The following pages contain the table of contents, index and first few sample pages of this title
Click here to purchase this title
or to visit the product page.
INDUSTRIAL CHEMICAL CLEANING

James W. McCoy

Formerly Supervisor, Refinery Services
Chevron U.S.A., Inc.

Chemical Publishing Co.
New York, N.Y.
Preface

This book has been written to provide information for chemists, process engineers, and management personnel who deal with industrial chemical cleaning contractors. Because of the specialized equipment required, chemical cleaning is seldom done in-house, but, even so, the client should be qualified to discuss the details of proposed procedures with the contractor when negotiating a contract. Furthermore, several of the methods discussed in the book are protected by patents, so they are best left to qualified contractors who have made the necessary licensing arrangements. As with any purchased service, however, it is to the purchaser's advantage to have a good understanding of the work to be done and the methods to be used. The principles and practice of industrial cleaning described here will enable any technically trained individual to understand chemical cleaning operations.

Chapter I contains a discussion of the sources and composition of various types of fouling deposits; the mechanism of corrosion; hazards that are encountered in chemical cleaning; and a brief description of the special equipment used by contractors. Chapters II, III, and IV contain detailed descriptions of the numerous chemicals used for industrial cleaning including alkalis, acids, corrosion inhibitors, and wetting agents, as well as some special agents. Several patented processes are also considered, as are nonaqueous solvents, foams, and a few nonchemical procedures, the most useful of which is high pressure water blasting.

Chapter V explores the principles and practice of the very important subject of passivation. Chapter VI deals with planning and contracting of chemical cleaning jobs with emphasis on safety and the proper disposal of hazardous wastes.
The next four chapters, VII-X, contain specific procedures for deoiling, cleaning, and passivating steam generators, heat exchangers, columns, reactors, and furnaces. The directions given here are intended as general information and should not be applied indiscriminately without the advice of a qualified professional contractor. Great care must be taken, for instance, to take account of specific metallurgical considerations to avoid major damage to equipment by incompatible chemicals.

Chapter XI includes laboratory procedures for measuring the strength of cleaning solutions, estimating solubilities, sampling fouling deposits, and evaluating industrial cleaners.

Although I must assume responsibility for any errors, I wish to thank my associate, Mr. Donald A. Alexander, for his thorough reading of the manuscript and his many suggestions that led to improvements in the work. He is widely recognized in the petroleum refining industry for his detailed knowledge of chemical cleaning processes and for his outstanding safety record as a supervisor of these inherently hazardous operations. Mr. Robert J. Hammond, who is unusually talented in piping layout work, kindly provided the piping diagrams. Finally, I am most grateful to my wife, Dolores, for her many contributions to the success of my books.

Richmond, California

May 31, 1983

James W. McCoy
# Table of Contents

Chapter I  Principles of Chemical Cleaning  
I.1 Sources and Composition of Fouling  
I.2 Mechanism of Corrosion  
I.3 Hazards of Chemical Cleaning  
I.4 Equipment Used by Contractors  

Chapter II  Chemicals Used in Industrial Cleaning  
II.1 Alkaline Solutions  
II.2 Acidic Solutions  
II.3 Corrosion Inhibitors  
II.4 Wetting Agents  
II.5 Special Agents  
II.6 Patented Cleaning Processes  

Chapter III  Nonaqueous Cleaning Solvents  
III.1 Types of Solvents  
III.2 Acidic Foams  
III.3 Hazards of Nonaqueous Solvents  

Chapter IV  Nonchemical Cleaning Procedures  
IV.1 Mechanical Methods  
IV.2 High-Pressure Water Jetting  

Chapter V  Passivation  
V.1 Theoretical Considerations  
V.2 Passivating Procedures  

Chapter VI  Planning and Contracting  
VI.1 Preliminary Testing and Inspection  
VI.2 Contracting  
VI.3 Planning for Chemical Cleaning  
VI.4 Safety Rules and Equipment  
VI.5 Disposal of Wastes  

Chapter VII  Steam Generators  
VII.1 Preoperational Cleaning  
VII.2 In-Service Boiler Cleaning
I

Principles of Chemical Cleaning

The formation of various types of scales, sludges, and deposits in process equipment of the petroleum refining and chemical processing industries occurs frequently. Some of these present serious problems—for example, the scaling of boiler tubes, or corrosive attack on the metals of which various types of reactors and similar vessels are constructed. Others are less significant—for instance, the phosphate sludges formed in boiler drums as the result of over-treatment with phosphate, or the formation of deposits of coke and salts on the floors of furnaces.

When such equipment is taken out of service, preferably on a scheduled shut-down for maintenance, but sometimes because of failure or loss of heat transfer capacity, the engineer in charge of operations often obtains a chemical analysis of any fouling material found. This is done for any of several reasons: to find whether the deposit resulted from corrosive attack on the vessel or from foreign material brought into the vessel; to indicate the reason for failure of equipment; or to assess the extent to which a vessel has been attacked during a certain period of operation. More often than not, however, all that is desired is an indication of the conditions necessary for the removal of the deposit from the site of formation. In this case, no analysis is required, but rather a report on the loosening effect of water, steam, detergents, dilute inhibited acids, alkalis, or other agents on the material.

Within the past 30 years it has become apparent that in-place cleaning of industrial equipment by means of chemical solutions is, in many instances, safer and more economical than the older, labor-intensive, mechanical methods. As the choice of cleaning agent is to some extent
empirical, laboratory performance tests with representative samples are desirable to determine solubility in various solutions, the most effective temperature, and the efficiency to be expected in cleaning the fouled equipment. Specific directions for sampling are difficult to provide because of the many different circumstances encountered. Nevertheless, it is evident that the interpretation of analytical and solubility data depends upon a knowledge of the normal operation of process units and upon information concerning the location, consistency, distribution, and other features of the deposit. In vessels containing sections, baffles, or trays, for instance, the distribution of fouling is often significant, and samples from different locations may vary greatly in composition and solubility.

I.1 SOURCES AND COMPOSITION OF FOULING

Before any attempt is made to dissolve or loosen scales or deposits with a chemical solution, it is necessary to characterize the material as to its composition, which in some measure is related to its origin. For the purpose of a systematic discussion, fouling material is here arbitrarily classified by origin as water-formed, corrosion, microbiological, organic, or combustion deposits.

I.1.a Water-Formed Scales and Deposits

Scales and deposits are regularly encountered in aqueous cooling systems, mixers, solution tanks, boilers, and other steam generators, surface condensers, and in equipment in which heat is transferred from a process stream to water. The term scale describes a continuous, adherent layer of foreign material crystallized on the water side of a surface through which heat is exchanged. In principle, by adding certain chemicals the growth of scales can be inhibited and the insoluble particles can be dispersed in the recirculating water and removed by blowdown. Should the particles come out of suspension, however, they can accumulate as sludge in quiet sections of a boiler or cooling system. Deposit is a general term applied to more-or-less loose accumulations often found in less-turbulent sections of boilers, cooling systems, and water-treating facilities.

Scales are objectionable because of their insulating effect. In a boiler tube, for instance, they cause overheating and eventual failure of the metal. Deposits often cause plugging in critical areas such as waterwalls, waterwall headers, in blowdown lines, and in gauge glasses. Many different mineral
structures have been identified in boiler scales by the methods of x-ray diffraction, electron diffraction, and polarizing microscopy. Examples of silicate scales are: acmite, Na₂O·Fe₂O₃·4SiO₂; analcite, Na₂O·Al₂O₃·4SiO₂·2H₂O; pectolite, Na₂O·4CaO·6SiO₂·H₂O; serpentine, 3MgO·SiO₂·2H₂O; sodalite, Na₂O·3Al₂O₃·6SiO₂·2NaCl; xonotlite, 5CaO·5SiO₂·H₂O. When phosphate is used for internal treatment, ferric phosphate, FePO₄, basic magnesium phosphate, Mg₃(PO₄)₂·Mg(OH)₂, and hydroxyapatite, Ca₁₀(PO₄)₆(OH)₂, may also be precipitated, as well as the more common anhydrite, CaSO₄, and aragonite, CaCO₃. As already noted, the presence of these and other scales impedes the circulation of water and reduces heat transfer, both of which cause overheating and failure of tubes.

Scales and deposits form in a boiler because the compounds of which they are composed are insoluble under the conditions prevailing there. Two factors combine to make calcium salts especially troublesome: certain anhydrous calcium salts, notably the sulfate, decrease in solubility as temperature and pressure increase, and increasing temperature shifts the equilibrium of the following reaction to the right, causing CaCO₃ to precipitate.

$$\text{Ca}^{++} + 2\text{HCO}_3^- = \text{CaCO}_3 + \text{CO}_2 + \text{H}_2\text{O}$$

(I-1)

In addition, hydrolysis of excess bicarbonate increases the concentration of hydroxyl ion, precipitating Mg(OH)₂, the solubility product of which is $5.5 \times 10^{-12}$. The solubility of CaSO₄ decreases rapidly with increasing temperature, producing an extremely hard, adherent, insoluble coating on boiler tubes, especially in locations where heat flux is high. The compositions of several scales containing aluminum, magnesium, calcium, and silicate have been given above. Analcite and acmite, which form at high temperature, are invariably found beneath sludges of hydroxyapatite or serpentine, or under porous deposits of iron oxides. Occasionally, other extremely insoluble iron or magnesium silicates are also encountered, and now and then α-quartz, SiO₂, appears, usually originating from colloidal silica, finely divided silt, or sand in the feed water.

The precipitate formed by calcium in phosphate-treated boiler water is usually represented as the normal phosphate, Ca₃(PO₄)₂. Attempts to precipitate this salt in the laboratory, however, invariably produce hydroxyapatite, the formula of which can be written in various ways including Ca₁₀(PO₄)₆(OH)₂, 3Ca₃(PO₄)₂·Ca(OH)₂, and Ca₁₅(PO₄)₃OH. A consideration of the solubility products (Ca²⁺)(CO₃⁻⁻) = $4.8 \times 10^{-9}$, $(\text{Ca}^{++})^3(\text{PO}_4^{3-})^2 = 1.3 \times 10^{-32}$, and $(\text{Ca}^{++})^5(\text{PO}_4^{3-})^3(\text{OH}^-) = 3 \times 10^{-58}$, indicates that the basic salt forms in boiler water. Magnesium forms
similar salts such as Mg₃(PO₄)·Mg(OH)₂ and Mg₅(PO₄)₃OH, which are undoubtedly much less soluble than Mg(OH)₂.

Latimer(1) notes that in aqueous solution silicic acids participate in complex equilibria on account of the small differences in free energy between the numerous polyacids and their salts. Thus, a variety of mineral types have been identified in boiler scales and deposits. Acmite, Na₂O·Fe₂O₃·4SiO₂, and analcite, Na₂O·Al₂O₃·4SiO₂, both of which are quite insoluble, require high temperature to form and, thus, are seldom found in boilers operated at less than 300 psi. On the other hand, serpentine, 3MgO·SiO₂·2H₂O, and hydrated magnesium orthosilicate, Mg₅Si₂O₇·2H₂O, can form at any pressure. Garrels and Christ(2) show that magnetite, Fe₃O₄, is unstable relative to ferrous metasilicate, FeSiO₃, so that if an aqueous solution contains sufficient silica to satisfy all of the iron present, ferrous metasilicate forms in preference to magnetite. Iron silicate scales are exceedingly insoluble and adherent. Table I-1 summarizes the components of deposits most commonly found in boilers and related equipment.

In addition to the inorganic components mentioned, boiler deposits may also contain organic material including starch, quebracho, pyrogallol, sodium alginate, sodium mannuronate, chestnut tannin, and carbonized sulfonated lignins, all of which have been used as sludge conditioners. When oil is present as a contaminant in boiler water, loose scales may form, particularly in water wall tubes. Oil serves as a nucleus and binder for scaling at hot spots, although these scales are often merely baked mud that is easily dislodged by hammering the tubes. The "oil balls" found in steam drums and water wall headers are typical formations in turbulent sections; they are especially common in steam drums, where they are formed by the rolling motion of the water.

A large proportion of the fouling that occurs in recirculating cooling systems is occasioned by mishaps related to pH control and contamination of the water by reducing agents. Failures in some part of the acid injection system are the source of most acid contamination. When the pH falls below 5.5 corrosion inhibitor films are damaged; at about pH 4 hydrogen begins to evolve, and iron dissolves rapidly.

\[
Fe + 2H^+ = Fe^{++} + H_2 \quad (I-2)
\]

In a system treated with chromate, ferrous ion formed in Eq. (I-2) is oxidized to ferric ion.
<table>
<thead>
<tr>
<th>Mineral</th>
<th>Formula</th>
<th>Nature of Deposit</th>
<th>Usual Location and Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acmite</td>
<td>Na₂O·Fe₂O₃·4SiO₂</td>
<td>Hard, adherent</td>
<td>Tube scale under hydroxyapatite or serpentine</td>
</tr>
<tr>
<td>Alpha quartz</td>
<td>SiO₂</td>
<td>Hard, adherent</td>
<td>Turbine blades, mud drum, tube scale</td>
</tr>
<tr>
<td>Amphibole</td>
<td>MgO·SiO₂</td>
<td>Adherent binder</td>
<td>Tube scale and sludge</td>
</tr>
<tr>
<td>Analcite</td>
<td>Na₂O·Al₂O₃·4SiO₂·2H₂O</td>
<td>Hard, adherent</td>
<td>Tube scale under hydroxyapatite or serpentine</td>
</tr>
<tr>
<td>Anhydrite</td>
<td>CaSO₄</td>
<td>Hard, adherent</td>
<td>Tube scale, generating tubes</td>
</tr>
<tr>
<td>Aragonite</td>
<td>CaCO₃</td>
<td>Hard, adherent</td>
<td>Tube scale, feed lines, sludge</td>
</tr>
<tr>
<td>Brucite</td>
<td>Mg(OH)₂</td>
<td>Flocculent</td>
<td>Sludge in mud drum and water wall headers</td>
</tr>
<tr>
<td>Copper</td>
<td>Cu</td>
<td>Electroplated layer</td>
<td>Boiler tubes and turbine blades</td>
</tr>
<tr>
<td>Cuprite</td>
<td>Cu₂O</td>
<td>Adherent layer</td>
<td>Turbine blades, boiler deposits</td>
</tr>
<tr>
<td>Gypsum</td>
<td>CaSO₄·2H₂O</td>
<td>Hard, adherent</td>
<td>Tube scale, generating tubes</td>
</tr>
<tr>
<td>Hematite</td>
<td>Fe₂O₃</td>
<td>Binder</td>
<td>Throughout boiler</td>
</tr>
<tr>
<td>Hydroxyapatite</td>
<td>Ca₁₀(PO₄)₆(OH)₂</td>
<td>Flocculent</td>
<td>Mud drum, water walls, sludge</td>
</tr>
<tr>
<td>Magnesium phosphate</td>
<td>Mg₃(PO₄)₂</td>
<td>Adherent binder</td>
<td>Tubes, mud drum, water walls</td>
</tr>
<tr>
<td>Magnetite</td>
<td>Fe₃O₄</td>
<td>Protective film</td>
<td>All internal surfaces</td>
</tr>
<tr>
<td>Noselite</td>
<td>4Na₂O·3Al₂O₃·6SiO₂·SO₄</td>
<td>Hard, adherent</td>
<td>Tube scale</td>
</tr>
<tr>
<td>Pectolite</td>
<td>Na₂O·4CaO·6SiO₂·H₂O</td>
<td>Hard, adherent</td>
<td>Tube scale</td>
</tr>
<tr>
<td>Serpentine</td>
<td>3MgO·2SiO₂·H₂O</td>
<td>Flocculent</td>
<td>Sludge</td>
</tr>
<tr>
<td>Sodalite</td>
<td>3Na₂O·3Al₂O₃·6SiO₂·2NaCl</td>
<td>Hard, adherent</td>
<td>Tube scale</td>
</tr>
<tr>
<td>Xonotlite</td>
<td>5CaO·5SiO₂·H₂O</td>
<td>Hard, adherent</td>
<td>Tube scale</td>
</tr>
</tbody>
</table>
\[ 3\text{Fe}^{2+} + \text{CrO}_4^{3-} + 8\text{H}^+ = 3\text{Fe}^{3+} + \text{Cr}^{3+} + 4\text{H}_2\text{O} \quad (I-3) \]

Above a pH of about 3 ferric ion is hydrolyzed to the hydrous oxide.

\[ \text{Fe}^{3+} + 3\text{H}_2\text{O} = \text{Fe(OH)}_3 + 3\text{H}^+ \quad (I-4) \]

If caustic soda is now added, as it often is in an acid spill, excess ferrous ion and chromic ions in the system precipitate as the hydrous oxides when the pH reaches about 7.

\[ \text{Fe}^{2+} + 2\text{OH}^- = \text{Fe(OH)}_2 \quad (I-5) \]

\[ \text{Cr}^{3+} + 3\text{OH}^- = \text{Cr(OH)}_3 \quad (I-6) \]

Ferrous hydroxide is then oxidized rapidly by oxygen in the water to ferric hydroxide, producing heavy, slimy fouling.

\[ 2\text{Fe(OH)}_2 + \frac{1}{2}\text{O}_2 + \text{H}_2\text{O} = 2\text{Fe(OH)}_3 \quad (I-7) \]

The voluminous and insoluble hydrous oxides settle in places where the flow of water is slow, then under-deposit corrosion ensues, adding further to the mass of fouling.

When reducing agents contaminate chromate-treated cooling water chromate is reduced to chromic hydroxide and corrosion rates increase rapidly. Two especially troublesome reducing agents are hydrogen sulfide and sulfur dioxide, both of which are common in chemical processing and petroleum refining. Catalytic cracking, for example, produces hydrogen sulfide and hydrogen cyanide from sulfur and nitrogen compounds in petroleum feed stocks. These acidic gases are evolved in process gas (methane and ethane). Admiralty brass exchangers used to cool the mixed gases are occasionally penetrated, allowing hydrogen sulfide and hydrogen cyanide to leak into the cooling water.

Hydrogen cyanide reacts with any ferrous ion in the water to form ferrocyanide [hexacyanoferrate (II) ion].

\[ 6\text{HCN} + \text{Fe}^{2+} = \text{Fe(CN)}_6^{3-} + 6\text{H}^+ \quad (I-8) \]

Hydrogen sulfide is oxidized to sulfur by chromate ion, which is itself reduced to chromic hydroxide.

\[ 3\text{H}_2\text{S} + 2\text{CrO}_4^{2-} + 2\text{H}_2\text{O} = 3\text{S} + 2\text{Cr(OH)}_3 + 4\text{OH}^- \quad (I-9) \]
If, as is usual, the chromate treatment also contains zinc ion, it is precipitated as ZnS, destroying the cathodic corrosion barrier. When an admiralty brass cooler is penetrated by hydrogen sulfide a tough, gelatinous sludge of ZnS, CuS, Cr(OH)$_3$, and elemental sulfur accumulates in the tubes and on the tube sheets.

Sulfur dioxide from stacks, SO$_2$-treating, and other sources occasionally is drawn into cooling towers. In addition to reducing chromate ion, the pH of the water is lowered by the hydrolysis of the gas.

\[
\text{SO}_2 + \text{H}_2\text{O} = \text{H}^+ + \text{HSO}_3^- \quad (I-10)
\]

\[
3\text{SO}_2 + 2\text{CrO}_4^{2-} + 4\text{H}_2\text{O} = 3\text{SO}_4^{2-} + 2\text{Cr(OH)}_3 + 2\text{H}^+ \quad (I-11)
\]

Process leaks occur frequently in petroleum refining that contaminate cooling water. Usually the bulk of a heavier oil collects on the surface of the water in the basin, from which it can easily be skimmed into a vacuum truck. Compounded lubricating oils, however, from leaking oil coolers, form extremely tight, thick emulsions of water, dirt, dispersant, and sometimes calcium salts; these emulsions tend to plug tubes and foul tube sheets of heat exchangers. Leaking oil seldom reduces chromate, but it coats the filling material in the cooling tower, particularly if it contains film packing, and interferes with the air/water contact.

Wind-borne dust is blown into cooling towers, dispersed in the water, then carried along until it reaches a place where the velocity of the water slows enough for the solids to settle and build up a deposit. This is especially troublesome during land filling, road work, or excavation, but every dry, windy day adds a great deal of dirt to a cooling system. Much of this settles in the basin of the cooling tower, but enough is carried into the cooling system to cause difficulties. Clays, for instance, are so finely divided that they readily form colloidal solutions, or sols, in cooling water that under certain circumstances undergo gelation, setting to a more-or-less homogeneous, firm, elastic gel containing 2–3 percent clay with the remainder water.$^{(3)}$ Particles of clay also tend to adhere to each other when wet, and deposit as impervious, sticky masses. Oil leaks further complicate matters, as clay and other soils have a marked affinity for oil.

If polyacrylamides are used to disperse mud through a cooling system, it is possible for soft, gelatinous masses to form if the polymer is added too rapidly. When this material enters the tubes of a heat exchanger, the heat transforms it to a hard, plastic mass that is most difficult to remove. Mechanical blockage also occurs frequently when wood fibers from cooling
tower deterioration or chips from carpentry repairs lodge in heat exchanger tubes or upon the faces of tube sheets.

Calcium, magnesium, and ferric phosphate are commonly found in scales and deposits in phosphate-treated cooling systems. A particularly voluminous and insoluble salt is formed in cooling water treated with, or contaminated by, ferrocyanide. This is the familiar, intensely blue ferric ferrocyanide, Fe₄[Fe(CN)₆]₃, also called Prussian blue \( (K_{SP} = 3.3 \times 10^{-31}) \). Other organic salts that occur in water-formed deposits include calcium carbonate, calcium sulfate, and magnesium silicate.

I.1.b Corrosion Deposits

Corrosion is the result of the oxidation of metal by some oxidizing agent in the environment. The area over which the metal is oxidized is called the anode and that at which the oxidizing agent is reduced is called the cathode. These areas are separated, but usually are not far apart. As corrosion proceeds, electrons flow through the metal between these areas and ions flow from one area to the other through the solution. This system constitutes an electrochemical cell.

The oxidation (corrosion) of iron by hydrogen ion is represented by the following equation:

\[
2H^+ + Fe = Fe^{2+} + H_2
\]  
(I-12)

This reaction is opposed by an irreversible potential called the hydrogen overvoltage, which is markedly affected by the condition of the surface of the metal. Agents that raise the overvoltage oppose or inhibit corrosion, while conditions that facilitate the escape of hydrogen from the cathodic surface (roughness, debris, etc.) augment corrosion. Table I-2 lists several anodic-cathodic couples that can occur in aqueous environments, for example, cooling systems or boilers.

Much iron corrosion is caused by failure to clean and passivate new equipment properly, and also by allowing metallic surfaces to become scaled or fouled. In general, the corrosion product of mild steel is ferric oxide, \( Fe_2O_3 \). In boilers under sulfite or hydrazine treatment magnetite, \( Fe_3O_4 \), is the usual product.

\[
3Fe_2O_3 + SO_3^{-} = 2Fe_3O_4 + SO_4^{-}
\]  
(I-13)

Oxides of iron are often mixed with other inorganic compounds, oil, tar,
TABLE I-2

Anodic-Cathodic Couples

<table>
<thead>
<tr>
<th>Anode</th>
<th>Cathode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stressed metal</td>
<td>Unstressed metal</td>
</tr>
<tr>
<td>Low oxygen concentration</td>
<td>High oxygen concentration</td>
</tr>
<tr>
<td>Clean metal</td>
<td>Fouled metal</td>
</tr>
<tr>
<td>Iron</td>
<td>Copper</td>
</tr>
</tbody>
</table>

wax, or coke and, if old, are likely to be quite insoluble. Copper and cuprous oxide derived from corrosion of copper alloys in preboiler equipment are also frequently seen in boiler corrosion deposits. Cupric ions dissolved from stage heaters, condensers, and evaporators subsequently plate on steel boiler tubes, become a cathode, and the surrounding and underlying steel corrodes.

Hydrogen sulfide is a source of corrosion in petroleum refineries, where reflux drums, stripping columns, and heat exchangers fabricated of admiralty brass, monel, and cupro-nickel alloys are exposed to it. Corrosion deposits from these units may contain sulfides of copper, nickel, zinc, and iron. Regenerators in hydrofluoric alkylation plants, which are also made of monel, are often found to contain nickel, copper, and iron fluorides as products of corrosion.

1.1.c Microbiological Deposits

Water in an open recirculating cooling system is continuously infested with a variety of nuisance microorganisms indigenous to soil including bacteria, algae, and fungi. These organisms are introduced in wind-borne dirt and once in the water they proliferate unless checked by the addition of microbicides. Algae are often visible as green, felt-like mats in internal sections of cooling towers that are wet and accessible to sunlight. Filamentous and capsulated colonial algae coat splash packing and interior structural members, thereby interfering with the formation of droplets that is essential for intimate contact between water and air; they are otherwise innocuous. As these microorganisms require sunlight to live, they are not found within heat transfer equipment. Although in the field of water treatment there is frequent reference to "dead algae," as a practical matter,
Index

Abietic acid, 68, 205  
Abietylamine, 68, 206  
Abietyaminodibutanone, 68  
Acetylenic alcohols, 65, 138  
Acidic emulsions, 58  
application of, 58  
composition of, 58  
Acidic foams, 89, 92-93, 122, 163, 204-205  
advantages of, 163  
cleaning boilers with, 92, 93  
cleaning columns with, 204-206  
cleaning surface condensers  
with, 92, 122, 162-163, 204  
effect of hydrocarbons on, 163, 205  
foaming agents for, 93, 204-205  
quality of, 205  
surfactants in, 204  
velocity of, 205  
wetness of, 205  
Acmite, 3, 4, 5, 73  
dissolution of, by hydrochloric acid, 73  
formula of, 3, 5,  
temperature of formation of, 3, 4  
Acridine, 138  
Admiralty brass, 25, 29, 35, 43, 49, 60, 92, 161, 182  
cleaning of, with hydrochloric acid, 43  
cleaning of, with sulfuric acid, 49  
density of, 25  
dezincification of, 29, 92  
by carbon tetrachloride, 92  
by sea and fresh water, 29  
in heat exchangers, 244  
resistance of, to sea water impingement, 60  
self-passivation of, 182  
stress corrosion cracking of, by ammonia, 35, 60, 161  
Aerobacter, 10  
AEROSOL OT, 72  
as an emulsifying agent, 72  
tendency of, to foam, 72  
Airheaters, 14  
corrosion of, by sulfuric acid, 14-15  
Algae, 9  
capsulated colonial, 9  
filamentous, 9  
in cooling towers, 9  
in cooling water, 9  
Alkaline emulsions, 40-41, 124, 165
addition of water-soluble surfactants to, 41
composition of, 40
removal of heavy organic material by, 40-41, 124, 165
Alkaline solutions, 34-41, 147, 164, 228-231, 234-237
chemical cleaning with, 34-41
deoiling with, 35-38, 147, 164
estimation of free alkali in, 228-231, 234-237
stress corrosion cracking of steel by, 38
Alkylamines, 65, 66
Alkylarylsulfonates, 40
Alkylcoronene, 11
Alkylenglycolalkyl ethers, 40
Alpha-quartz, 3, 5
Aluminum, 34, 44, 60, 92, 150
dissolution of, by carbon tetrachloride, 92
effect of alkalies on, 34, 60
effect of hydrochloric acid on, 44, 60
in copper alloys, 60
labyrinth rings of, in compressors, 44
Aluminum brass, 60, 161, 182, 245
arsenic in, 60
composition of, 60
self-passivation of, 182
stress corrosion cracking of, by ammonia, 161, 245
Aluminum bronze, 49, 60, 161, 245
cleaning of, by sulfuric acid, 49
composition of, 60
stress corrosion cracking of, by ammonia, 161, 245
Ammonia, 35, 60, 151, 161, 192, 245
copper complex with, 151
formula of, 151
production of, in catalytic reforming, 165
stress corrosion cracking of copper alloys by, 35, 60, 161, 245
stripping of, 192
Aluminum bifluoride, 28, 54, 73-74, 137, 146, 147, 245, 246, 247
addition of, to citric acid, 73, 137
concentration of, in cleaning solutions, 74
corrosivity of solutions of, 73-74, 146, 147
for dissolving silicate scales, 28
in the determination of copper, 245, 246, 247
toxicity of, 28
with hydrochloric acid, 54, 146
Ammonium bromate, 79, 80, 245
as an oxidizing agent, 79, 80
for removing copper, 79, 80, 245
Ammonium citrate, 80-81
dissolution of magnetite by, 80
Ammonium ion, 229, 230
effect of, on solubility of zinc hydroxide, 229
hydrolysis of, 230
hydrolysis constant of, 230
Ammonium isopropylbenzenesulfonate, 204
Ammonium persulfate, 79, 245
as an oxidizing agent, 79
for removing copper, 79, 245
pitting by, 79
Amphibole, 5
n-Amylbenzene, 90
Analcite, 3, 4, 5, 73
dissolution of, by hydrofluoric acid, 73
formula of, 3, 5
temperature of formation of, 3, 4
INDEX

Anhydrite, 3, 5, 194
  dissolution of, by sodium gluco-
  nate, 194
  solubility of, 194
Aniline, 66, 69
Anionic wetting agents, 72, 76
  in gluconate solutions, 76
Anode, 8, 20, 21, 151
Aragonite, 3, 5,
ARMOHIB, 70
Aromatic solvents, 89-90, 195
  boiling range of, 89, 90
  dissolution of residual material
  by, 89-90
  flash points of, 89
  physiological effects of, 195
  table of, 90
Arsenic, 198
  in crude petroleum, 198
  in desalter sediments, 198
Arsenite, 29, 63, 125, 170, 198
  as corrosion inhibitor, 29, 63,
  170, 198
  in alkanolamine gas sweet-
  ening, 125, 170, 198
  reduction of, to arsenic, 170
Arsine, 29, 125, 170, 171, 198
  from hydrolysis of ferrous ar-
  senide, 125
  generation of, in aluminum
  tanks, 170
  oxidation of, by permanganate,
  29, 125, 171
  release of, in chemical cleaning,
  29, 125, 170, 198
  toxicity of, 29, 170
Ascorbic acid, 144
Ash modifiers, 216
Asphaltenes, 88, 90
  dissolution of, 90
Asphalts, 88, 90, 195, 216
  association of vanadium with,
  216
  dissolution of, 90, 195
Available acid in cleaning solu-
  tions, 231-234
Bacteria, 9, 10
  in cooling water, 9
  slime-forming, 10
Basic copper carbonate, 244
Basic magnesium phosphate, 3
Benzobisantrene, 11
Benzoperylene, 11
Benzopyrene, 11
Benzotriazole, 65
3-Benzylamino-1-butyne, 68
Benzylsulfide, 67
p.p'-Bisdodecylbibenzyl, 145
Bitumens, 88, 193
Bivalve molluscs, 10
  effect of chlorine on, 10
  in sea-water cooling, 10
Blowdown lines, 2
  plugging of, 2
Boil-out solutions, 37-38, 134-
  136, 147, 234-237
  for steam generators, 134-136,
  147
  free alkali in, 234-237
  wetting agents in, 37
Boilers, 1-9, 19, 22, 23, 24, 28,
  30, 36-38, 44-45, 77-79, 81-83,
  92, 93, 97-98, 109-110, 114,
  116, 118, 123, 131-152, 218-
  226, 244, 245
  acid cleaning of, 142-150
  corrosion caused by, 143
  blend-filling of, 44-45, 148-
  149
  boil-out solutions for deoiling
  of, 37-38, 134-136, 147
  causes of pitting in, 145-146
  caustic gouging in, 19, 150
  chemical cleaning of, 28, 81-
  83, 92, 93, 114, 136
with acidic foams, 92, 93
with alkaline EDTA, 81-83
with hydroxyacetic acid, 28, 136
corrosion in, 8, 9, 22, 144, 244, 245
effect of copper on, 9, 22, 244, 245
drums, 97, 142, 150
inspection of, 97, 150
water-jetting of, 97
wire brushing of, 97
effect of copper in, 77, 78-79, 151, 225
effect of oil in, 4, 134-135, 147, 220
foaming in, 135
generation of hydrogen during cleaning, 30
hydrostatic pressure testing of, 132, 134
in-service cleaning of, 123, 140-142
ion-exchange resins in, 220
mechanical cleaning of, 97-98
metallic copper in, 79, 116, 142, 150, 151, 245
oil balls in, 4, 135, 222
on-stream cleaning of, 123, 140-142
optical inspection of, 118
organic sludge conditioners in, 4
particulates in, 36, 150
passivation of, after cleaning, 109-110, 139-140, 151-152
phosphate sludges in, 1
pitting in, by oxygen, 132, 145-146
positioning of corrosion coupons in, 24
preoperational cleaning of, 37, 131-140
ratio of magnetite to copper in, 78
removal of acids and debris from, 145
removal of copper from, 72-79, 150-152
removal of mill scale from, 23, 37, 136, 137, 142
scales in, 1, 2-8, 159, 164, 221
analysis of, 218-226
composition of, 221
tube failures in, 3
turbining of tubes in, 97
water-formed deposits in, 2-8
components of, 4, 5, 142, 221
copper in, 142, 150, 151
organic components of, 220
water-jetting of, 145
Bronze, 43, 60, 182
cleaning of, by hydrochloric acid, 43
composition of, 60
self-passivation of, 182
Brucite, 5
n-Butylbenzene, 90
2-Butyne-1,4-diol, 138
Calcium carbonate, 8, 197
dissolution of, by mixed chelants, 197
Calcium caseinate, 194
dissolution of, by sodium gluconate, 194
Calcium salts, 3, 12, 159, 183
in fuel oil, 12
properties of, 3
removal of, by water-jetting, 183
solubility of, 3, 159
Calcium sulfate, 50, 140
dissolution of, 140
solubility of, 50
INDEX

Carbon tetrachloride, 91, 92, 94
reaction of, with aluminum, 92
Carboxymethylcellulose, 141
Cast iron, 59
cleaning of, with hydrochloric acid, 59
inhibition of corrosion of, 59
porosity of, 59
Cathode, 8, 21, 151
Cationic wetting agents, 37
Caustic availability, 168–169
Caustic gouging, 19, 150
Caustic scrubbers, free alkali in,
228–231
Caustic soda, 48, 50, 199
neutralization of spent acid with, 48, 50
sweetening strippers with, 199
Cementite, 22
formula of, 22
Chalcedony, 154
Chelants, 142, 197, 223
corrosivity of, 142
effect of, on iron oxides in boilers, 142
effect of organic material on,
223
mixed, as cleaning agent, 197
checklists for, 125–127
contracting for, 119–121
decoiling before, 123–124, 147
disposal of wastes from, 128–129, 160
economic aspects of, 121–122
metallurgy of equipment in,
123, 160–163
on-stream, 123
planning for, 121–126, 147–148
safety rules and equipment for,
126–127
solutions, emergency disposal of, 122
Chestnut tannin, 4, 147
Chlorinated alkanes, 89
Chlorinated hydrocarbons, 28, 90–92, 94, 95, 195
allergic reactions to, 95
corrosion of aluminum and zinc by, 92
disposal of, 91
generation of phosgene by, 91
physiological effects of, 195
properties of, 91
reclamation of, 91
systemic effects of, 94
threshold limit values of, 91
toxicity of, 91
use of, for cleaning vertical vessels, 90
use of teflon hoses for, 91
Chloroform, 91, 94
in cooling water treatment, 4–7
passivation of iron by, 104,
thickness of passivating films of, 106–107

effect of water-jetting on,
111–112
Chromic acid, 27, 50–52, 242–244
attack of various metals by, 51
available determination of, 242–244
concentration of solutions of,
51–52
effect of, on hoses, 52
hazards of, 27, 51
oxidation of coke and tars by,
27, 50–52
oxidation of pyrite by, 51
preparation of solutions of, 52
toxicity of, to marine life, 52
Citratoferrate ion, 56, 59, 152
instability constant of, 57, 152
stability of, 56, 152
Citric acid, 56, 61, 69, 76, 80,
136-140, 197, 233
ammoniated, 56, 69, 80
cleaning of stainless steel with,
56, 136-137
cleaning of titanium with, 56,
61
for preoperational cleaning, 56,
136-140
formation constants of, 76
titration of, 233
with mixed chelants, 197
CITROSOLV process, 80, 81, 152,
153
elimination of passivation step
in, 153
pH of, 152, 153
use of ammonium bifluoride in,
80
use of sodium nitrite in, 81,
152, 153
Clay, 7, 12
gelation of, 7
in fuel oil, 12
Cleaning methods, 27-31, 126-
127, 131-155, 155-187, 189-
211
for catalytic reformer plants,
162
for columns, 189-211
for heat exchangers, 159-187
for steam generators, 131-153
for steam turbines, 153-155
hazards of, 27-31, 126-127
special equipment for, 30-31
Cleaning solutions, 27-30, 34-84,
137-138, 142, 145-146, 160-
165, 197, 202, 231-237, 241-
151
acidic emulsions as, 58
acidic solutions as, 41-58
inorganic, 41-54
organic, 55-58
alkaline EDTA in, 81-83
available acid in, 231-234
chromic acid in, 27, 50-52
available, 242-244
citric acid in, 28, 55, 56-58,
197
corroosivity of, to carbon steel,
146
determination of copper in,
244-247
determination of iron in, 247-
250
determination of phosphate in,
250-251
disposal of, 160, 165, 202
effect of, on fouling, 1, 41
formic acid in, 27, 55, 137-138
free alkali in, 234-237
gluconic acid in, 28
hazards of, 27-30, 41, 49, 50,
55
hydrochloric acid in, 27, 41,
43-48
hydrofluoric acid in, 41
hydroxyacetic acid in, 28, 55,
137-138
laboratory performance tests
of, 2, 41, 142, 163-164
metallurgical damage by, 27,
143, 145-146, 161
mixed chelants in, 197
oxalic acid in, 27, 55
oxidizing agents as, 79
phosphoric acid in, 27, 41, 52-
53
proprietary, 80-84
protective equipment when us-
ing, 28
release of toxic gases by, 27,
28-30
INDEX

residual chelant in, 241–242
reusing partially spent, 75
special, 73–79
sulfamic acid in, 27, 41, 53–54
sulfuric acid in, 27, 41, 49–50
Coke, 1, 7, 9, 11, 27, 39, 50–52, 98, 183, 213–214
composition of, 51
in boilers, 9
in corrosion deposits, 9, 193
in distillation columns, 193
in furnaces, 1, 11, 213–214
nature of, 214
removal of, by dry-firing, 214
removal of, by shot-blasting, 98
removal of by steam and air, 11, 51
removal of, by water-jetting, 183, 200
induced by salts, 214
oxidation of, by chromic acid, 27, 39, 50–52
porous, 214
shell, 214
Columns, 189–211, 221
bubble-cap tray, 191, 192
cascading of, 202–204
capacity of, 200, 208
cleaning of, 195–211
composition of, 193–195
deoiling of, 195
distillation, 189–195, 221
organic fouling in, 193, 221
flooding of, 200–202
foam cleaning of, 204–206
fouling in, 192–195, 221
functions of, 189–192
high-pressure water jetting of, 197
holdup in, 203–204
packed, 192
tray, 200
vapor phase degreasing of, 206–207
Contracts for chemical cleaning, 119–121
Cooling systems, 4–7, 8, 60, 123, 159–160, 182
chromate-treated, 4–7
effect of reducing agents on, 4–7, 160
corrosion in, 8, 159
dirt contamination in, 7, 159–160
oil contamination in, 7, 160
on-stream cleaning of, 123
passivation in, by chromate, 182
unsuitability of stainless steels in, 60, 124
Copper, 244–247
corrosion of, by ammonia, 245
corrosion of, by ferric ion, 245
corrosion of, by hydrogen cyanide, 245
determination of, 244–247
in acid solutions, 246
in chelant solutions, 246
in oxidizing solutions, 246–247
Copper alloys, 59–60, 65, 69, 150, 161, 182
alloying elements in, 60
benzotriazole as corrosion inhibitor for, 65
corrosion inhibitors for, 69
effect of velocity on, 60
protective films on, 60
resistance of, to corrosion, 59–60, 150
self-passivation of, 182
stress corrosion cracking of, by ammonia, 161
Copper films, 151-153
 composition and structure of, 151
 in boilers, 151
 removal of, by CITROSOLV process, 152-153
 Coronene, 11
 Corrosion, 8-9, 15-27, 44, 71, 106, 142, 146-147
 by chelants, 142
 crevice, 24
 current, 20-22
 effect of impressed potential on, 106
 effect of velocity on, 24, 71
 electrode processes, 22
 inhibitors, 146-147
 polymerization of, 146-147
 mechanism of, 8-9, 15-27
 rate of, 23-27, 44
 conversion units for, 25-26
 effect of ferric ion on, 44
 expression of, 24-26
 measurement of, 23-27
 by polarization, 26-27
 by resistance, 26
 by weight loss, 23-26
 surface effects in, 22-23
 Corrosion inhibitors, 61, 63, 61-71, 178, 226-227
 addition of, to acids, 71
 chemisorption bonds formed by, 63, 226
 heat of adsorption of, 64
 commercial formulations of, 69-71
 dyeing of, 71
 surfactants in, 70
 vapor phase inhibitors in, 70
 composition of, 63, 65
 decomposition of, 71
 effect of hydrogen sulfide on, 178
 effect of, on corrosion rate, 61, 66
 effect of, on hydrogen overvoltage, 65
 effect of, on metals, 61, 226
 filming amines, 24, 226
 for chemical cleaning, 69
 formation of protective films by, 63
 thickness of, 67
 inorganic, 63
 mechanism of action by, 63-64
 polymerization of, 71
 steel wool test for, 226-227
 surface complex formation by, 64
 types of, 64-69
 Coupons, 23-26
 preparation of, 23
 Cristobalite, 154
 CRONOX, 70
 composition of, 60
 copper foils from, 150
 density of, 25
 exfoliation of, 118, 150
 self-passivation of, 182
 stress corrosion cracking of, by ammonia, 35, 161
 Cuprous cyanide ion, 245
 stability constant of, 245
 Cuprous sulfide, 195
 in hydrogen sulfide strippers, 195
 solubility of, in ammonia, 195
 Cyanogen, 29
 hydrolysis of, by alkali, 29
 reduction of cyanide by copper, 29
 Cupric ammonia complex, 153
 formula of, 153
 Cupric oxide, 154-155, 197
 dissolution of, by mixed chelants, 197
INDEX

in turbines, 154
removal of, 154-155
steam distillation of, 154
Cuprite, 5
Cupro-nickel, 25, 35, 43, 49, 60,
118, 150, 161, 195
cleaning of, by hydrochloric
acid, 43
cleaning of, by sulfuric acid, 49
release of, in chemical cleaning,
29
toxicity of, 29
Cycle oils, 222-223
Cyclohexylamine, 66, 69
Decamethylenelamine, 66
Dehydroascorbic acid, 144
Densities of metals, 25
Department of Transportation,
129
Deposits, 1, 2, 3, 12-15, 142, 145,
150, 159-160, 163, 192-195,
198-199, 213, 219-220, 222-226
analysis of, 195, 218-226
definition of, 2
dissolution of, by acids, 15
entrapment of acid beneath,
145
in columns, 192-195
in furnaces, 12-15
in process equipment, 1, 159-160,
192-195
in steam generators, 142
composition of, 142, 150
mechanism of formation of, 3,
194
sampling of, 2, 163, 194, 198-199,
219-220
solubility of, 222-226
water-formed, 159, 213
oil in, 220
DEQUEST 2010, 197

Desalters, 193-194
arsenic in sediments from, 198
efficiency of, 214
Desincification, 29, 92
by carbon tetrachloride, 92
inhibition of, by arsenic, 29
Dibenzylsulfoxide, 65, 67, 68, 69
Dichloroacetylene, 95
s-Dichloromethyl ether, 144
Dichlorotetrafluoroethane, 204-205
formula of, 205
Diesel fuel, 205
foaming of, 205
Diethanolamine, 170
s-Diethylamino-1-propane, 68
o-Diethylbenzene, 90
Dihydroxyethylauramid, 93
as foaming agent, 93
o-Diisopropylbenzene, 90
Dimethylsulfide, 145
2,4-Dinitrophenol, 69
Diphenylamine, 65, 69
Dodecylbenzyltrimethylsulfonium
chloride, 145
Dodecylphenoxynbenzenedisulfonic
acid, 72
as anionic wetting agent, 72
p-Dodecyltoluene, 145
Dow Corning silicone, 206
DOWEL, 70
Dowell Sulfide Scale Removal, 83
Duranickel, 161, 190
stress corrosion cracking of, by
hydroflouric acid, 161

Economizers, 14-15, 150
blockage of, by ferrous sulfate,
15
composition of, 150
corrosion of, by sulfuric acid,
14-15
Eddy current testing, 118
EDTA, 81-83, 153, 241-242, 245, 246, 249-250
alkaline, for copper removal, 81-83, 153
advantages of, 82-83
corrosion rate of, 83, 153
destruction of, by oxidizing agents, 245
determination of copper in, 246
determination of total iron in, 249-250
estimation of residual, in cleaning solutions, 241-242
Ferric ferrocyanide, 8, 76
  dissolution of, by sodium gluconate, 76
  solubility product of, 8
Ferric gluconate, 197
dissociation of, 197
Ferric hydroxide, 57, 149, 196
  formation constant of, 196
  precipitation of, during rinsing, 149
  reduction of, by hydrogen sulfide, 74-75, 178
  reduction of, by stannous chloride, 74-75
  sequestration of, by gluconate ion, 75
  solubility product of, 57, 196
Ferric ion, 74-75, 143, 144, 149, 164, 178, 245, 249
  in cleaning solutions, 149, 164
  determination of, 249
  oxidation of chromium by, 75
  oxidation of copper by, 75, 245
  oxidation of nickel by, 75
  oxidation of zinc by, 75
  reaction of, with iron, 74, 143, 247
  reduction of, by ascorbic acid, 144
  Ferric ion corrosion, 74-75, 143-145
    elimination of, by benzylsulfonium salts, 145
    mechanism of, 145
    elimination of, by hydrogen sulfide, 74-75, 143
    elimination of, by thioacetamide, 143
    ineffectiveness of amines in, 144
    pitting in, 75
    reduction of, by ascorbic acid, 144
    reduction of, by isoascorbic acid, 144
    reduction of, by stannous chloride, 74-75
Ferric oxide, 164, 192, 194
  rate of dissolution of, by acids, 164, 194
Ferric phosphate, 3, 8
Ferro cyanide, 6
  formation of, in cooling water, 6
Ferrous arsenide, 125
  formula of, 125
  hydrolysis of, to arsine, 125
Ferrous ferrite, 193
Ferrous fluoride, 198
Ferrous hydroxide, 196
  formation constant of, 196
  solubility product of, 196
Ferrous metasilicate, 4
Ferrous sulfide, 124, 160, 161, 165-167, 177, 193, 195-197, 207-208
  dissolution of, 167, 176-177, 193
  evolution of hydrogen sulfide from, 124, 160, 165-167, 177, 193, 196, 197
  rate constant for, 167
INDEX

formation constant of, 196
in hydrogen sulfide strippers, 195
oxidation of, to sulfuric acid, 161
particulate, 207-208
solubility of, in ammonia, 195
solubility product of, 196
Fiber optics inspection, 118
Filming amines, 24, 226
Flade potential, 108
Flame temperatures, 13
Flammable solvents, 89
flash points of, 89
Flash rusting, 108
Flue gas, 13
temperature of, 13
Fluoboric acid, 198
Foam stabilizers, 204-205
Formaldehyde, 83, 143-144
reaction of, with hydrogen sulfide, 83, 143-144
toxicity of, 83
Formation constants, 76
Formic acid, 55-56, 60, 76, 137-138, 233
attack of stainless steels by, 60
combination of, with hydroxyacetic acid, 55-56, 137-138
concentration of commercial grade of, 55
disposal of, by incineration, 56
dissociation constant of, 56
formation constant of ferric complex with, 56
formation constants of, with various ions, 76
titration of, 233
toxicity of, 55
acid corrosion beneath, 145
analysis of, 114-119, 218-226
spectrographic, 115, 218
x-ray diffraction, 116, 150, 218
x-ray fluorescence, 218
by petroleum products, 10-11, 160, 193, 220, 221
composition of, 11, 193, 221
caracterization of, 221-222
combustion, 2
corrosion, 2, 8-9, 150, 159, 193-195, 199, 221
composition of, 8-9, 150, 159, 193-195, 199, 221
elements found in, 117, 150, 192-195
evolution of toxic gases from, 116, 193
in boilers, 2-4, 220-222
in columns, 192-195
in recirculating cooling systems, 4-8, 159-160, 221
by phosphates, 8
by Prussian blue, 8
iron oxides in, 3, 159, 192
microbiological, 2, 9-10, 159, 221
organic, 2, 4, 159, 193, 220, 221
in boilers, 4, 220
in distillation columns, 193, 221
removal of, 121
sampling of, 115, 163, 194, 219-220
significance of distribution of, 2, 194, 218-221
solubility of, 114, 116, 142, 163-164, 222-226
estimation of, 222-226
sources and composition of, 2-15, 114, 115, 150, 192-195, 218-221
Fractionators, 189-190, 221
  multiplate, 189-190
composition of fouling in, 221
Free alkalinity, 168, 218-231, 234-237
  in alkaline hydrogen sulfide scrubbers, 228-231
  in boil-out solutions, 234-237
Free energy, 18-19
FREON, 114, 205
  as foaming agent, 205
Fuel oil, 11, 12-13, 14, 215-216
  additives, 216
  ash modifiers for, 216
  metallic contaminants in, 11, 215
  nickel in, 215-216
  sea water in, 12
  sulfur in, 14, 216
  vanadium in, 12-13, 215-216
  concentration of, 216
  effect of, in furnaces, 12-13, 215-216
Fungi in cooling systems, 9
Furfuraldehyde, 65, 67, 69
Furnaces, 13-15, 98, 115, 213-217, 221
  cleaning of, 213-217
  evolution of hydrogen sulfide during, 215
  coke in, 214
  removal of, by steel shot, 98
  composition of deposits in, 221
  convection section of, 13, 213
  corrosion in, 216
  flame temperatures in, 13
  formation of slag in, 216
  formation of sulfuric acid in, 14-15
  fouling in, 193
  integral, 215-217
  fouling in, 213
  laminar scales in, 115, 219
  preheat, 213-215
  fouling in, 213
  salt deposits in, 214
  radiant section of, 13, 213
  temperatures in, 13
Galvanized iron, 44
  effect of hydrochloric acid on, 44
Gluconic acid, 28, 76
  dissociation constant of, 76
  formation constants of, with various ions, 76
Glycolic acid (See Hydroxyacetic acid)
Gypsum, 5, 193-194
Hazardous wastes, 38, 41, 122, 128-129
  disposal of, 128-129
  hauling of, 129
  incineration of, 128
  minimizing creation of, 41, 122, 128
  recycle of, 128
Heat exchangers, 51, 110-112, 114, 159-187, 221
  backflushing of, 163
  cleaning of, 114, 159-187
  caustic scrubbers in, 171, 176-181
  piping for, 172, 174
  composition of, 160-163
  composition of deposits in, 221
  corrosion of baffles in, 159
  deoiling of, 171, 172-176
  deposits in, 159, 163, 221
  effect of, on circulation, 159
  effect of, on heat transfer, 159, 163
  design of, 159, 160-163
  ferrous sulfide in, 165-170, 171
  fixed tube-sheet, 163
fouling of, by dirt, 159-160
hydrostatic testing of, 172, 187
internal-floating-head, 163, 171
  water-jetting of, 185-187
pass partitions in, 162, 185
passivation of, 110-112, 163, 187
  by chromate, 110-112
  by polyphosphate, 112
preheat, effect of fouling in, 51.
  193-194
shell-and-tube, 163, 171
tubes in, 163
  inspection of, 163
plugging of, 163, 171
water-jetting of, 183-187
types of, 159, 162-163, 171
types of fouling in, 159-160, 163, 221
  sampling of, 163, 219-220
Heat transfer equipment, 10, 23,
  24, 114-119, 131, 150, 151,
  159-187
chemical cleaning of, 114, 131,
  159-182
composition of, 150, 151
corrosion rates in, 24
flow rate through, 24
inspection of, 114-119, 163
removal of mill scale from, 23
sea water in, 10, 161
water-jetting of, 183-187
Hematite, 5, 142, 247, 248
dissolution of, by hydrochloric acid, 247, 248
Hexafluoroaluminium ion, 73, 234
Hexafluoroferric ion, 54, 73, 137,
  234
dissociation constant of, 54, 73,
  137
stability of, 54, 73, 137
High-pressure water-jetting, 41,
  98-102, 111-112, 122, 145,
  183-187, 197, 199-200
addition of polymer in, 101-102, 183
  concentration of, 102
  mixing of, 102
addition of sodium nitrite in, 101
cavitation damage in, 99
cleaning of boiler tubes by, 100
  outline of procedure for, 100
  effect of, on passivating films, 111-112, 187
elimination of hazardous waste in, 183
flexible lances in, 183
for cleaning heat exchangers,
  98-100, 183-187
for removing acids and debris from boilers, 145
for removing coke deposits, 200
for removing oily or greasy materials, 101, 184
of columns, 197, 199-200
of outside of tube bundles, 184
of U-tubes, 184-185
rigid lances in, 183
safety precautions in, 102, 187
shotgunning in, 184
Hydrated lime, 48
  neutralization of spent acid by, 48
Hydrazine, 8, 109, 132, 134, 144
  as an oxygen scavenger, 8, 132,
  134, 144
  in passivating solutions, 109
Hydrochloric acid, 27, 43-48, 60,
  65, 119, 124, 146-152, 199,
  200, 233
  as a cleaning agent, 27, 43-48
  velocity of, 43-44
attack of stainless steels by, 60
  cleaning boilers with, 146-152
cleaning columns with, 199, 200
concentration of commercial
grades of, 45
correcting the concentration of,
45-47
corrosion rate of inhibited, 119,
124
corrosivity of, to carbon steel,
146
effect of, on aluminum, 44
effect of, on stainless steels, 44
effect of, on zinc, 44
inhibition of, 43
neutralization of, by various
bases, 47-48
preparation of solutions of, 45-
48
suitable corrosion inhibitors
for, 65
titration of, 45, 233
types of fouling attacked by,
43
Hydrofluoric acid, 42, 54, 68, 73,
74, 137, 197-198
addition of ammonium bifluo-
ride to, 54
applications of, in steel mills,
54
burns caused by, 197
dissociation constant of, 42, 54,
73
dissolution of silicates by, 42,
73
effect of, on stainless steels, 54,
74, 137
inhibitor for, 54
Mannich bases as inhibitors for,
68
toxicity of, 54, 74
transformation of, by boric ac-
id, 197-198
Hydrofluoric acid alklylation
plants, 9, 115, 161, 194, 197-
198
acid salts from, 115, 194
composition of deposits from,
194
corrosion in, 9, 161, 194
neutralization of acid in, 197-
198
sampling of fouling from, 115,
194
Hydrogen, 125
release of, in chemical cleaning,
125
Hydrogen cyanide, 6, 29, 125,
166, 167, 245
absorption of, in sodium hy-
droxide, 167
corrosion of copper by, 245
effect of, on admiraltry brass, 6
formation of, in catalytic crack-
ing, 6, 29, 166
reaction of, with ferrous ion, 6
release of, in chemical cleaning,
29, 125, 166
toxicity of, 29, 166
Hydrogen overvoltage, 8, 17-20,
65, 137-138
effect of corrosion inhibitors
on, 65, 137-138
Hydrogen sulfide, 6-7, 28-30, 66,
73-74, 80, 83, 125, 143-144;
160, 165-170, 172, 176-181,
192-196, 199, 207, 208, 215
absorption of, in alkaline scrub-
ers, 28, 74, 83, 125, 167-
170, 172, 176-181, 196, 208,
215
capture of, by formaldehyde,
80, 83, 143-144
corrosion of iron by, 66, 166,
193, 207
disposal of alkaline solutions of,
181
effect of, in process units, 9
effect of, on admiralty brass, 6, 7
effect of, on chromate, 6
effect of, on corrosion inhibitors, 178
effect of, on high-tensile-strength steels, 178
enhancement of hydrogen embrittlement by, 66, 178
explosive mixtures of, in air, 166
flaring of, 74, 83, 172, 196, 208
formation of, in catalytic cracking, 6, 165-166
generation of, during chemical cleaning, 28-29, 30, 125, 165-170, 215
leaks of, into cooling water, 160
measurement of, in the atmosphere, 28-29
lead acetate paper for, 28-29
neutralization of, by sodium hydroxide, 199
oxidation of, by chromate, 6-7
precipitation of zinc by, 7
production of, in catalytic reforming, 165
properties of, 28
rate of evolution of, from ferrous sulfide, 166-167
reaction of, with steel, 207
reduction of ferric ion by, 73-74
release of, by ferrous sulfide, 160, 165, 193, 215
safety equipment in presence of, 126, 166, 179, 181
OSHA regulations governing, 166, 179, 181
second dissociation constant of, 168
strippers, 192, 194-195
composition of deposits in, 195
toxicity of, 28, 166
Hydroxyacetic acid, 28, 55-56, 137-138, 233
combination of, with formic acid, 55-56, 137-138
concentration of commercial grade of, 55
disposal of, by incineration, 56
dissociation constant of, 56
for cleaning stainless steels, 55
formation constant of ferric complex with, 56
formation constants of, with various cations, 76
titration of, 233
Hydroxyapatite, 3, 5
solubility product of, 3
1-Hydroxyethylidene-1,1-diphosphonic acid, 141, 197
Hydroxylamine hydrosulfate, 80, 84, 154-155
decomposition of, 155
for removing copper, 80, 154-155
nitrous oxide from, 84
Hypoferrite ion, 20

Imidazole, 138
Inconel, 161, 190
stress corrosion cracking of, by hydrofluoric acid, 161
Industrial cleaners, 39-40, 251-253
application of, 39-40
composition of, 39-40
evaluation of, 251-253
pH of solutions of, 252
screening of, 40
wetting time of, 252-253
Inhibitors (See Corrosion Inhibitors)
Integranular cracking, 44
Iron, 248-250
determination of, in acidic solutions, 248-249
determination of, in chelant solutions, 249-250
Isoascorbic acid, 144

Kerosene naphtha, 89, 205
boiling range of, 89
dissolution of polymers by, 89
dissolution of waxes by, 89
flash point of, 89
foaming of, 205
Knocker heads, 97

Latent heat of vaporization, 190
Lead, 34
effect of alkalis on, 34
Lignins, 141, 147
Limestone, 48
neutralization of spent acid by, 48
Line moling, 123, 214
Linoleic acid, 205

Magnesium orthodisilicate, 48, 73
dissolution of, by hydrofluoric acid, 73
Magnesium salts, 3-4, 5, 8, 11, 159, 193
corrosivity of, 193
in fuel oils, 11
of phosphate, 3-4, 5, 8
of orthodisilicate, 4, 8, 73
Magnetite, 4, 5, 44, 78, 142, 150, 192, 197, 247, 248
dissolution of, by hydrochloric acid, 44, 247, 248
dissolution of, by mixed chelants, 197
dissolution of, in the presence of copper, 78
particulate, 150
ratio of, to copper in fouled boilers, 78
Malachite, 244
Manganese brass, 244
Manganese bronze, 244
Mannich bases, 65, 68, 69, 138
Mechanical cleaning, 97-98, 217
Mercaptans, 228, 230, 231
Metallic oxides, 150
Metals of construction, 58-62, 190, 195, 202, 225
aluminum as, 60
cast iron as, 59
cleaning of, 59
compatibility of solvents with, 58-59, 62, 225
copper alloys as, 59-60
effect of solutions on, 58-62
for columns, 190, 202
stainless steels as, 60, 195
steels as, 59
alloying elements in, 59
Methyl diethylperfluoroctylsulfonamide quaternary ammonium salt, 205
Methylene chloride, 91, 92, 94
o-Methyllethylbenzene, 90
Methylpyridines, 64
Mill scale, 23, 37, 44, 52-53, 118, 121, 131, 137
composition of, 137
effect of oil coating on, 44
properties of, 137
removal of, by chemical cleaning, 118, 121, 131
removal of, by phosphoric acid, 52-53
thickness of, 137
INDEX

Millipore filter test, 209, 210, 227-228
Molybdate, 104
passivation of iron by, 104
Monel, 9, 25, 43, 49, 60, 161, 182, 190-192, 195, 244
  cleaning of, by hydrochloric acid, 43
  cleaning of, by sulfuric acid, 49
  composition of, 60
  density of, 25
in hydrofluoric acid alkylation plants, 9, 60, 190-192, 195
self-passivation of, 182
susceptibility of, to sour water, 161
Monoethanolamine, 125, 170, 198, 207
  compounds found in, 170
  sweetening process, 207
  arsenite as corrosion inhibitor in, 125, 170, 198
Muntz metal, 60
  composition of, 60
Muriatic acid, 45

Nepheline, 153
  in steam turbines, 153
  formula of, 153
Nernst equation, 17
Neutralization, 181-182
Nickel carbonyl, 198
  formation of, in unregenerated catalyst, 198
  physiological effects of, 198
  toxicity of, 198
Nickelous sulfide, 195
  in hydrogen sulfide strippers, 195
  solubility of, in ammonia, 195
Nitrilotriacetic acid, 197
p-Nitroaniline, 69
Nitrobenzene, 69
Nitrogen-blasting, 214
  effect of oil on, 214
  of furnace tubes, 214
p-Nitrophenol, 69
Nitrous oxide, 84
  from hydroxylamine, 84
Noble metals, 15
Nonamethylenimine, 66
Nonaqueous cleaning solvents, 88-102
  deoiling with, 88
  dissolution of organic materials by, 88-89
  effect of, on hoses, 88
  flammable, 88
  hazards of, 93-95
  inhalation of, 95
  methods of heating, 88
  vapor phase degreasing with, 88-89, 91
Nonionic wetting agents, 37, 38, 40, 98, 172, 174, 217
  use of, for removing slags, 98, 217
Nonylphenoxypolyoxyethylene ethanol, 40, 71, 146
  formula of, 71
Noselite, 5, 153
  formula of, 153
  in steam turbines, 153

O'B-HIBIT, 70
Occupational Safety and Health Act, 121
Oil, 34-38, 147, 160, 164, 172-176, 195
  emulsification of, by hydroxyl ion, 36, 160
  emulsification of, by wetting agents, 72, 160
  removal of, by alkaline solutions, 34-38, 147, 164
removal of, by ortho-dichlorobenzene, 195
removal of, by trisodium phosphate, 172-176
Oil of vitriol, 49
Oleic acid, 205
Open-circuit potential, 21
Ortho-dichlorobenzene, 195, 207
deoiling columns with, 195
disposal of, 207
physiological effects of, 195
toxicity of, 195
Ovalene, 11
Oxalic acid, 27, 55, 56, 60
attack of stainless steels by, 60
attack of titanium by, 56
Oxidation potentials, 15-18, 22
effect of pH on, 17-18, 22
Oxygen concentration cells, 24, 159
in heat exchangers, 159

Packing in columns, 192
Passivation, 38, 39, 52, 53-54, 104-112, 139-140, 149-152, 182, 206, 210-211, 250
by impressed electrical potential, 104-106
by molybdate, 104
by oxidizing agents, 39, 104, 182
by oxygen, 104
by permanganate, 39
by phosphoric acid, 52
by sodium nitrite, 38, 104, 106, 107, 108, 110, 139, 182, 206, 210-211
effect of sulfamic acid on, 53-54, 149-150, 250
by tungstate, 104
decay of, 108
induced by chloride ions, 108
induced by reducing agents, 108
effect of oil and debris on, 104
films, 104-112, 182
composition of, 106-107, 108
diffusion barrier, 182
effect of high-pressure water on, 111-112
ferric oxide in, 105, 106, 107, 108, 112
ferric phosphate in, 105, 107
thickness of, 106-107, 110, 111
weakening of, by heat, 110
zinc in, 182
importance of, after cleaning of steel, 104, 108, 182
of boilers, 108-110, 139-140, 149-152
of columns, 210-211
of heat exchangers, 182
procedures for, 108-110, 139-140, 149-152
rapid oxidation in absence of, 104, 182
self, of certain alloys, 182
spontaneous, 104, 182
theory of, 104-108
Pectolite, 3, 5,
formula of, 3, 5
Permanganate, 39, 171
alkaline, 39
dissolution of polymers by, 39
oxidation of arsine by, 171
passivating effect of, 39
pH, 17-18, 38, 40, 42, 56, 152, 153, 168, 202, 210, 252
effect of, on oxidation poten-
INDEX

Phosphates, 1, 3-4, 8, 35-38, 104, 109, 110, 112, 250-251
boil-out solutions of, 37
composition of, 37-38
determination of, in cleaning solutions, 250-251
hydrolysis of, 35-36
in cooling water, 8
passivating solutions of, 109, 110, 112
passivation by oxygen in presence of, 104
precipitates of, with calcium, 3, 8
precipitates of, with iron, 8
precipitates of, with magnesium, 3-4, 8
sludges of, 1
Phosphor bronze, 244
Phosphoric acid, 27, 35, 53, 65, 164, 233-234
as a cleaning agent, 27
cleaning of stainless steels by, 53, 164
dissociation constants of, 35
preparation of solutions of, 53
suitable corrosion inhibitors for, 65
titrination of, 233-234
2-Picoline, 64
3-Picoline, 64
4-Picoline, 64
Picric acid, 69
Pitches, 88, 90
dissolution of, 90
Pitting, 23, 119, 145, 150
at anodes, 23
by acids, 119, 145
by oxygen, 119
Polarization, 20-22
curves, 21
Polyacrylamides, 7
Polyphosphates, 112
hydrolysis of, 112
passivation of iron in presence of oxygen by, 112
Porphyrs, 215
classes of, in petroleum, 215
in residual fuel oils, 215
molecular weights of, 215
structure of, 215
Preboiler equipment, 9, 132-134, 150, 151
cleaning of, 132-134
copper alloys in, 9, 150, 151
corrosion of, 9, 150, 151
elimination of particulates in, 132
Process equipment, 1, 189-211
cleaning of, 189-211
corrosion in, 1
scales in, 1
Propargyl alcohol, 67, 69, 138
  detonation of, in sulfuric acid, 67
n-Propylbenzene, 90
Protective films, 22-23, 37, 104-112, 131, 182
  formation of, in passivation, 104-112, 182
  thickness of, 106, 107, 110, 111
  of magnetite, 37, 131
  oxide, 22-23
  penetration of, by chloride ions, 23
Prussian blue, 8
Pseudomonas, 10
Pyrene, 11
Pyridine, 64, 65, 66, 69, 138
Pyridiniumxanthogenate, 68
Pyrite, 51, 160, 193, 214
  formula of, 51, 160
  insolubility of, in hydrogen ion, 160
  oxidation of, by air, 214
  oxidation of, by chromic acid, 51
Pyrogallol, 4
Pyrophoric deposits, 27, 51, 117-118, 198
  locations of, 117, 198
  of coke from sulfuric acid sludges, 51
  of iron sulfide, 117-118, metallic luster of, 118
Pyrrhotite, 160
  formula of, 160
  insolubility of, in hydrogen ion, 160
  magnetic properties of, 160
Radiography, 118, 142, 214
Reactors, 189
Reboilers, 189, 221
  composition of fouling in, 221
Rectifiers, 189, 192
Reflux drums, 9
Relief systems, 176
Reversing manifold, 201
RODINE, 70
Rotating rods, 23, 24
Salt deposits, 1, 153-154, 214
  in furnaces, 1, 214
  in steam turbines, 153, 154
SANDJET process, 98, 122, 214
  for cleaning piping runs, 98, 122, 214
Scales, 1, 2-4, 15, 97-98, 115, 159, 161, 163, 164, 218-226
  analysis of, 218-226
  definition of, 2
  dissolution of, by acids, 15
  in boiler tubes, 1
  in process equipment, 1
  insulating effect of, 2-4
  mechanism of formation of, 3
  removal of, by knocker heads, 97-98
  removal of, by turbining, 97
  sampling of, 2, 115, 161, 163, 219-220
  solubility of, 222-226
  water-formed, 2-8, 159, 164
Serpentine, 3, 4, 5
  formula of, 3, 5
Silicic acid, 153-154
  deposition of, in steam turbines, 153
  forms of, in turbines, 153-154
  volatilization of, in steam, 153
  effect of steaming rate on, 154
Quebracho, 4, 147
Quinolines, 65, 66, 69, 138
Slags, 13-14, 98, 215-217
  composition of, 13-14, 215-216
  variations in, 14
compounds in, 216
effect of sodium salts on, 13
inhibition of formation of, 216
mechanism of formation of, 13, 215-216
pores in, 98
removal of, by chipping, 98
removal of, by high-pressure water, 98, 217
removal of, by sandblasting, 98, 217
removal of, using nonionic wetting agents, 98, 217
x-ray diffraction of, 216
x-ray fluorescence analysis of, 216

Sludges, 1, 2, 114, 115, 141, 218-220
  analysis of, 218, 219
  in boilers, 141
  in process equipment, 1, 115
  phosphate, in boilers, 1
  sampling of, 2, 219-220

Soda ash, 48, 50
  neutralization of spent acid by, 48, 50

Sodalite, 3, 5
  formula of, 3, 5

Sodium alginate, 4

Sodium chloride, 153
  in steam turbines, 153

Sodium cocamine acetate, 204

Sodium dioctylsulfosuccinate, 40, 72, 160
  formula of, 72
  emulsification of oil by, 160

Sodium disilicate, 154, 237
  hydrolysis of, 154, 237
  in steam turbines, 154, 237

Sodium gallate, 81
  as a corrosion inhibitor, 81

Sodium gluconate, 75-76, 109, 110, 194
  as a sequestrant for cupric and ferric ions, 75
  biodegradability of, 76
  dissolution of anhydrite by, 194
  dissolution of calcium caseinate by, 194
  in passivating solutions, 109, 110
  manufacture of, 75
  nontoxicity of, 76

Sodium hydroxide, 28, 153, 199, 202
  in steam turbines, 153
  sweetening strippers with, 199, 202

Sodium mannuronate, 4

Sodium 2-mercaptobenzothiazole, 81
  as a corrosion inhibitor, 81

Sodium metasilicate, 37-38, 153
  emulsification of oil by, 37-38
  hydrolysis of, 38
  in steam turbines, 153

Sodium nitrate, 135
  as an inhibitor of stress corrosion cracking, 135

Sodium nitrite, 28, 79, 81, 104, 106, 107, 109, 110, 139-140, 165, 182, 206, 211, 245
  as an oxidizing agent, 79, 81
  decomposition of, 139-140, 165, 182, 211
  for removing copper, 79, 81, 245
  passivation of steel by, 104, 106, 107, 109, 110, 182, 206
  toxicity of, 28
Sodium N-lauroyl-β-iminodipropionate, 204
Sodium N-methyl-N-oleyltaurate, 204
Sodium perborate, 70, 245
as an oxidizing agent, 79
for removing copper, 79, 245
Sodium sulfate, 153
in steam turbines, 153
Sodium sulfite, 8
as an oxygen scavenger, 8
Sodium sulfonate, 40
Sodium vanadyl vanadate, 216
in furnace slags, 216
Solubility, estimation of, 222-226
Solubility products, 3, 8, 57, 111, 196
of calcium carbonate, 3
of calcium phosphate, 3
of calcium sulfate, 3
of ferric ferrocyanide, 8
of ferric hydroxide, 57, 196
of ferrous hydroxide, 196
of ferrous sulfide, 196
of hydroxyapatite, 3
of magnesium hydroxide, 3
of zinc hydroxide, 111

Spinels, 142, 150
formula of, 150
Stage heaters, 9, 59, 151, 244
copper alloys in, 59, 151, 244
Stainless steels, 25, 44, 49, 56, 60, 69, 109, 134, 161
alloying elements in, 60
attack of, by ferric and cupric ions, 60
cleaning of, by oxalic acid, 56
cleaning of, by sulfuric acid, 49
corrosion inhibitors for, 69
density of, 25
effect of hydrochloric acid on, 44, 161
pitting of, 151
self-passivation of, 110, 182
stress corrosion cracking of, 60, 109, 134, 161
by alkali, 109, 134
by chloride ion, 60, 161
by sulfurous acid, 161
Stannous chloride, 74-75
addition of, to hydrochloric acid, 75
disadvantages of, 75
inhibition of ferric ion corrosion by, 74-75
reduction of ferric ion by, 74, 75
Starch, 4
Steam-air decoking, 214
Steam generators, 131-153, 221
alkaline boil-out of, 134-136
certification of, 147
chemical cleaning of, 131-153
preliminary steps in, 147-148
with organic acids, 136-138
composition of fouling in, 221
in-service cleaning of, 140-142
phosphate treatment in, 142
effect of chelant on, 142
operational cleaning of, 142-153
with acids, 142-152
with ammonium citrate, 152-153
passivation of, after cleaning, 139-140, 149-150
pitting in, after acid cleaning, 145-146
preoperational cleaning of, 131-140
temperature of, before cleaning, 148
Steel, 20, 25, 30, 43, 49, 52-53, 59, 69, 119, 124, 146, 190, 195
acid cleaning of, 20, 30
  generation of hydrogen during, 30
acridic attack on, 119
  characteristics of, 119
alloying elements in, 59
  cleaning of, by hydrochloric acid, 43
  cleaning of, by phosphoric acid, 52-53
  cleaning of, by sulfuric acid, 49
  corrosion inhibitors for, 69
  corrosion rate of inhibited acid on, 119, 124, 146
density of, 25
Steel wool test, 226-227
Strippers, 9, 189, 192, 194-195, 199
  sweetening of, 199
Sulfamic acid, 27, 53-54, 233, 250
  advantages of, 53
  as a cleaning agent, 27, 53-54
  combined with sodium chloride, 53
  hydrolysis of, 53
  reaction of, with nitrite ion, 53, 250
  titration of, 233
Sulfide ion, 167-168
  hydrolysis of, 168
  constant for, 168
Sulfonic acids, 220
Sulfur dioxide, 6-7, 125, 160, 172
  effect of, on chromate, 6-7
  hydrolysis of, 7
  leaks of, into cooling water, 160
  production of, by hydrogen sulfide, 172
  reduction of chromate by, 7
  release of, in chemical cleaning, 125
Sulfuric acid, 14-15, 27, 49-50, 65, 233
  as a cleaning agent, 27, 49-50
  cleaning of stainless steels with, 49
  concentrations of commercial grades of, 49
dew point of, 14
  effect of, on tissues, 27, 49
  formation of, in furnaces, 14-15
  heat of solution of, 27, 49
  preparation of solutions of, 49-50
  safe handling of, 49, 50
  suitable corrosion inhibitors for, 65
  titration of, 233
Sulfurous acid, 161
  oxidation of ferrous sulfide to, 161
  stress corrosion cracking of stainless steels by, 161
Superheaters, 148
  protection of, during chemical cleaning, 148
Surface condensers, 59, 92, 114, 151, 162-163, 204, 221, 244
  cleaning of, 114
  cleaning of, with acidic foams, 92, 162-163, 204
  composition of deposits in, 221
copper alloys in, 59, 151, 244
design of, 162
  fouling of eductors in, 162
  effect of, on efficiency of, 162
  principle of, 162
Sweetening, 199, 202
Sym-trithiane, 83, 144
  formula of, 144
Tafel slopes, 21
Tall oil, 205
Tars, 88, 90, 160, 195, 197
  dissolution of, 90, 195
  formation of, in columns, 197
Tempering water, 148
Tetrachloroethylene, 91, 94
Thermal cracking, 214
Thioacetamide, 143
  hydrolysis of, 143
Thiomorpholine, 65
Thiols, 65
Thiourea, 63-64, 65, 66, 68, 69, 70-79, 138, 150-152, 245
  as a corrosion inhibitor, 63-64, 77
  concentration of, in cleaning solutions, 78, 151
  coordination complexes of, with copper ions, 77-79, 151
  for removing copper and its salts, 70-79, 150-152, 245
  reactions of, with copper, 77-79
  substituted, 65, 66, 68, 69, 138
Tin, 60
  in copper alloys, 60
Titanium, 25, 44, 49, 56, 61, 69
  attack of, by oxalic acid, 56
  corrosion inhibitors for, 69
  corrosion of, by sulfuric acid, 49
  density of, 25
  effect of hydrochloric acid on, 44
  susceptibility of, to hydrogen embrittlement, 44, 61
Total alkalinity, 168
Toxic gases, 29, 30, 123, 125, 165-171, 172, 176-181, 198
  flaring of, 29, 123, 172, 196
  pockets of, in chemically cleaned equipment, 30, 181
  release of, in chemical cleaning, 125, 165-171, 172, 176-181, 198
Transgranular cracking, 44
Triamylamine, 138
1,1,1-Trichloroethane, 91, 92, 94, 205
  foaming of, 205
1,1,2-Trichloroethane, 91, 94
Trichloroethylene, 91, 92, 94, 95, 205
  foaming of, 205
  formation of toxic chemicals by, 95
Triethanolamine, 81, 109, 160
  as an iron sequestrant, 81
  in passivating solutions, 109
  leaks of, into cooling water, 160
1,2,3-Trimethylbenzene, 90
1,2,4-Trimethylbenzene, 90
1,3,5-Trimethylbenzene, 90
Trioxane, 83
Triphenylamine, 66
Trisodium phosphate, 35-36, 174, 176
  dehydrate, 36
  disposal of solutions of, 176
  light deoiling with, 171-172, 174
  pH of solutions of, 35-36
Troilite, 160
  formula of, 160
Tubes, 97, 131
  turbining of, 97, 131
Tungstate, 104
  passivation of iron by, 104
Turbines, 84, 153-155, 237-241
  alpha-quartz in, 154
  chalcedony in, 154
INDEX

cleaning of, 84, 153-155

copper deposits in, 84, 154

cristobalite in, 154

nepheline in, 153

noselite in, 153

siliceous deposits in, 153-154, 237

effect of, on efficiency of, 153

effect of temperature on formation of, 154

sodium silicate in, 154, 237

throttle valve seats in, deposits on, 154

washings of, 155, 237-241

analysis of, 237-241

determination of chloride in, 238-239

determination of silica in, 240-241

determination of sulfate in, 155, 239-240

Waterwalls, 2, 4, 135, 142, 220

plugging of, 2, 135, 220

by oil, 4, 135, 220

removing tubes from, 142

Wetting agents, 37, 38, 40, 71-72, 98, 160, 172, 174, 217

alkylphenol-ethylene oxide as, 71

anionic, 72, 76

cationic, 37

dodecylphenoxybenzenedisulfonic acid as, 72

effective concentrations of, 72

nonionic, 37, 38, 40, 98, 172, 174, 217

nonylphenoxypolyoxyethylene ethanol as, 71

oil-soluble, 71

to improve effectiveness of solvents, 71

to remove oil and grease, 71, 160

use of, in removing slag, 98, 217

water-soluble, 71

Xonotlite, 3, 5

formula of, 3, 5

X-ray diffraction, 216

X-ray fluorescence analysis, 216

Vanadium pentoxide, 12-13

Vapor-phase degreasing, 88-89, 91, 206-207

of columns, 206-207

Vapor phase inhibitors, 70

Ultrasonic inspection, 118

U-tubes, 163, 184-185

cleaning of, in heat exchangers, 163

water-jetting of, 184-185

Waterwall headers, 2, 4, 135, 136, 164, 220

blowdown of, 136

plugging of, 2, 135, 164, 220

by oil, 4, 135, 220

Zinc, 34, 44, 60, 92

dissolution of, by carbon tetrachloride, 92

effect of alkalis on, 34, 60

effect of hydrochloric acid on, 44, 60

in copper alloys, 60

Zinc hydroxide, 111, 229

effect of ammonium ion on solubility of, 229

solubility product of, 111