in the solutions. The test conditions adopted in each investigation may have been dictated by specific objectives but, in comparing results of the tests, the possible influence of the test variables should be taken into account. Some of the corrosion rates reported for the chemical specialties are given in specialized units dictated by the test procedures used by the original investigators; usually, however, rates have been converted into micrometers per year when attack is generally fairly uniform. In most cases, the short test periods give higher annualized corrosion rates than would occur with continuous exposure for a year.

Table 5.3 covers agricultural chemicals (including pesticides, both inorganic and organic); Table 5.4 covers fire-extinguishing materials.

Some of the trials reported in Tables 5.1–5.4 are on zinc and others are on zinc-coated steel; normally, similar performance is expected.

The behavior of fertilizers in relation to crop-spraying aircraft is examined by Marshall and Neubauer (1955), who rate copper or cobalt sulfides (either on their own or in superphosphates) as unsuitable for use with galvanized steel equipment. Ammonium phosphate (measured corrosion rate 250  $\mu\text{m}/\text{year}$ ) and nitrolimes (corrosion rate 300  $\mu\text{m}/\text{year}$ ) can be used only with care, for short times. Salt (100  $\mu\text{m}/\text{year}$ ) is better, as is calcium phosphate, while chalk and bone meal have little effect on galvanized steel.

Table 5.2 Corrosion Data for Zinc and Zinc Coatings with Inorganic Chemicals

Some references that occur frequently (and are mainly tabular summaries) are referred to in this table by letter code:

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F	=	Zinkberatung (1959)
G	=	Wiederholt (1976)
H	=	Friend and Tidmus (1924)
I	=	International Nickel Co. (direct data)
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Corrosive media	Time (days)	Temperature (°C)	Corrosion rates		General suitability <sup>a-c</sup>	Remarks	Ref.
			$\text{g}/\text{m}^2/\text{year}$	$\mu\text{m}/\text{year}$			
Acids		All			d	Including aqueous solutions	
All with pH < 5							
Alkalies		Room			b	See specific alkalies	
≅ pH 12.5		Heated			c	See specific alkalies	
≅ pH 12.5		All			c-d	See specific alkalies	
> pH 12.5							
Aluminum chloride					b	As soldering flux	Imperial Smelting Co. (1969)
Molten					d		D, I, Tödt (1961)
26% solution	21	10	510,000	71,400	b		D
Aluminum hydroxide					d	In polishing solutions	D
Aluminum nitrate							
Ammonia					a	Chloride increases corrosion	Jones and Wilde (1977)
Pure, dry, vapor	240	20	33	5	a		
pH 12.5					b		

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Corrosive media	Time (days)	Temperature (°C)	Corrosion rates		General suitability <sup>a-c</sup>	Remarks	Ref.
			g/m <sup>2</sup> /year	µm/year			
Ammonium acetate							
Solution					d		D, Kloetz (1965)
0.2% solution		60			d		
Ammonium acid fluoride							
5% NH <sub>4</sub> F · HF	1	20	6,900	965	d	Corrosion products not removed	B
10% NH <sub>4</sub> F · HF	1	20	13,900	1,950	d		
20% NH <sub>4</sub> F · HF	14	20	15,330	2,150	d		D, Kloetz (1965)
Ammonium bisulfate					d		Miskidch'jan (1970)
Ammonium bromide					b	Inhibitor in acids	D
Ammonium carbamate					b		D, Roebeck (1972)
Ammonium carbonate					b		
Ammonium chloride							
0.1 N	2	35			c		I
10%		20	694	97	b-c		B
Zn-1% Cd		20	1,390	195	c		B
Zn-1% Pb		20	621	87	b-c		B
Technical grade 10%		20	621-1,715	87-240	b-c		D
Ammonium dichloride					d		D
Ammonium dichromate					b	Dissolves phosphate films	Kaysser (1972)
Ammonium dihydrogen phosphate		bp			d		Roebeck (1972)
Ammonium fluoroborate					b	In solders	Alcoa (1968)
Ammonium fluoride							
5%			6,900	960	d		
20%	20		1,600	220	c		Köhler (1955)
Ammonium hydrogen phosphate							
5%		100	6,900	960	d		Köhler (1955), D
10%		100	6,600	920	c		Köhler (1955), D
20%		100	1,600	220	c		Köhler (1955), D
Ammonium hydrogen sulfite					d		D
Ammonium hydroxide							
Vapor	30						I
Reagent	2	30	1,680	235	c		I
Reagent	2	30	2,750	385	c		A
3.5% solution (1 N)	2	30	2,120	295	c		A
3.5% solution (1 N), aerated	2	30	5,150	715	d		Markovic et al. (1958)
pH 7.3		20	980	135	c		Markovic et al. (1958)
pH 10.6,		20	2,630	365	c		Benninghof (1970)
Anodized					b		
Cr in surface film							
zero	30	RT	226	31	b	Attack may increase when Cr is depleted	A
0.2 µg/dm <sup>2</sup>	30	RT	15	2	a		A
1.3 µg/dm <sup>2</sup>	30	RT	4	0.6	a		A
2.2 µg/dm <sup>2</sup>	30	RT	4	0.6	a		A
Ammonium molybdate		60-70			a		D, Huber (1968)
Ammonium nitrate		bp			b-d	Zn-coated steel used in explosives industry	
Ammonium sulfamate							
7-40% solution		RT	1,500	210	b		Marshall and Neubauer (1955)
Ammonium sulfate			1,780	250	c		I
10% + free NH <sub>3</sub>			2,225	310	c		

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			g/m <sup>2</sup> /year	µm/year			
Ammonium thiocyanate					b	Anodic dissolution of Ni/Cr from zinc	Dillenberg (1968)
Antimony chloride 90%		20			b	Used to strip zinc from steel	C BS 729 (1971)
Antimony oxide							
Antimony trichloride					b		Draugelates et al. (1966)
Araldite					a		D
Argon							
Arsenic pentoxide Moist					d		D
Pure					a		D
Arsenious acid 0.2% in 2% H <sub>2</sub> SO <sub>4</sub>						For stripping zinc from steel	DIN 51 213
Barium chloride pH 7.1-7.3		106	4,850	675	c		D
Saturated solution Molten		80			d c		C Kokorin (1969)
Barium hydroxide Solution					c-d	Similar to NaOH	B, D, F, Rodionova (1957, 1960)
Barium nitrate Solution			415	58	b	Aftertreatment of chromate films	Underwood et al. (1971)
Barium sulfate Solution					b		D
Beeswax					c		D
Borates 5-15%					b	Used in prefluxes	Thiem Corp. (1971)
Borax					b	Used in prefluxes	Thiem Corp. (1971)
Bromides					c	Less corrosive than Cl <sup>-</sup>	
Bromine Pure dry		100			b		D, E
Moist					d	Hygroscopic	D
Cadmium chloride Solution					d		D
Cadmium nitrate Solution					b		Czakow (1967)
Cadmium sulfate Solution					d		D
Calcium chlorate 1.57%	10	20	511	71	b		I, Hercules (1966)
Calcium chloride 1.1%	2	35	1,180	164	c	Partial immersion	I
20%: sheet	30	-5	438	61	b	Based on immersed area	I
20%: galvanized	30	-5	>562	>78	b	Based on immersed area	I
20%: sheet	10	33	126	18	a		I
20%: galvanized	10	33	82	11	a		I
20%: with silicate: sheet	10	35	92	13	a		I
20% + 0.05% Ca(OH) <sub>2</sub>	10	35	95	13	a		I
20% + 0.17% Na <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub>	10	80	80	11	a		I
Saturated solution		60			d		C

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			g/m <sup>2</sup> /year	μm/year			
Calcium hydroxide		RT			b	Transport in galvanized containers	D
Pure, dry		80			d		D
saturated solution					b	Maximum	D, E, Tödt (1961)
20% solution			365	50			
Calcium sulfate		80			d		C
Saturated solution					b	Chromating protects	B, D
Moist, 23% H <sub>2</sub> O							
Cesium acetate					b		D
Pure, neutral							
Cesium hydroxide					d		D, Gmelin (1956)
Solution					a	Porous anode in amalgamating zinc	Mallory (1968)
Chlorates		20	475	66	b		B
1.57%							
Chloric acid		40			d	Explosive reaction	E
20%							
Chlorine					a		B, D, F
Pure, dry							
Chlorine water		80			d		C
100%							
Chromates					a		G (many)
Solution					d		D, King and Mayer (1953)
Chromium chloride		20					
Chromium oxide					b		D
Dry solution							
Chromium sulfate					d		D
Solution							
Copper chloride					d		D
Solution					d	Accelerates attack	
Copper ions					b	In fluxes, wood preservatives, surface treatment solutions	G (many)
Fluorides							
Fluorine		20			a		E
Pure, dry					d	Acidity/product contamination	Grillo (1973)
Fruit juices							
Halogens					b		Grigorev (1967)
Dry					d		
Moist							
Hydrochloric acid					d		J
Still	2	30	273,750	38,000			J
Aerated	2	30	237,250	32,950			Barton (1968)
Gas					d		
Hydrogen peroxide		20			b		Gmelin (1956), B
30%							
Hydrogen sulfide						ZnS protective layer	D, E
Gas							
Hyperchlorites					a-d	Depends on purity	Metal Progress (1973)
Solution							

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			g/m <sup>2</sup> /year	µm/year			
Iodides							
Solution						With sulfate	Radovici and Kovacs (1968)
Iodine					b		D
Molten, dry					d		D
Moist							Ginzburg (1969/71)
Gas							
Iron chloride							
10% solution		60			d		B, D
60% solution		80			d		C
					b	For dissolving metal coatings from cast zinc	Rüegg (1970), C
Iron sulfate							
100% solution		80			d		B, D
Lead nitrate							
Moist		100			d	Forms NO <sub>2</sub> and O <sub>2</sub>	D, Huber (1968)
100% solution		80			d		C
Lead arsenate							
3.8 g/L			90	12	b		N
Lead sulfate					d		D
Lead sulfite					b	Reduces electrode gassing	ESB (1968)
Lithium chloride							
Gas		RT			b	Air conditioning equipment	I
30% solution vapor	40	115	18,250	2,535	d	Solution is worse	I
30% solution	40				d	Very heavy attack	I
40% solution					d		D
40% solution					b	With 1% Na <sub>2</sub> CrO <sub>4</sub> Fe/Zn alloys OK	D
In alcohol + 0.01% HCl					b		Heitz et al. (1970)
Molten					b		
Lithium hydroxide							
0.1-1 N solution					d		Rodionova (1957)
Lithium silicate					a	Paint binder	Du Pont (1965), Kohnen (1968)
Lithopone							
Pure, dry					a	Drying equipment made in galvanized steel	D
Moist					b		D
Magnesium carbonate					b		D
Magnesium chloride							
42.5% solution	30	-5	320-560	45-78	c	Pitting	I
1.2% solution	14	20	767	110	b		B; also Schikorr (1960)
Magnesium fluoride					a		D
Magnesium hydroxide							
Saturated solution		20	730	100	b	Stored in galvanized steel	D
Magnesium oxide							
Dry, pure					b	Stored in galvanized steel	D
Magnesium oxychloride					d		D
Magnesium sulfate							
0.004%		95	730	100	b		D
2%		20	77	11	b		Steinrath (1960)
10%		40			d		C

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			g/m <sup>2</sup> /year	µm/year			
Manganese dioxide Dry, pure					a		D
Manganese phosphate Solution					a	Phosphating solution	Dettner and Elze (1964-1969), Neuhaus and Gebhardt (1966)
Mercury 100%		60			d	Forms amalgams	D
Mercury salts Electrolyte					b		Sony (1966), Mallory (1967)
Milk of Magnesia					b	Stored in glass	G (many)
Molybdenum chloride Wet		"High"			b	Equipment uses, Mn/Zn alloy	Heumann and Venker (1968)
Molybdate ions					b	Protective layer forms	
Nickel acetate					d		D
Nickel ammonium sulfate					d		D
Nickel chloride					d		D
Nickel ions In solution with NH <sub>4</sub> Cl · ZnCl <sub>2</sub>						Accelerates corrosion	Era et al. (1967)
Nickel sulfate Electroless plating					b	With additives	Gavranek and Levchenko (1967)
Niobium chloride Vapor		"High"			b		Heumann and Venker (1968)
Nitrates Pure, dry					b		G (many)
Nitrates Solution					d		B, D
Nitric acid					d		Halliday and Horton (1967), Petrov (1968)
Nitric acid					b	For brightening, etching	
Nitrites Pure, dry					b		Bukowiecki (1968)
Nitrites Moist					d		Bukowiecki (1968)
Nitrogen Pure, dry		20			a		B, D, G
Nitrogen oxides Pure, dry					b		E
Nitrogen oxides Pure, dry		300			c	More than in oxygen	E
Oxygen Pure, dry					a		
Oxygen Moist		300-400			c	May form protective layer; parabolic time law	Lucas (1971)
Ozone Pure, dry		20				Similar to oxygen	D, E
Perborates Solution					d		D

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Corrosive media	Time (days)	Temperature (°C)	Corrosion rates		General suitability <sup>a-c</sup>	Remarks	Ref.	
			g/m <sup>2</sup> /year	μm/year				
Perchlorate Solution						Mechanism studies	Schwabe (1957), Gaspar and Soriano (1971)	
Perchloric acid Solution					b	In polishing solutions	Dettner and Elze (1964-1969)	
Permanganate Solution					b	In dye solutions	<i>ILZRO Digest</i> (1970)	
Peroxide Pure, dry					b		Gmelin (1956)	
Moist					d		Gmelin (1956)	
Persulfate Solution					d	Wood preservatives, polishes, laundry powders, surface coatings	B G (many)	
Phosphates								
Phosphor (red) Pure, dry					b			
Moist					b			
Phosphor (white) Molten					d			
Phosphor chloride Pure, dry		20			b		D	
Trace water		20			d		D	
Phosphoric acid 0.3-3% solution					a	With 0.5-3% chromic or 0.1-0.4% sodium nitrite	D	
					b	Electroplating, lithography	G (many)	
Phosphorus pentoxide Pure, dry					b		D	
Moist					d		D	
Potassium acid fluoride 5-20% KF-HF	28	20	540-810	75-110	c	Corrosion product left	Köhler (1955), Dirkse and Hampson (1972)	
5-20% KF-HF	1	80			d			
Potassium bicarbonate					b	With 0.1 M KCl	Krochmal and Puacz (1965)	
Potassium carbonate 10% solution		80			d		C	
>50% solution		20			d		D	
Potassium chloride 0.07%	30	25	1,300	180	d	Partial immersion: 2-30 days test without aeration or agitation: 35°C tests on galvanized sheet; rest on zinc sheet; approximately linear with time	Borgmann and Evans (1934) except 35°C tests Borgmann (1937)	
0.75% (1 N)	4	25	2,565	355	d			
0.75%	2	35	3,525	490	d			
1.86%	2	35	4,235	590	d			
3.64%	30	25	3,700	520	d			
7.13%	4	25	3,880	540	d			
13.7%	30	25	4,170	580	d			
19.8%	4	25	5,275	730	d			
5-30%	65	12	664-430	92-61	c			Immersion 65 days
10%		40			d			

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			g/m <sup>2</sup> /year	μm/year			
Potassium chlorate					b	Protective layer forms	D
Neutral solution					d		C
10% solution		80				Activates chloride	Krochmal and Puacz (1965)
With 0.1 M KCl							
Potassium dichromate							J
14.7% (1 N)	2	30	27	4	a	15 g/m <sup>2</sup> /year with aeration	D
1 N		20	73	10	a		D
20%		45			b	With 5-6 cm <sup>3</sup> /L H <sub>2</sub> SO <sub>4</sub>	D
Potassium disulfate					b	With 1 mol NaCl	Bianchi (1958)
0.5 mol					b	With 1 mol KCl	Kronshorst (1972)
Solution							
Potassium fluoride					a	Corrosion product left	Köhler (1955), Dirske and Hampson (1972)
5-20%	28	20	157-gain	22-gain	a		
5-20%	1	80	gain	gain	a		
Potassium hydroxide							
Solution		20			d		Gmelin (1956), B, C, Huber (1968), Vorkapit et al. (1974)
Potassium hypochlorite							
Neutral solution		20	2-55	0.3-8	b		B, D
Potassium nitrate							
5-10% solution	189	20	44-110	6-15	b		H
Unaerated			310-415	43-58	c		D, G
Aerated			415-625	58-87	c		D, G
Potassium peroxide					d		D
Potassium persulfate							
10%		40			d		C, D
Potassium phosphate					c		D
Potassium silicate					b	Depends on alkalinity	D
Potassium sulfate							
0.5-10%	57	12	400-182	55-25	b		B, D, H
100%		80			d		C
Potassium sulfate							
pH <12					b		D
Potassium sulfite							
Solution					d		D
Potassium zincate					b	Plating electrolyte	Matsuda et al. (1970)
Selenium chloride							
Pure, dry		20			b		Gmelin (1956)
Silver bromide							
Pure, dry					b	Becomes black	
Silver chloride							
Pure, dry		20			b		Gmelin (1956)
Moist, wet					d		
Silver nitrate							
Solution					d		Summerville (1970)
Silicates					b		G



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Corrosive media	Time (days)	Temperature (°C)	Corrosion rates		General suitability <sup>a-c</sup>	Remarks	Ref.
			g/m <sup>2</sup> /year	μm/year			
Silica Solution					b	With 0.01 N KOH	Lovreček and Petric (1971), Petric (1972) Konnik (1969)
Sodium acetate					b		D
Sodium aluminate					d		D
Sodium aluminum fluoride					d		D
Sodium aluminum sulfate					d		D
Sodium arsenate 10% solution (pH 10)		20	1,970	275	d		D
Sodium arsenite 60 g/L			1,970	275	c		D
Sodium benzoate 2% solution		20			b	Steel anodic to zinc	D
Sodium bicarbonate Saturated solution		80			d		C
5%		20			c		B
Sodium bifluoride					d		D
Sodium bisulfate					d		D
Sodium bisulfite			42,000	5,830	d		B
Sodium borate Solution					a		D
Solution with NaOH					b	pH 9–12.3; zinc passivates	Davies and Lotlikar (1966)
Sodium bromate 1% solution	10	45	12,630	1,750	d		B
2% solution	10	45	5,000	700	d		B
3% solution	10	45	15,695	2,180	d		B
Sodium bromide Vapor	365	24	650	90	c	30–45% RH	I
100%		80			d		A, C
Sodium carbonate 0.5%	5 h	66	1,400	195	c		I
Saturated solution		80			d		C
3.7–7%		RT	36–255	5–35	b	In degreasers, dyes	E
Sodium chloracetate Pure, neutral					d		D
Sodium chlorate 1.57%	10	RT	475	66	b		B, D
10%		40			b		C
100%		80			b		C
Sodium chloride 0.5–3%	64	12	660–372	92–52	c	Depends on aeration	H
0.5% solution		20	657	91	c		D
1.5% solution		20	511	71	c		D
6.0% solution		20	256	35	b		D
Saturated solution pH 8.5		20	110	15	b		D
3.5%	90	–8	4,625	650	d	Halved if only sprayed	I
5.6% (1 N)		30	694–1,643	97–230	c	5 m/min speed: pits	I
5.6%	31	35	339	47	c	300 m/min speed pH 7.85	Union Carbide (direct data)
5.6%	30	35	1,350	148	c	300 m/min speed pH 8	I
5.6%	2	30	910–2,390	25–390	c	Highest with aeration	J

Table 5.2 Continued

Some references that occur frequently (and are mainly tabular summaries) are referred to in this table by letter code:

A	=	Helwig and Bird (1973)
B	=	Ritter (1958)
C	=	Ried (1964)
D	=	Dechema (1953)
E	=	Bauer and Schikorr (1934)
F	=	Zinkberatung (1959)
G	=	Wiederholt (1976)
H	=	Friend and Tidmus (1924)
I	=	International Nickel Co. (direct data)
J	=	Fuller (1927)
N	=	New Jersey Zinc Co. (direct data)
R	=	Clarke and Longhurst (1961)

Corrosive media	Time (days)	Temperature (°C)	Corrosion rates		General suitability <sup>a-c</sup>	Remarks	Ref.
			g/m <sup>2</sup> /year	µm/year			
Molten					d		Imperial Smelting Co. (1969), Ishutin (1971)
3% solution	2-14		3,470-5,140	485-720	d		B
0.58%	2	35	3,336	470	d		I
1.45% 0.25 N	2	35	4,245	595	d		I
2.9% 0.5 N	8.5	25	2,376	330	c		I
20% immersed	24	RT	59	8	b		I
20% spray	21	35	2,628	370	c	Zinc sheet: the erratic results are not explained	I
	63	35	1,168	164	c		I
	119	35	2,957	415	c		I
	21	35	2,701	380	c	Galvanized steel: it would appear that corrosion products slow reaction with time; pitting up to 500 µm in 119 days	I
	63	35	730	102	c		I
	119	35	803	112	c		I
24% immersed	30	-5	73-318	10-45	b	Pitting	I
60-400 g/L	64	12	274-91	38-13	b		H
3% solution + 10 g/L NaSO <sub>4</sub> · 10 H <sub>2</sub> O	2-14		4745-8213	660-1,140	a		B
3% solution + 12 g/L MgCl <sub>2</sub> · 6H <sub>2</sub> O	2-14		110-183	15-25	b		B
Sodium chlorite Saturated solution		80			b	Transported in galvanized containers pH 4	C, D
0.5% solution		80	17,155	2,383	d		Petrov et al. (1970)
0.5-1%		70			b	Black coating with ac	
Sodium chromate Saturated solution		80			d		C
4%		20			b		D
Sodium dichromate Solution					c	Attack increases with temperature	D
Sodium fluoride Solution						Increases attack	D
Sodium hydride In NaOH melt					d		D
Sodium hydroxide 0.5% solution	5	21	172-438	24-61	c		I
0.5% solution	5 h	66	3,250-7,450	450-1,035	d		I
3.9% solution	2	30	3,200-6,400	445-890	d		J
50% solution	1	30	156,000- 217,000	21,670- 30,140	d	Galvanized iron only 13,834 g/m <sup>2</sup> in the 1-day test	J
Solution pH 7.3			2,790	390	d		G
Solution pH 10.6			2,520	350	d		G
Molten					d		Zarubitsky and Salabai (1969)
Sodium hypochlorite Solution			766	106	c	0.24 g/L active chlorine: increases with pH and time	D
10%		20			d		C
Sodium iodide					d		D
Sodium nitrate 1%		20	310	43	b	Unaerated: attack increases with aeration and temperature	D

Table 5.2 Continued

Some references that occur frequently (and are mainly tabular summaries) are referred to in this table by letter code:

A	=	Helwig and Bird (1973)
B	=	Ritter (1958)
C	=	Ried (1964)
D	=	Dechema (1953)
E	=	Bauer and Schikorr (1934)
F	=	Zinkberatung (1959)
G	=	Wiederholt (1976)
H	=	Friend and Tidmus (1924)
I	=	International Nickel Co. (direct data)
J	=	Fuller (1927)
N	=	New Jersey Zinc Co. (direct data)
R	=	Clarke and Longhurst (1961)

Corrosive media	Time (days)	Temperature (°C)	Corrosion rates		General suitability <sup>a-c</sup>	Remarks	Ref.
			g/m <sup>2</sup> /year	µm/year			
Sodium nitrite					b		D
Sodium oxide							
Pure, dry					b	Galvanized containers	D
Moist					d		D
Sodium perborate							
0.064%		20	285	40	b	pH 9.75	D
Sodium perchlorate							
pH 3.4-7					c		Gusev and Rakcheev (1968), Tanaka et al. (1969)
Sodium peroxide							
Dry, solid		20			b	Galvanized containers	D
Sodium silicate, SiO <sub>2</sub> /Na <sub>2</sub> O							
1:1, 1%		20	150	20	b		D
2:1, 1%		60	150	20	b		D
2:1, 5%		60	1,200	170	c		D
2:1, 10%		60	3,300	460	c		D
2.4:1, 1%		60	400	55	b		D
2.4:1, 5%		60	550	75	b		D
2.4:1, 10%		60	1,460	200	c		D
Sodium silicofluoride					d		D
Sodium stannate					d		D
Sodium sulfate							
5-300 g/L	60	12	475-473	65-10	b	60-day test	H
10 g/L	14		584	80	b	14-day test	B
Sodium sulfide		bp	2,860	400	c	Galvanized apparatus for concentrating	D
Sodium sulfite					d		D
Sodium thiosulfate							
Saturated solution		150	13,320	1850	d	pH 7.8	G
Sulfides							
Pure, dry		20				Discolored surface	Gmelin (1956)
Sulfur dioxide							
Liquid	14	20	1,095	152	c	+ 1% H <sub>2</sub> O + 0.21% O <sub>2</sub> 89% RH	D, Bollinger (1952) Sanyal and Bhadwar (1959)
0.6% vapor	7	40	672	93			G
Zinc chloride					d		Kerridge and Tariq (1967)
Molten		500-700			d		Parker Co. (1967)
Zinc chromate					b		G
Zinc sulfate					b		
Zinc sulfides					b	In 5 N NaOH	Merkulov and Flerov (1968-1969)
Zirconium oxide		800				Zn with 10% Mg reduces ZrO to Zr	Garg (1970)

<sup>a</sup>Most dry materials have no significant corrosion reaction with zinc; those that do are specifically mentioned. This general classification usually covers either chemical solution or moist materials. Where specific corrosion rates are not given, there is a general classification.

<sup>b</sup>Ratings: d = definitely not suitable (>3000 µm/year); c = corrosive (100-3000 µm/year); b = borderline for zinc; bad for coatings (10-100 µm/year); a = acceptable usually (<10 µm/year).

<sup>c</sup>It should be noted that these ratings are not always aligned with results of short-term tests; often the zinc corrosion products formed initially slow down corrosion subsequently.

Table 5.3 Corrosion Data for Zinc and Zinc Coatings with Agricultural Chemicals (Inorganic and organic) and Pesticides

Letter code for references cited in this table:

D	=	Dechema (1953)
I	=	International Nickel Co. (direct data)
N	=	New Jersey Zinc (direct data)
O	=	Cook and Dickinson (1950)
S	=	Marshall and Neubauer (1955)
T	=	Consolidated Mining and Smelting Co. of Canada Ltd. (direct data)

Materials	Time (days, except as otherwise indicated)	Temperature (°C)	Corrosion rates		Remarks	Ref.
			g/m <sup>2</sup> /year	µm/year		
<b>Agricultural Chemicals</b>						
Ammonium sulfamate	98	15-40	548	76		I
Blue Amate Brush Killer	112	15-40	172	25		I
Esteron Brush Killer (2-4D + 2,4,5-T) L/100 L water	119	15-32	675	95		I
Ammonium sulfate	121		Zinc stripped	7250		S
						S
						S
						S
						S
Nitrolime	121		Zinc stripped	300	Alternate humidity, weekly cycle forced air circulation 24 h, 100% RH (1), 24 h dry air (2); repeat (1) and (2) then 8 h 100% RH, 64 h dry air	S
300 g/L CuSO <sub>4</sub> · 5H <sub>2</sub> O	121		Zinc partly stripped	75		S
280 g/L CoSO <sub>4</sub> · 5H <sub>2</sub> O	121		Pits			S
Potassium chloride (com)	121		Zinc partly stripped	95		S
Superphosphate	121					
Supercompound	121					S
Supercompound + small amount of copper sulfate	121		Pits			S
Supercompound + small amount of cobalt sulfate	121					S

Agricultural lime	121		Zinc not penetrated		Alternate humidity, weekly cycle forced air circulation 24 h, 100% RH (1), 24 h dry air (2); repeat (1) and (2) then 8 h 100% RH, 64 h dry air	S		
Burnt lime	121					S		
Basic slag	121					S		
Bone meal	121					S		
Phosphorized Pollard	121					S		
<b>Damp granular fertilizers</b>								
Type	Components	Water (%)						
11-48-0	NH <sub>4</sub> H <sub>2</sub> PO <sub>4</sub> · (NH <sub>4</sub> ) <sub>2</sub> HPO <sub>4</sub>	5.41	33	60	2,920	400	Fresh water once a week; SHG	T
11-48-0	NH <sub>4</sub> H <sub>2</sub> PO <sub>4</sub> · (NH <sub>4</sub> ) <sub>2</sub> HPO <sub>4</sub>	5.41	33	60	1,675	240	AG-40A	T
12-12-12	11-48-0 (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> · KCl	6.18	33	60	36,680	5,140	SHG	T
12-12-12	11-48-0 (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> · KCl	6.18	33	60	53,290	7,460	AG-40A	T
13-16-10	11-48-0 (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> · KCl	6.68	33	60	1,825	255	SHG	T
13-16-10	11-48-0 (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> · KCl	6.68	33	60	2,010	280	AG-40A	T
16-20-0	11-48-0 (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	4.10	33	60	1,280	180	SHG	T
16-20-0	11-48-0 (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	4.10	33	60	5,695	800	AG-40A	T
35.5-0-0	NH <sub>4</sub> NO <sub>3</sub>	3.54	33	60	83,585	11,700	SHG	T
35.5-0-0	NH <sub>4</sub> NO <sub>3</sub>	3.54	33	60	28,760	4,030	AG-40A	T
21-0-0	(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	2.50	33	60	800	112	SHG	T
21-0-0	(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	2.50	33	60	250	35	AG-40A	T
(a) 11-48-0		5.4	11	RT	1,370	190	SHG	T
(a) 11-48-0		5.4	11	RT	720	100	AG-40A	T
(a) 11-48-0		5.4	11	60	1,405	200	SHG	T
(a) 11-48-0		5.4	11	60	518	73	AG-40A	T
(b) 16-20-0		4.1	11	RT	600	84	SHG	T
(b) 16-20-0		4.1	11	RT	518	73	AG-40A	T
(b) 16-20-0		4.1	11	60	3,047	425	SHG	T
(b) 16-20-0		4.1	11	60	2,830	400	AG-40A	T
(c) 33.5-0-0		3.5	11	RT	9,125	1,280	SHG	T
(b) 33.5-0-0		3.5	11	RT	2,400	335	AG-40A	T
(b) 33.5-0-0		3.5	11	60	21,720	3,040	SHG	T
(b) 33.5-0-0		3.5	11	60	6,130	860	AG-40A	T
<b>Damp granular fertilizers</b>								
(d) 21-0-0		2.5	11	RT	1,350	190	SHG	T

Table 5.3 Continued

Letter code for references cited in this table:

D	=	Dechema (1953)
I	=	International Nickel Co. (direct data)
N	=	New Jersey Zinc (direct data)
O	=	Cook and Dickinson (1950)
S	=	Marshall and Neubauer (1955)
T	=	Consolidated Mining and Smelting Co. of Canada Ltd. (direct data)

Materials	Time (days, except as otherwise indicated)	Temperature (°C)	Corrosion rates		Remarks	Ref.	
			mg/m <sup>2</sup> /year	µm/year			
(d) 21-0-0	2.5	11	RT	720	100	AG-40A	T
(d) 21-0-0	2.5	11	60	3,085	430	SHG	T
(d) 21-0-0	2.5	11	60	1,725	240	AG-40A	T
(e) 27-14-0 (a), (b)	4.5	11	RT	3,360	470	SHG	T
(e) 27-14-0 (a), (b)	4.5	11	RT	1,090	152	AG-40A	T
(e) 27-14-0 (a), (b)	4.5	11	60	12,590	1,760	SHG	T
(e) 27-14-0 (a), (b)	4.5	11	60	2,210	310	AG-40A	T
(f) 8-32-16 (a), (d), KCl	5.0	11	RT	3,360	470	SHG	T
(f) 8-32-16 (a), (d), KCl	5.0	11	RT	1,185	166	AG-40A	T
(f) 8-32-16 (a), (d), KCl	5.0	11	60	4,745	665	SHG	T
(f) 8-32-16 (a), (d), KCl	5.0	11	60	3,650	510	AG-40A	T
(g) 6-24-24 (a), (d), KCl	5.2	11	RT	3,395	475	SHG	T
(g) 6-24-24	5.2	11	RT	1,640	230	AG-40A	T
(g) 6-24-24 (a), (d), KCl	5.2	11	60	4,930	690	SHG	T
(g) 6-24-24 (a), (d), KCl	5.2	11	60	2,460	345	AG 40A	T
<b>Liquid fertilizers</b>							
Type: 27-14-0, 25% solution	21		RT	1,240	174		T
Type: 27-14-0, 25% solution	14		RT	4,180	585	Oxygen added daily	T
Type: 27-14-0, 25% solution	21		60	1,625	227		T
Type: 27-14-0, 25% solution	14		60	3,830	540	Oxygen added daily	T
Type: 27-14-0, 25% solution	21		RT	237	33		T

Four changes of moist fertilizers in all tests

Type: 27-14-0, 25% solution	14		RT	1,223	171	Oxygen added daily	T
Type: 27-14-0, 25% solution	21		60	310	43		T
Type: 27-14-0, 25% solution	14		60	1,645	230	Oxygen added daily	T
Type: 6-16-7 liquid fertilizer	16		RT	858	120		T
Type: 6-16-7 liquid fertilizer	8		60	2,755	385		T
Type: 6-16-7 liquid fertilizer	16		RT	1,480	207		T
Type: 6-16-7 liquid fertilizer	8		60	310	43		T
Type: 6-16-7 liquid fertilizer	14		RT	675	95		T
EB-32 fertilizer solution, contains S + 0.1% Na <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub>			60	1,697,250	237,700		T
8-24-0 fertilizer solution	5h		RT	18,800	2,630		T
8-24-0 fertilizer solution	10h		RT	14,600	2,050		T
8-24-0 fertilizer solution	100h		RT	8,760	1,230		T
<b>Herbicides</b>							
7% zinc sulfamate	28		RT	237	33	Commercial zinc	T
7% zinc sulfamate	28		RT	237	33	Galvanized steel	T
40% zinc sulfamate	28		RT	110	15	Commercial zinc	T
40% zinc sulfamate	28		RT	237	33	Galvanized steel	T
7% ammonium sulfamate	28		RT	1,280	180	Commercial zinc	T
7% ammonium sulfamate	28		RT	2,375	330	Galvanized steel	T
40% ammonium sulfamate	28		RT	1,640	230	Commercial zinc	T
40% ammonium sulfamate	28		RT	2,740	380	Galvanized steel	T
7% guanidine sulfamate	28		RT	1,020	143	Commercial zinc	T
7% guanidine sulfamate	28		RT	875	123	Galvanized steel	T
40% guanidine sulfamate	28		RT	164	23	Commercial zinc	T
40% guanidine sulfamate	28		RT	164	23	Galvanized steel	T
7% Du Pont Ammate	28		RT	402	56	Commercial zinc	T
7% Du Pont Ammate	28		RT	1,515	210	Galvanized steel	T
40% Du Pont Ammate	28		RT	128	18	Commercial zinc	T
40% Du Pont Ammate	28		RT	2,245	315	Galvanized steel	T

Table 5.3 Continued

Letter code for references cited in this table:

D	=	Dechema (1953)
I	=	International Nickel Co. (direct data)
N	=	New Jersey Zinc (direct data)
O	=	Cook and Dickinson (1950)
S	=	Marshall and Neubauer (1955)
T	=	Consolidated Mining and Smelting Co. of Canada Ltd. (direct data)

Materials	Time (days, except as otherwise indicated)	Temperature (°C)	Corrosion rates		Remarks	Ref.
			g/m <sup>2</sup> /year	μm/year		
<b>Pesticides/fungicides</b>						
Bordeaux mixture: 10 g/L copper sulfate + 10 g/L quicklime <sup>a</sup>	20	RT	5	<0.1	*Solutions prepared from commercial products, changed after 3 and 6 days, weight changes as removed from test	N
Calcium arsenate <sup>a</sup>	20	RT	Gained weight			N
Chlordane-water emulsion	56 weeks	25	2,628	368		O
Copper sulfate - 10 g/L <sup>a</sup>	20	RT	7,850	(1,100)		N
DDT, 5% in distilled water	56 weeks	25	840	117		O
DDT, 5% solution in saltwater		25	1500	210		D
DDT, 10% solution in kerosene		25	5	0.7		D
DDT emulsion, 95% water and 5% mixture of 25% DDT, 65%						
Dry lime sulfur - 36 g/L <sup>a</sup>	20	RT	166	(23)		N
White hellebore - 2.5 g/L <sup>a</sup>	20	RT	Gained weight			N
Formalin <sup>a</sup>	20	RT	Gained weight			N
Lead arsenate: 4 g/L <sup>a</sup>	20	RT	88	(12)		N
Paris green <sup>a</sup>	20	RT	Gained weight			N
Pyrethrum <sup>a</sup>	20	RT	Gained weight		N	
Xylol 5% Triton X 100		25	985	140	D	
<b>Urea</b>						
20% solution	1 month	30		Trace	Solutions changed weekly	T
Saturated urea solution	1 month	30	37	5	Solutions changed weekly	T
Moist urea salts, 3% water	1 month	30	369	52	Slight pitting, kept moist daily	T

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Table 5.4 Weight Change of Zinc-4% Copper-0.2% Aluminum Alloy After 5 Weeks in Fire-Extinguishing Solution at 60°C<sup>a</sup>

Fire-extinguishing liquids	Weight losses (mg/dm <sup>2</sup> /day) <sup>b</sup>
45 g Al(OH) <sub>3</sub> , 10 g KHCO <sub>3</sub> , 22 g Na <sub>2</sub> SO <sub>4</sub> , 113 g K <sub>2</sub> SO <sub>4</sub> , 10 g foaming agent per liter of solution	1099+
11 g Al(OH) <sub>3</sub> , 8 g KHCO <sub>3</sub> , 37 g Na <sub>2</sub> SO <sub>4</sub> , 88 g K <sub>2</sub> SO <sub>4</sub> , 175 g glycerin, 45 g glycol, 15 g foaming agent per liter	558+
187 g KHCO <sub>3</sub> , 34 g NaHCO <sub>3</sub> , 15 g foaming agent per liter	11+
47 g NaHCO <sub>3</sub> , 141 g KHCO <sub>3</sub> , 230 g glycerin, 63 g glycol, 15 g foaming agent per liter	47+
180 g NaCl + 14 g Na <sub>2</sub> CO <sub>3</sub> per liter	321+
500 g commercial K <sub>2</sub> CO <sub>3</sub> per liter	117+
Carbon tetrachloride (water-free)	Gain
Carbon tetrachloride (water-free)—vapor	Gain
Carbon tetrachloride + 1 v/o water	Gain

<sup>a</sup>Cooled overnight.<sup>b</sup>Weight changes determined without removing corrosion products.

Source: Beytheim (1947).

Fungicides and pesticides were studied by Steinrath (1960), who found many of the proprietary products then available suitable for use with galvanized steel. New Jersey Zinc data are given in Table 5.3, but other work reports Bordeaux slurry as having a corrosion rate of 165 μm/year, hence not suitable for continued contact with zinc. New Jersey work on herbicides is also given in Table 5.3. Some agricultural chemicals are in other tables but can be located through the index.

Table 5.4 deals specifically with work by Beytheim (1947) on the corrosion of phosphated zinc alloys by the fire-extinguishing liquids then available.

Since most galvanized and thermally sprayed coatings are around 100 μm thick, continuous contact with any material that gives a corrosion rate in excess of 30 μm/year is likely to result in unsatisfactory or uneconomic service unless supplementary coatings are provided. However, zinc and zinc alloy coatings and wrought zinc may well be suitable in many uses, even with rather higher rates of attack.

Additional early qualitative information is given by the American Zinc Institute (1928), and Wiederholt (1976) has additional information of a qualitative nature.