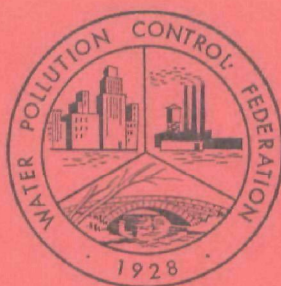


**WPCF Manual of Practice No. 17**



# **Paints and Protective Coatings for Wastewater Treatment Facilities**

**Prepared Under Direction**

**of the**

**Technical Practice Committee**

**by the**

**Subcommittee on Paints and Protective Coatings**

**1969**

**Water Pollution Control Federation**

**3900 Wisconsin Avenue**

**Washington, D. C. 20016 U. S. A.**

# MANUALS OF WATER POLLUTION CONTROL PRACTICE

The Committee on Sewage and Industrial Wastes Practice, now the Technical Practice Committee, was created by the Board of Control of the Water Pollution Control Federation (formerly Federation of Sewage and Industrial Wastes Associations) on October 11, 1941.

A primary function of the committee is to originate and produce, through competent subcommittees, special reports dealing with important technical aspects of the broad interests of the Federation (see inside back cover)

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# Paints and Protective Coatings for Wastewater Treatment Facilities

MANUAL OF PRACTICE NO. 17

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Prepared Under Direction

*of the*

TECHNICAL PRACTICE COMMITTEE

*By the*

SUBCOMMITTEE ON PAINTS AND PROTECTIVE COATINGS

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## Preface

In 1946 the Board of Control of the Water Pollution Control Federation, then the Federation of Sewage Works Associations, approved the establishment of a Subcommittee on Paints and Protective Coatings of the Technical Practice Committee, then the Sewage Works Practice Committee. The Subcommittee was charged with the production of a Manual of Practice intended to provide designers, operators, and maintenance personnel of wastewater collection and treatment facilities with the fundamental theory and practical aspects of the need for, choosing, application, and maintenance of paints and protective coatings.

During the period of preparing the draft of the manual the Subcommittee was chaired successively by Kerwin L. Mick, Maurice L. Robins, and Oral H. Hert. Rapidly changing technol-

ogy contributed to the problem of consolidating the latest information in a manual. Undoubtedly changes will continue but the manual is intended to provide a base to which improved techniques can be added.

The manual was serialized in three installments in the September, October, and November 1967 issues of JOURNAL WATER POLLUTION CONTROL FEDERATION. Reader comment was solicited for a period following completion of the serialization. The Subcommittee was able to take advantage of reader suggestions before the manual was printed in final form.

To the Subcommittee and those who have contributed to its efforts goes appreciation for this contribution to the Federation's manual of practice series.

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# 1. INTRODUCTION AND EXPOSURE CONDITIONS

The installation of treatment facilities for wastewater in the United States has reached large numbers. As of January 1962, there were reported 6,898 municipal facilities of the mechanical type. A 1964 survey indicated the need for 4,749 new treatment works. The number of municipal plants increased by 62 percent during the period 1945-1962. If this rate continues, there may well be 10,000 mechanical-type treatment facilities by 1980.

The present installed replacement value (in 1963 construction cost) of wastewater utilities is estimated at \$40/cap for about 100 million persons, or a total replacement value of approximately \$4 billion. The expenditures from 1963 to 1980 are estimated at \$18 billion to meet backlog and future requirements. Thus, the investment in treatment works by 1980 will approximate \$22 billion.

The above figures apply only to municipal facilities. Industrial treatment works are probably as numerous as municipal works. A tabulation of industrial plants with treatment works in 26 states lists the number at 6,675. The replacement value of these facilities is probably not known, but annual expenditures are estimated at \$600 million for the next 10 yr to meet the new and backlog needs.

If the replacement value of industrial works was estimated conservatively at one-half the value of municipal works, the total replacement value of all existing wastewater treatment works in the United States would be at least \$6 billion. By 1980, the investment could be expected to reach \$30 billion.

Based on the figures given above, it

is obvious that plant superintendents are charged with a tremendous investment of public and private funds. It, therefore, is advisable to save and protect this investment from deterioration by a thorough and effective maintenance program. An important part of such a program involves the use of paints and protective coatings to safeguard equipment and materials against the corrosive and otherwise deteriorating environment common to all wastewater treatment works. Paints and coatings not only prevent deterioration, but they also preserve plant efficiency and, in addition, enhance the appearance of the facility.

The subject of corrosion and protective coatings is very broad and relatively complicated. The wide variety of products and the voluminous literature and reference material which is available seriously taxes the time of a busy plant superintendent to keep abreast of the field. It is the purpose of this manual, therefore, to provide information to enable operators to become familiar with the many phases involved. These phases include the exposure conditions, the types of corrosive action, the prevention of corrosion, the action of destructive agents on metals and paint films, factors affecting the choice of metals and protective coatings, preparation of surfaces for painting, selection of paints, types of use and conditions, method of application, and miscellaneous factors of importance such as painting records, color dynamics, and paint for pipe identification.

This manual is not intended to obviate seeking counsel from qualified consultants and from the manufacturers of the products.

## 1.1 EXPOSURE CONDITIONS

Equipment and materials in a treatment works are exposed to different kinds of deteriorating conditions depending on the particular function involved and the nature of the climate. These exposures may be classified as follows. There are sub-classifications of most of these general classifications as will be indicated in the discussion.

### 1.11 Submerged Exposures

Submerged exposures are characterized by the following conditions which deteriorate protective coatings:

- (a) Water is normally present.
- (b) Oxygen is present in solution.
- (c) Water line exposure is most severe.
- (d) Oils, greases, and soaps are present.
- (e) Hydrogen sulfide is present in certain places.
- (f) Carbon dioxide usually is present.
- (g) Floating material usually is present.

**1.111 Waterline Conditions:**—These conditions involve most of the agents mentioned above and are found in structures, chambers, and flumes containing or transporting wastewater. The concentration of these agents in various treatment units depends on the stage of the treatment.

Obviously, water is present in all submerged and waterline conditions. This agent is destructive because it acts as an electrolyte, in the presence of certain salts, to corrode metal whenever it penetrates a protective film. Water also hydrolyzes many paint vehicles so that they lose their strength, their bond to the metal, and their resistance to the passage of oxygen and acid-forming gases which may be present in solution. These gases are also prime agents of corrosion.

A feature peculiar to most waterline exposures is the presence of oils,

greases, and soaps in the wastewater. While these substances tend to coat the wetted surface below the waterline and to an extent protect this surface by preventing the easy passage of oxygen and acids, their most obvious characteristic is, nevertheless, to congeal on tank and sewer walls at the waterline in a heavy, black, cheesy crust. Since the constituents of this crust are solvents of many paints, the crust tends to soften the paint wherever there is contact. The paint thus becomes more susceptible to abrasive damage by floating debris and cleaning operations.

Another characteristic of submerged exposures largely confined to the waterline, is the physical stress of the paint film caused by wetting-and-drying, the heating-and-cooling effect in warm weather, and the freezing-and-thawing of moisture in and on the paint film in winter. The action of these reversing forces is highly destructive.

Ice may form on the surface of trickling filters in cold climates, but rarely is it formed elsewhere in waterline conditions. An exception may be found where extreme low temperatures are sustained. In this case, proper design through insulation and auxiliary heat will eliminate a large percentage of the freezing locations and associated problems. Ice, when formed, will grip paint on side walls and appurtenances. When the ice falls away, the paint may pull with it, especially if the paint or bond has been weakened by the actions described above.

Sunlight also may be a deteriorating factor in waterline attack. Sunlight tends to age organic films causing them to lose their effective life.

**1.112 Submergence in Raw Wastewater:**—In this exposure the paint is submerged in raw wastewater or in wastewater receiving only preliminary treatment.

Here, the water often is devoid of oxygen or nearly so. There may be dissolved salts present but these, for the most part, are harmless. They may even be of benefit by neutralizing strong mineral acids. Carbon dioxide and hydrogen sulfide are nearly always present, the amount depending largely on the freshness of the wastewater. If there is any agitation of the wastewater so that it takes up oxygen, a part of the hydrogen sulfide will be converted to sulfurous and sulfuric acids, but these acids will be neutralized promptly by the carbonates in the wastewater. The effect of the hydrogen sulfide on paints will be discussed later.

Ammonia may be a minor constituent of wastewater at this point, but it, too, is likely to be neutralized by the mineral acids present. Greases, oils, and soaps are usually in abundance and sometimes gasoline is present. The effect of these solvents already has been discussed. Grit and floating debris vary in amount according to the incidence of storms and the time elapsed since the heavy flow in the sewer began. The amount also varies with the time of year, the type of contributing industries, and with the amount of screening and settling provided. Ice may be a problem in this exposure in cold climates.

In industrial communities, raw wastewater may contain strong alkalies or strong mineral acids. The alkalies are particularly damaging to oil paints while the acids attack exposed steel and concrete wherever they are not neutralized.

**1.113 Submergence in Aerated or Chlorinated Wastewater:**—This type of exposure occurs in aeration tanks and in the settling and chlorine contact tanks which follow these oxidizing processes. An additional exposure is found where an aerated effluent is chlorinated and stored in a supply tank for use about the treatment facility.

A large amount of carbon dioxide is in solution which characterizes this exposure. Greases, oils, and soaps are present. Ice may more likely be present in the settling and contact tanks since heat in the wastewater has been lost by the earlier processes.

While this exposure is moderately severe on paints, the condition in aeration tanks is less severe on steel as long as the steel remains completely submerged. Steel takes on a glassy iron oxide film which is tight and fairly protective so long as it is not exposed to the atmosphere. When the tank is emptied, however, and exposed to the weather, the oxide coating quickly comes loose and corrosion then may proceed at a rapid rate.

The exposure in aeration tanks is destructive to metallic zinc coatings. This is due apparently to a high content of carbon dioxide in solution resulting from the biologic digestion of the carbonaceous matter. Another factor in this destruction may be the high oxygen content in the liquid.

### 1.12 Moist Atmosphere Exposures

Moist atmosphere exposures contain the following undesirable agents or conditions:

- (a) Moisture and oxygen.
- (b) Hydrogen sulfide.
- (c) Carbon dioxide.
- (d) Sulphur dioxide (occasionally).
- (e) Carbonic acid.
- (f) Sulphur acids.
- (g) Wetting-and-drying, heating-and-cooling, freezing-and-thawing.

Moist atmosphere exposures occur inside buildings, manholes, screen chambers, wet wells, grit chambers, and closed water tanks or wherever wastewater surfaces are exposed in an enclosed area. Under such conditions, moisture tends to condense in a film on cold surfaces such as windows, doors, handrails, structural members, blowers, pumps, electrical equipment,



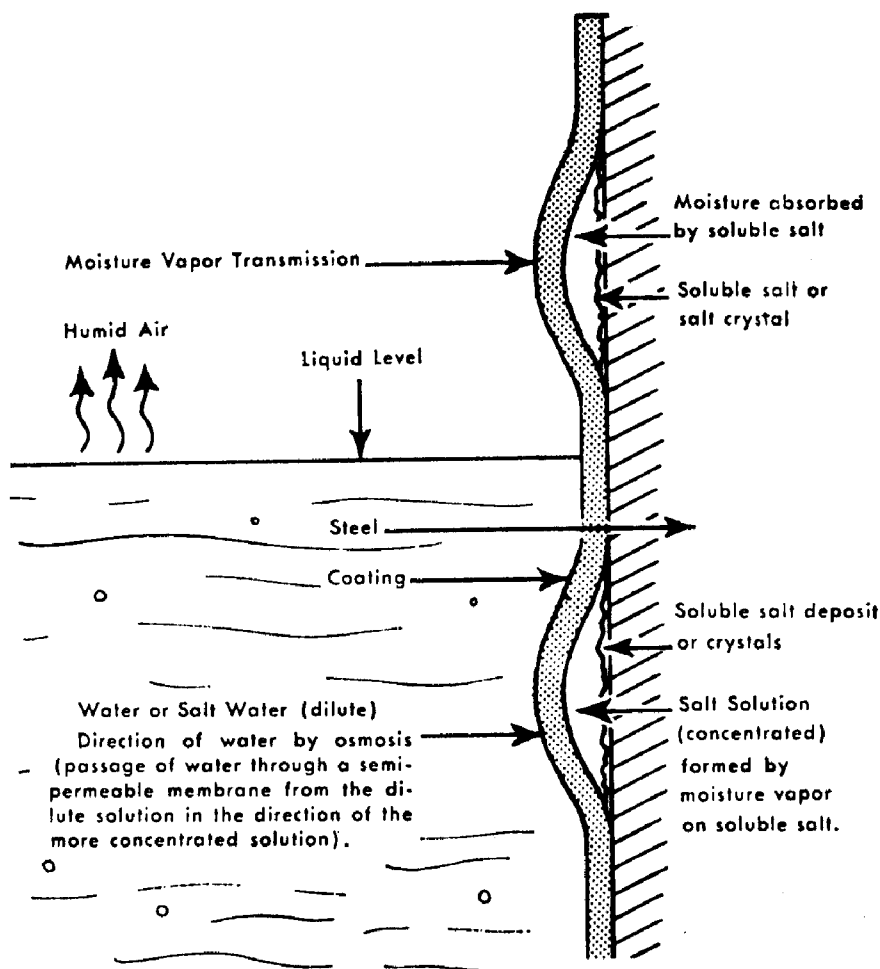


FIGURE 1.—Diagram of mechanism by which blisters are formed due to moisture vapor transmission and osmosis. (Courtesy Amercoat Corp.)

pipes, ducts, conduits, etc., as well as concrete, brick, and plaster. This film of moisture takes up oxygen and other gases such as carbon dioxide and hydrogen sulfide if they are present.

Experience has shown that hydrogen sulfide passes through many paint films. When it reaches steel, it attacks the metal to form black iron sulfide. This reaction not only destroys the surface to which the paint is bonded, but it also frees hydrogen gas which collects in blisters beneath the film. The loss of the bond and the formation of these blisters make the paint more susceptible to abrasion damage.

Moisture sometimes also penetrates the paint film along with the hydrogen

sulfide in which case the steel becomes coated with a black slime instead of the black iron sulfide. The presence of this black slime is evidence that the paint is not well suited to the surface.

Some of the hydrogen sulfide in the moisture film on painted surfaces, instead of penetrating the paint directly, is oxidized on the surface to sulfurous and sulfuric acids. These acids are actively corrosive of both steel and concrete. Along with carbonic acid and oxygen, which are also in solution in the moisture, these aggressive agents spread out over the painted surface, pass through it wherever pinholes, skips, or abraided spots occur, and vigorously attack the metal or cement



FIGURE 2.—Corrosion by oxidized  $H_2S$ . (Courtesy Amercoat Corp.)

beneath. The attack tends to spread laterally underneath the paint film so that the damage is extended widely.

An important factor in these exposures is the physical effect brought about by frequent changes in dimension in the paint film induced by reversing stresses. Such changes in dimension are brought about by wetting and drying of the paint film, by heating and cooling of the paint and metal on which it is placed, and in cold climates, by freezing and thawing of the moisture in and on the paint film.

This movement tends to thin the paint over rivets, bolt heads, and nuts and over the sharp edges of plates and shapes until tension breaks the film. It also tends to pull the film away from the metal at these points until the unsupported film breaks. Movement also

tends to crystallize the vehicle so that the paint becomes increasingly brittle and more subject to the cracking. When the film is no longer intact, it ceases to protect the surface.

Moist atmosphere exposures where sewage gas also is present is perhaps the most destructive to paint films and structures of all exposures generally encountered in a treatment works.

**1.121 Exposure Above Raw Wastewater:**—This type of exposure occurs in wet wells, in enclosed screen and grit chambers, in manholes, and wherever wastewater is allowed to come in direct contact with air confined in an enclosed space.

A particularly severe exposure occurs where a tall screen house with ventilators in the roof is built over a

deep screen pit into which sewers are running partly full. Here the tall building acts as a chimney to draw warm, wet air heavily laden with sewer gas from the sewer. When metal parts and the walls of the housing structure and its equipment become cold, moisture condenses on them. This moisture takes up oxygen and sewer gas to do damage as described previously. In addition, cold outside air tends to mix with warm inside air so that the screen chamber or wet well may be filled with a corrosive fog. The result is that at certain seasons of the year the paint remains saturated over long periods of time and the damage is thereby extended. Windows and doors in these structures suffer most because the wetting-and-drying, heating-and-cooling, and freezing-and-thawing processes are much more frequent on these surfaces than elsewhere.

This particular exposure, besides damaging painted surfaces, makes repainting difficult because the excessive moisture prevents effective drying of the surfaces prior to painting.

**1.122 Exposure Above Aerated Plant Effluent:**—This type of exposure occurs most often where the aerated plant effluent is chlorinated and stored in a tank for various uses about the wastewater facility. The condition is similar to other moist atmosphere conditions except that traces of free chlorine gas may be present which combines with the moisture to become highly aggressive on metal.

### 1.13 Inside Dry Atmosphere Exposures

Inside dry atmosphere exposures are characterized by the following conditions:

- (a) Little moisture present.
- (b) Oxygen is present.
- (c) Hydrogen sulfide in sufficient concentrations to discolor certain paints.

- (d) Sulphur dioxide only slightly present.

This exposure occurs in offices, laboratories, pump and blower rooms, workshops, store rooms, and the like. Conditions are not as severe as in other exposures about a plant. Metal and other deteriorating surfaces should be protected against the effects of hydrogen sulfide, however. Regardless of corrosive conditions, interiors will no doubt be painted for appearances sake if for no other reason. A well-painted interior is the best assurance of a tidy plant from the housekeeping point of view.

### 1.14 Outside Weather Exposures

These exposures are probably the most variable of all exposures around a treatment plant. They include the following deteriorating agents or conditions:

- (a) Actinic light and radiant heat (sunlight).
- (b) Hydrogen sulfide.
- (c) Sulphur dioxide.
- (d) Carbon dioxide.
- (e) Salt air.
- (f) Abrasion by windblown sand, etc.
- (g) Wetting-and-drying, heating-and-cooling, freezing-and-thawing.

This type of exposure occurs on the exteriors of treatment plant structures and buildings, fences, guard rails, unloading docks, etc.

The exposure is not radically different from that experienced outside on any other building in the same region, except that the presence of sewer gas complicates the problem. As the sewer gas usually is small in amount, its effect on the durability may be of little importance. Its effect on the surface appearance, however, may be considerable since it discolors many pigments which may be present in the paint.

Ordinary outside exposures about a treatment plant are characterized by the effect of sunlight, humidity, temperature and temperature variation, dust and sand blowing, and discoloration by sewer gas.

Rays from the sun greatly stimulate oxidation of oil paints so that they age rapidly. The aging is evidenced by a chalking of the surface and sometimes by a checking and cracking of the paint film. Paints that chalk appear to fade due to a change in the diffusion of light brought about by the presence of the oxidation powder on the surface.

Checking and cracking are evidence that chemical combinations are taking place which reduce the paint volume so that the paint fails by tension.

Coal tar paints "alligator" due to oxidation and polymerization of the top surface and elimination of the more volatile parts of the tar which causes a reduction of the paint volume and a drawing together of the remaining constituents. Sunlight increases the rate of this action.

Moisture and sunlight together may cause certain soluble compounds like acetic acid to be formed. For that reason, the humidity of the climate often governs the type of paint which is best suited to a given location.

The physical effects of wetting-and-drying, heating-and-cooling, and freezing-and-thawing are important in outside exposure. For example, the formation of dew at night and its drying out in daytime is one of the reasons for the destructive nature of the Florida climate.

Another factor affecting paint life in an outside exposure is the wear sustained from blowing dust, dirt, sand, and rain. This wear accelerates the damage done by sunlight and other agents because it cleans the surface of accumulations of decay so that new surfaces are presented for active agents to work on.

In addition to damage done to the

paint, sunlight also affects the color of certain pigments. For instance, it fades prussian blue and causes certain grades of lithopone to darken.

Certain pigments are much affected by the presence of sulfur gases from an industrial region or from sewers. These sulfur gases darken paints in which lead compounds such as white lead, lead chromate, or chrome green are used. In fact, most all lead pigments are unsuited to decorative coats where these gases are strong. Yellow ochre and ferrite yellow (which are iron hydrates) also are darkened by these gases. Cadmium yellow is turned white by the carbonic acid gas of sewers. There is probably no yellow pigment available which is entirely satisfactory for use about a treatment plant.

Because of the discoloring effect of sewer gas and sunlight, careful consideration always should be given to the final aesthetic result to be obtained from top coats and the coloring selected.

### 1.15 Miscellaneous Exposures

In the treatment plant, there are many different types of apparatus and appurtenances, and therefore many different problems of maintenance. Often these problems are associated with the type of surface rather than environmental conditions as previously discussed.

Although these exposures are discussed in more detail in later chapters, it may be pertinent to list some of them on which protective coatings are indicated:

- (a) Pumps, blowers, turbines, and motors.
- (b) Heat insulation.
- (c) Plaster, brick, and concrete.
- (d) Floors.
- (e) Radiators and bare steam pipe.
- (f) Boilers, piping, and controls.
- (g) Bearing and rubbing surfaces.

- (h) Heating coils and other metal surfaces in separate sludge digestion tanks.
- (i) Laboratory facilities.

In extreme sustained low temperature areas, the treatment plant may be enclosed entirely except for sludge storage or drying. This method of design will cause additional problems of maintenance. The air will be saturated, in most cases, and condensation

will take place making the use of specially designed coating and methods of application necessary. Proper design and selection of materials is essential in this type of construction, as well as special means of ventilation or control of humid air. In Fairbanks, Alaska, the aeration chamber is housed in a glass enclosure within the main structure which encloses the entire plant.

## 1.2 SUMMARY

Superintendents and operators of wastewater treatment plants in the United States are charged with responsibility for maintaining equipment, materials, and structures valued in the billions of dollars. Part of this maintenance involves the preservation of surfaces subject to deterioration by the corrosive and otherwise hostile nature of the environment.

Three general classifications of exposures are of most serious concern, namely, submergence or partial submergence, moist inside atmosphere, and outside atmosphere.

Water, oxygen, and hydrogen sulfide are the most common elements responsible for deterioration of surfaces with steel surfaces being most susceptible.

## 2. THE NATURE OF CORROSIVE ACTION

Corrosion is the unmaking of metals or the process by which they tend to revert back to the more chemically stable forms of the ores from which

they were derived. These processes can be either direct chemical reactions, electrochemical reactions, or a combination of both. Corrosion in all of its

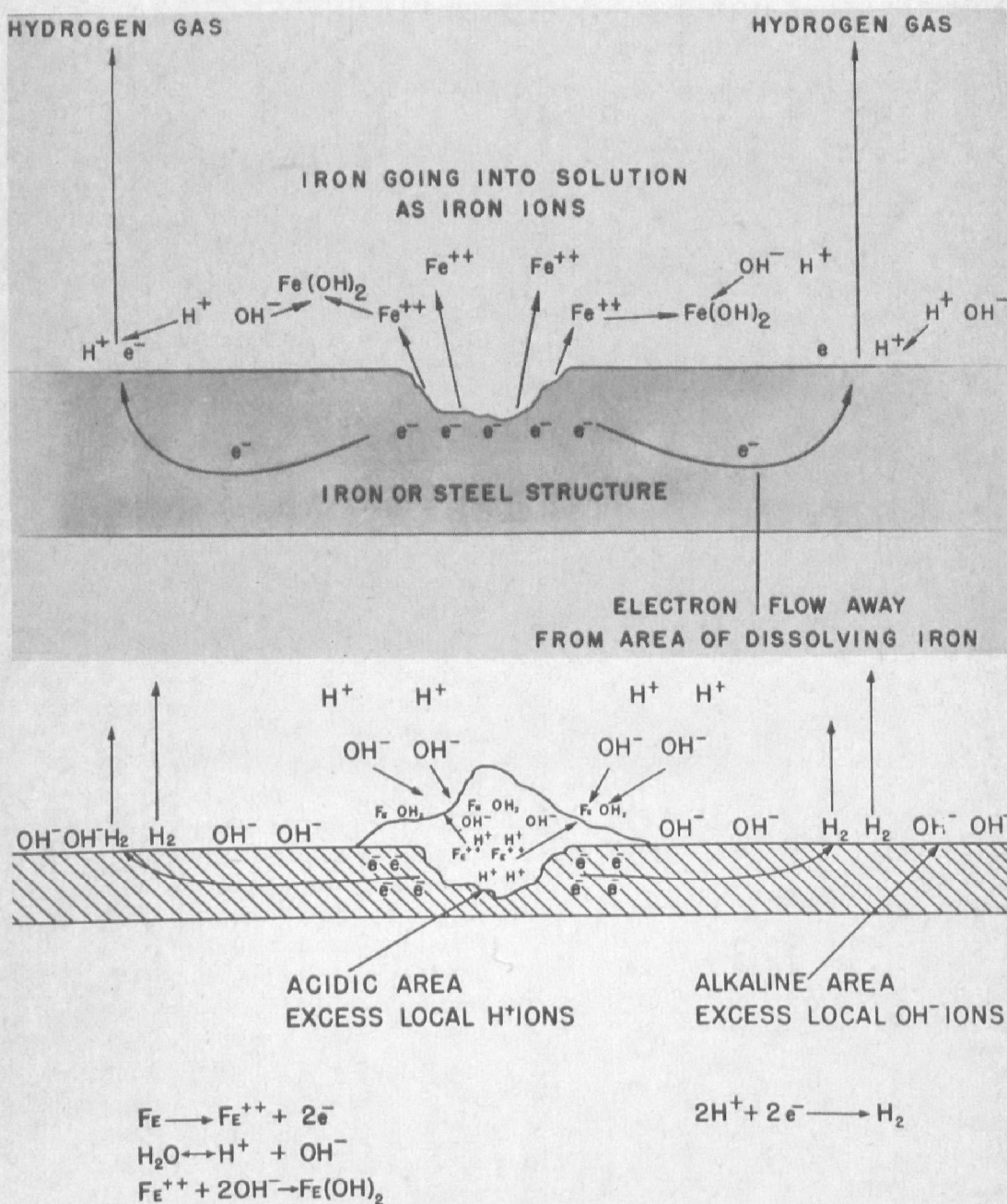


FIGURE 3.—Top: Conventional diagram of the corrosion process. Bottom: Corrosion process showing formation of acidic anode and alkaline cathodic areas. (Courtesy Amercoat Corp.)



many manifestations falls within these three categories and is not necessarily a steady-state condition either as to rate or type of reaction. In many cases the exact nature of the type of reaction is debatable and distinction is largely theoretical.

The term "corrosion" applies only to metals and not to the deterioration

of concrete, wood, plastic, or other materials of construction found in a treatment plant. Likewise, the term does not apply to deterioration by such physical causes as wear, erosion, vibration, or stress but corrosion may accompany these physical phenomenon in the form of a chemical change.

## 2.1 DIRECT CHEMICAL CORROSION

The most easily understood general type of corrosion is the direct chemical union of a metal with one or more of the components in its environment.

### 2.11 Oxidation

The most familiar form of corrosion is the oxidation of ferrous metals in the presence of "free" oxygen which forms rust ( $\text{Fe}_2\text{O}_3$ ). The rusting of iron takes place in the atmosphere, when buried in the earth, or when submerged in water or most any common environment so long as moisture and "free" oxygen are present and in direct contact with the metal. Under high temperatures such as in welding or heat treating iron or steel, a black oxide ( $\text{Fe}_3\text{O}_4$ ) is formed which is commonly known as "mill scale." Heat and the lack of free oxygen account for the difference in the type of oxide formed.

Oxidation is not just a union of *metallic atoms with oxygen atoms*, but rather an exchange of electrons. An iron oxide crystal ( $\text{Fe}_2\text{O}_3$ ) is not just a group of iron and oxygen atoms arranged on a lattice but actually two iron ions (iron atoms with three electrons missing on each) connected to three oxygen ions (oxygen atoms with two extra electrons each). Since the six extra oxygen electrons have been given up to replace the six missing electrons, the oxygen is now electrically neutral and takes on something of the structure and stability of an inert gas. Since the oxide molecule thus formed also has a neutral charge or potential,

it is more stable and reluctant to react than the metal. The buildup of these neutral ions on the surface of a metal reduces the reaction rate as it gets thicker by acting as insulation between the metal and the active elements in its environment. However, if these, or other, active elements in the environment are reactive enough to react with the oxides to form sulfates, chlorides, or some other chemical compound capable of conducting an electrical current, or if they are capable of dissolving the oxide, then the reaction rate may become accelerated. Those metals whose oxides have the most compact structure provide the most effective barriers. The oxides of chromium, aluminum, and nickel, for example, will form an effective barrier to further corrosion under normal conditions while still of microscopic thickness.

Since the oxide coating is less reactive than the metal underneath, it becomes the cathode (passive element) with a negative potential and the metal becomes the anode (reactive element) with a positive potential. In the event that this oxide coating is porous or becomes scratched or eroded away, individual galvanic cells are set up between the coated areas and the exposed areas and the reaction rate actually is accelerated until the exposed areas are "self-healed" or the availability of oxygen is reduced. If the rate of erosion or oxide reduction equals or exceeds the rate of oxide formation then the corrosion rate remains more or less constant unless some of the



other factors affecting the corrosion rate are altered.

In the case of anhydrous oxidation (wet corrosion) the presence of water is required and hydroxides may form instead of anhydrous oxides. The hydroxides generally react later to become oxides, sulfates or, if acidified, may revert back to the metallic ion and water.

Another condition that frequently occurs to pipes or metal structures buried in the earth is the formation of "oxygen cells" caused by variations in the amount of available oxygen ions in the soil at different points. This results in lower potentials where the oxides are formed readily and higher potentials where restricted thus creating galvanic cells and the transfer of metallic ions from the area where the oxide coating is deficient.

## 2.12 Hydrogenation

When a metal is immersed in non-aerated water or a non-oxidizing acid, some of the water is reduced to separate  $H^-$  and  $OH^-$  ions which then are free to react with the metal as well as the  $H$  ions of acid in the environment. Under conditions of stress, high temperatures, or high pressures, hydrogen penetrates the lattice structure of the metal and reacts with its internal structure. This changes its physical properties which results in a loss of ductility and the creation of internal pressures. This loss of ductility is called "hydrogen embrittlement." In the case of cast iron and high strength steels, the internal pressures may cause splitting (hydrogen cracking) and, in more malleable metals, the results are surface blistering.

As in oxidation most of the reactions that occur between the hydrogen and the metal are single or multi-step ionic exchanges that rightfully could be called electrochemical reactions rather than direct chemical actions. Students of electro-chemistry refuse to acknowl-

edge the term "direct chemical action" and the evidence evolved in the study of the processes involved in the oxidation and hydrogenation of a metal provide strong proof for their theories.

Increasing the temperature, roughening of the surface, working the metal, or the presence of an internal stress in a metal tend to separate the metals "structural boundaries" or grain, thus allowing the hydrogen to penetrate the metal more readily and attack the exposed faces in the interior of the metal. As the ions build up on these interior surfaces, they slowly join to form molecules of free hydrogen which then are unable to escape and the internal pressures result. Proof of this theory lies largely in the fact that free hydrogen is found in the blisters of the more ductile metals.

## 2.13 Chlorination and Other Direct Chemical Reactions

Because of the diversified nature of wastewater in different sections of the country the types and concentrations of chemicals vary considerably. Normally the concentration of any particular corrosive chemical will not reach concernable proportions at the disposal plants because of dilution and reaction with other materials in the wastewater collection system. In coastal areas and in areas where oil field brine wastes are discharged into the sewer, the concentration of sodium chloride and other chlorides may become a serious problem.

The dissolution of the cement in concrete lines and structures and the subsequent erosion of the aggregate leaves the reinforcing steel exposed to attack from these salts which react directly with the iron to form ferric or ferrous chlorides. These immediately dissolve and leave the metal exposed to continuous attack. Where splashing occurs above the water surface, this condition is further accelerated by concentration of the salts due to evaporation and oxidation by atmospheric oxygen.

The organic acids found in wastewater, and especially in sludge supernatant liquor, are very corrosive. Since they are generally the product of bacterial decomposition, they will be dealt with under the heading of bacteriological corrosion.

The two gases  $H_2S$  and  $SO_2$ , both in their gaseous state and after they have reacted with water and oxygen to form  $H_2SO_4$ , are perhaps the most serious corrosive problem encountered around the average wastewater treatment plant. In those areas where the water supply contains sulfates the formation of  $H_2S$  is usually the result of the sulfate-reducing bacteria (*sporovibrio desulfuricans*) and also is covered under bacteriological corrosion. Some water sources, however, contain free  $SO_2$  which may remain in trace amounts in the wastewater. Possibly the most serious problem lies in the combustion of digester gas. The  $H_2S$  in the gas reacts with oxygen to form  $H_2SO_4$  in the burner or engine and a direct chemical action takes place when the hydrogen ions in the acid replace the metallic ions in any exposed metal with which they come in contact. That which fails to react during combustion enters the atmosphere with the other stack gases and

attacks adjacent exposed surfaces in the form of sulfuric acid.

The  $CO_2$  in the digester gas may possibly be considered to be beneficial since it usually leaves the stack unchanged. It then may react with water vapor to form  $HCO_3$  which reacts slowly with metals to form protective coatings in the form of carbonates. This may contribute to the passivity of the metal as well as serving as a cathodic coating to react with any sulfuric acid vapors that also contact the surface.

In coastal areas the sodium chloride in solution in atmospheric vapor is more damaging than the water vapor and may extend several miles inland. In industrial areas, dew can be very corrosive due to the absorbed stack gases from the atmosphere and the chemical salt content of the dust deposited on exposed surfaces. The addition of moisture to the dust also creates an electrolyte that can support galvanic corrosion. Dew is more corrosive than rain because the dust and corrosion products are not flushed away.

Besides being a fire hazard, free methane from digester gases breaks down in the heat of an electrical arc and leaves free carbon deposits on electrical contacts.

## 2.2 BACTERIOLOGICAL CORROSION

Perhaps the most complicated and unique forms of corrosion are the result of bacterial action either directly or indirectly. While most of these bacteria are anaerobic there are some that are aerobic. Those commonly found in sewers are generally of both types. The sulfate-reducing bacteria are anaerobic and may be found in wastewater or in the soil. While they are tolerant to a fairly wide range of temperature, they are most active between  $80^\circ$  and  $100^\circ F$  ( $26.6^\circ$  and  $37.8^\circ C$ ) and at least one species found in the soil is able to survive temperatures in excess of  $130^\circ F$  ( $54.5^\circ C$ ).

These bacteria do not attack the metal itself but reduce the protective sulfate coating on the metal and leave it vulnerable to attack from the  $H_2SO_4$  that results from oxidation of the  $H_2S$  usually produced in the sulfate-reduction process. A second type of bacteria lives in the moist slimes above the water surface and oxidizes the  $H_2S$  in the atmosphere. The concentration of  $H_2SO_4$  in these slimes has been measured as high as 10 percent.

Still other types attack and destroy asphaltic protective coatings that are resistant to normal chemical attack. A wide variety of bacteria is involved

in the process of digesting wastewater sludge and the enzymes formed are organic acids that are corrosive to metals and most organic and inorganic protective coatings. Like the sulfate-splitting bacteria they are non-tolerant to high pH although they will survive a wide temperature range as long as an abundance of moisture is present.

In addition to the direct chemical action of these bacteria and their enzymes, an equally serious problem results from the formation of galvanic cells due to the differences in pH and salt content throughout the liquid which serves as an electrolyte. The

liquid or slime in the immediate area of each colony of bacteria, having a lower pH and lower potential becomes a cathode and the adjacent metal becomes anodic with corrosion appearing at that point.

As well as the sulfate-reducing and sulfur-oxidizing bacteria, there are other specific types that reduce nitrates to form ammonia and hydrogenate  $\text{CO}_2$  to form methane.

While this study deals only with the corrosion of metals, the damage done to concrete pipe and structures is an equally serious problem to treatment plant maintenance.

## 2.3 FATIGUE CORROSION

Any ductile metal has a relative limit to the number of times it can be bent or otherwise stressed in a non-corrosive environment. When similar stresses are placed on the same metal in a corrosive environment the number of times is reduced greatly before failure occurs. The process by which the work limit is reduced is called "corrosion fatigue" or "fatigue corrosion." The actual corrosion may be oxidation, hydrogenation, direct chemical, or a galvanic action due to the heat and stresses generated within the metal.

In the first three instances, the acceleration is brought about by the dis-

tortion of the grain boundaries which tends to separate them and permits the penetration of the corrosive element to the interior of the metal. The slippage of the grain boundaries also exposes more surface on the metal faces and helps to erode the protective corrosion products that would otherwise tend to retard the rate of corrosion. The friction of this movement generates heat within the metal (which accelerates most chemical reactions) and produces slight electrical currents and differential pressures within the metal which are conducive to the formation of galvanic cells with subsequent corrosion at the anodes.

## 2.4 STRESS CORROSION

Stress corrosion is similar to "fatigue corrosion" in the manner in which the corrosive action actually takes place, but without the actual working of the metal while the corrosion is taking place. The stress is generally pre-applied and may be the result of temperature (in unannealed metals) or strains occurred by working. In a non-corrosive element these internal stresses may go undetected for months or years, only to show up in a matter of minutes or hours after being placed in a corrosive environment.

Cracking or splitting are the usual signs of failure. In general, temperature appears to have relatively little affect on this type of corrosion, nor does the period of time that lapses between the incurrence of the stress and the time when it is emersed in the corrosive element.

The straining of metal also produces electrical energy which polarizes the metal and increases its "attraction" to oxygen and other corrosive elements. The electrical energy remaining in stressed metal can alter its polarity

so that an otherwise "passive" metal becomes active and remains so until the energy is discharged.

Corrosion generally starts at points

of structural disarrangement or stress. Unannealed metal in the vicinity of welds is a very common example of this phenomenon.

## 2.5 FRETTING CORROSION

Fretting corrosion is a type of corrosion-erosion. It is a combination of wear and the oxidation or other chemical reduction of the wear products and the freshly exposed interfaces of the metal. While vibration is the most common instigator of this type of corrosion, the action of the flights along the rails in the bottom of a clarifier also typify this type of action. In this case the wearing action of the metal

"shoes" is complemented by the grit included in the sludge and the chemical reduction is accomplished by the many corrosive agents present in the wastewater.

Heat is not a necessary factor in this type of corrosion although high temperatures can accelerate the chemical action and, in some cases, even prevent the formation or buildup of protective corrosion products.

## 2.6 CAVITATION EROSION

While this type of corrosion is generally found on pump impellers and boat propellers it also can occur on venturi tubes and jets or nozzles where high liquid velocities and sudden violent reductions of fluid pressures exist. A severe pitting of the surface may develop in these areas even though the liquid is of an otherwise non-corrosive nature.

Several theories have been evolved to explain this phenomenon. Some of the most popular are as follows:

1. The sudden violent changes in fluid pressure cause unit distortion of the surface which assists in the penetration of oxygen or hydrogen into the metals lattice structure during moments of high pressure. Molecules of

the gas combine and literally explode during moments of reduced pressure to blow off sections of the surface of atomic thickness.

2. The penetration of the metals lattice structure in the above explained manner results in the oxidation or hydrogenation of the metal and the subsequent erosion of the corrosion products by the velocity of the liquid.

3. The formation of galvanic cells in the metal as a result of the differential pressures in the liquid with the subsequent transfer of metallic ions from the anodic area. Once pitting has started, a further reduction in pressure occurs in these areas, thus accounting for the localized nature of the corrosion.

## 2.7 FILIFORM CORROSION

Whenever a metallic surface is coated with an organic coating there is a possibility of "filiform corrosion." This is caused by pin-point penetration of moisture through the coating at numerous points. By a combined chemical and electrochemical process the corrosion progresses laterally in narrow lines resembling filaments be-

neath the coating. The process is perpetuated by the infiltration of oxygen through the coating and continues as long as any moisture remains in the "head" of the filament.

These filaments never cross each other nor themselves because the polarity in the corrosion products remains the same as that in the periphery

of the "head" of the filaments and like poles repel each other. The actual reaction in the "head" of the filament is galvanic and a groove is left in the

metal where the metallic ions were displaced during the interval that point was acting as the anode in the center of the head.

## 2.8 ELECTROCHEMICAL CORROSION

While it may be debatable as to whether the previous types of corrosion rightfully should be termed electrochemical processes, there is little argument regarding the following types. Here the reaction is galvanic and involves the formation of cells having different electrical potentials. This induces the flow of ions between potentials resulting in the disintegration of the anode. The formation of these cells may involve two or more metals, different physical properties within the same metal, or different physical properties within the electrolyte. These essentials play a vital role in the rate at which the electrical current is generated and passes from the anode to the cathode. It is not only the conductivity of the electrolyte that affects the rate of corrosion but also its pH, temperature, velocity, and chemical composition. These factors determine what corrosion products will be formed and whether or not they will be dissolved or eroded away. They also may remain as a protective coating or increase the passivity of the anode. Thus, the process can be either continuous, accelerated, or retarded. In an aerated electrolyte the oxygen ions can react with the anode just as the hydrogen ions generally do in an unaerated electrolyte. The electrolyte also may serve only as a catalyst to trigger the reaction.

### 2.81 Bimetallic or Galvanic Corrosion

This type of corrosion involves two or more metals being immersed in an electrolyte. Here again the electrolyte may be an aqueous or non-aqueous solution such as water, earth, or even atmosphere, or gas as long as

moisture is present. The type of cells thus formed are referred to as "dissimilar electrode cells" and the wide range of conditions under which this type of reaction will take place makes it perhaps the most frequently encountered and most difficult to predict and combat.

There are various terms used to describe the tendency of metals to enter into this type of reaction. The terms most commonly used are "electromotive force" (EMF), "fluid pressure," "electrical potential," or just "potential." The metals are listed in the order in which they tend to react: magnesium, aluminum, zinc, chromium, iron, cadmium, nickel, tin, lead, hydrogen, copper, mercury, silver, platinum, and gold.

When any two metals form such a cell, it is the higher one on the list that forms the anode and takes on a negative polarity as a result of the loss of the positively-charged ions. Conversely, the cathode is given a positive charge and an increase in density as a result of its acquisition of the ions.

The rate at which this action takes place is determined by a number of factors which may not be uniform under all conditions. The effect of proximity of the two metals and the conductivity of the electrolyte are constant as is the effect of work or erosion. An increase of temperature can accelerate the process or actually retard it by driving the oxygen from the electrolyte which may result in the formation of more protective corrosion products. Raising or lowering the pH of the electrolyte can have the same effect. In aqueous solutions the rate of corrosion is usually the most rapid at or

just below the water surface due to the availability of oxygen at this point. Not only do steel tanks corrode in this manner on standing while partly filled with water, but also steel-hulled boats are frequently "cut off" at the waterline when they are left anchored for a long period of time without corrosion protection.

The extent of the dissimilarity of two metals need not be great in order to set up a "dissimilar electrode cell." Impurities in the metal are a common cause and even the difference in the composition of the cast iron used in the fabrication of pipe fittings by two different companies frequently is adequate to cause corrosion in buried or submerged piping systems. The use of brass or bronze valves with iron pipe is particularly conducive to this type of action as is the use of galvanized and uncoated pipe. It is not a case of one section being protected and the other unprotected but actually the acceleration of corrosion by the instigation of bimetallic corrosion.

Pipe lines buried in the ground are subject to a number of different types of electrochemical attack as a result of differences in the composition and temperature of its environment. Perhaps the most commonly encountered form is "the concentration cell." This can be due to the difference in the chemical composition of the backfill material around the pipe, the difference in the amount of moisture in the soil, or the difference in salts dissolved in the water in saturated conditions. These are commonly referred to as salt concentration cells and also can affect pipes running through a series of tanks where evaporation, dilution, or a bacteriological or chemical process has created a non-uniform condition in the various sections of the same tank.

An equally common type of concentration cell is the "differential aeration cell" in which case the amount of oxygen or other gases dissolved in

the electrolyte are dissimilar. This results in different potentials being created at various points with the resultant flow of current from those points having the higher "potentials." This type of action is generally "local" and results in pitting.

A third type of concentration cell frequently encountered in pipelines is the "differential temperature cell." This usually is caused by introducing hot liquids into a pipe and the subsequent cooling as it passes through the pipe. It also can be created in shallow or exposed pipelines that pass through shaded and sunny areas. Different potentials are created within the metal and either or both the liquid inside the pipe and the environment outside the pipe can act as electrolytes. Which one is actually serving can be determined by which surface is pitted.

Any of these local types of corrosion can be serious because failure can occur at one point while the remainder of the system is relatively unattacked. When most of a system is protected by cathodic protection, or especially by protective coating, and a relatively small area is exposed, the small area generally becomes anodic and the corrosion rate is accelerated greatly by the dissipation of the current created in the whole system discharging through the small unprotected area. When various conditions such as those listed above, are known in advance of installation of a pipeline, sections of non-conductive pipe are sometimes used to separate these sections and thus disrupt the flow of current.

## 2.82 Parting

When any alloy is immersed in an electrolyte a series of dissimilar electrode cells are formed between the various metallic components of the alloy. In many cases this action is instigated deliberately by selection and quantity of the components in order to cause the formation of corrosion products that will give the metal a

passive or protective coating. Sometimes, however, unexpected results occur when the corrosion products are soluble in the electrolyte or are eroded by the velocity of the electrolyte. In these instances the anode (which is generally the lesser percentage) is removed from the alloy but leaving the cathodic portion intact. The nature of the alloy can result in a number of different forms. When the base metal is ductile the removal of the second metal may create the appearance of a sponge or if the percentage of the metal that was removed was originally small, the only change visible to the naked eye may be discoloration (as in the case of bronze) but a reduction of ductility and strength usually has taken place.

In some cases, the corrosion products tend to coat the outer surface as the corrosion itself penetrates into the alloy. When the dissipation of molecular oxygen or hydrogen is impeded, "layering" occurs. This also may be due to the granular structure of the alloy but in either case the corrosion progresses in planes parallel to the surface and the layers of uncorroded metal literally are lifted off. When these layers are thick the term "spalling" is used to describe the process and when they are thin such as flakes, it is known as "defoliation."

Two specific types of parting have been identified separately because of the frequency with which they are encountered. The first is the removal of zinc from brass leaving the copper in its original form. The zinc constituting a relatively small percentage of the alloy, leaves the copper in its original shape, however, the strength of the copper is reduced greatly by the removal of the zinc. This is known as "dezincification."

The other type of parting, is just the reverse of dezincification in that the metal constituting the major portion is reduced and the trace metal and corrosion products remain in the

original shape. This is called "graphitic corrosion" and occurs when gray cast iron is submerged in a non-oxidizing acid environment. The iron is reduced to the oxide and hydroxide salts as well as some sulfates and chlorides which in turn tend to cement the particles of graphite remaining from the cast iron. Where pressures are slight and no movement occurs, a graphitized pipe may continue to carry the flow for months or even years after the corrosion has been completed. The black coating of graphitic corrosion should not be confused with the soft black coating that frequently is found inside steel or iron pipe that has been carrying wastewater or sludge. In this case the deposit is usually iron sulfide, formed by the reaction of iron with the  $H_2S$  in the liquid being carried.

### 2.83 Electrolysis or Stray Current Corrosion

A type of corrosion that has received a great deal of publicity and causes millions of dollars in damage each year is "electrolysis or stray current electrolysis." This type of corrosion is of little concern to the average wastewater treatment plant. It is caused by a stray or external current of electricity passing through the ground or water in which a metal is submerged. Since the metal is usually a better conductor than the environment, the current enters the metal at a point nearest its source and leaves at a point nearest its destination. At the point where the current leaves the metal (in the form of metallic ions) disintegration takes place. This also is known as the anode, but since the current is from an external source and is virtually "pushed" through the metal the anodes have a positive polarity.

The most common location for this type of electrolysis is in pipelines adjacent to streetcar tracks. A certain amount of current "leaks" from



the tracks and takes the path of least resistance (the pipelines) on its return trip to the powerhouse. This is direct current electricity with high amperage and the corrosion rate could be extremely high. Since electrolysis rarely occurs with alternating current (due to its reciprocating nature) it should be of little concern to wastewater treatment plant operation and

maintenance. About the only place direct current is still used is in the starting and lighting systems of mobile equipment and in electronics devices. Careless operation of a stationary battery charger might conceivably give some trouble but since the two electrodes are so close together it appears unreasonable to suspect an interception of any stray current would be possible.

### 3. FACTORS AFFECTING THE CHOICE OF CORROSION PROTECTION

#### 3.1 GENERAL

The basic consideration in selecting a method of protecting equipment is to obtain the most durable protection for the least amount of money. Resistance to corrosion can be obtained by either selecting materials of construction that resist chemical attack in the required service environment such as stainless steel, copper alloys, aluminum, or plastics, or by applying a protective coating to the material in the form of paint, plating, or galvanizing.

There are several good reasons to pay more initially for a good level of protection:

1. The use of corrosion resistant alloys may be advantageous.
2. If plating or galvanizing is called for, the separate parts must be processed individually. This is not practical after the material has been erected.

3. Surface cleaning and preparation for optimum bond between metal and paint can be done more economically and with better control at the factory.

4. If the surface is not prepared properly, subsequent field painting cannot adhere properly.

The cost of corrosion protection may be resolved into capital cost and maintenance cost, which are interdependent, i.e., the higher the capital cost, the less the maintenance cost. It is not a simple problem to evaluate the relationship between these two costs but several factors to be considered are:

1. The absolute cost;
2. The degree of protection required;
3. Appearance;
4. Ease of repainting;
5. Design; and
6. The cost of painting.

#### 3.2 THE ABSOLUTE COST

This is simply the actual cost of the equipment over its life expectancy. It is the sum of the initial cost and the cost of the maintenance required to keep it in service. The environment in which the equipment is to serve must be evaluated carefully to determine the frequency of repainting required. This will vary from the very mild conditions present in the plant office and maintenance shops where the air is dry and clean to the more difficult conditions present in the pumping stations and screen wells where there is a large

amount of moisture and hydrogen sulfide present.

An extreme case of severe environment is pump impellers. Here the deterioration is the result of both corrosion and erosion. Pumps are selected with great care because their power consumption constitutes an important cost item in the operation of a plant. To maintain their original operating efficiency for a reasonable period of time, the impeller should be of the best material available for this service.

#### 3.3 DEGREE OF PROTECTION REQUIRED

This factor takes into account the importance of keeping the equipment

in service. A good example of this is the protection of mounting bolts for

settling tank weir plates. Failure of these small items would take a major component out of service and drastically reduce the efficiency of the entire plant. Obviously, corrosion re-

sistant alloy bolts are justified. Other items in this category are buried electrical conduit and submerged gas engine cooling piping.

### 3.4 APPEARANCE

Surfaces that are in full view must be maintained in near perfect condition to present an attractive appearance. This will require much greater attention than cases where the structural integrity of the metal is all that

is important. The use of galvanized surfaces, painting, and corrosion resistant alloys may well be justified. The surface should be able to withstand repeated washing with various detergents without deteriorating.

### 3.5 THE EASE OF REPAINTING

In many instances, the surface under consideration may be virtually inaccessible. Good examples of this are the annular space between a tank and the lift of a gas holder and the space between the roof and the bottom of a floating digester cover. The extreme difficulty of repainting these areas greatly increases repainting cost and, therefore, justifies a much higher level of initial protection than would be required for readily accessible surfaces. If the structure is large the use of alloys or galvanizing would be pro-

hibitively expensive. The best choice is to supervise carefully the cleaning, preparation, and painting of the steel surfaces at the factory or during erection so that the best possible chemical bond between the protective coating and the metal surface is achieved. It also is important to select the best paint for the service intended, but this is of little value if improperly applied. The cost of this supervision is, of course, part of the total cost of the equipment.

### 3.6 DESIGN

Steel with sharp edges requires more frequent repainting than smooth surfaces. Equipment can be designed to avoid sharp edges and inaccessible areas. In submerged structures structural shapes should be replaced by tubular members where possible. These tubes should be sealed to prevent corrosion of the interior surfaces.

Conventional protection on gratings for walkways is quite satisfactory for building interiors but is not adequate

in exterior applications, particularly where subjected to hydrogen sulfide and moisture. After corrosion starts, they cannot be protected properly because of the multiplicity of sharp edges and inaccessible corners. Gratings should be used only where necessary and should be of non-corrosive alloys, removable precast concrete slabs, or combinations of non-corrosive alloys for support and steel floor plates which can be repainted easily.

## 4. PREVENTION OF CORROSION

There are many ways to prevent corrosion; there are also ways of retarding or diminishing its damaging effects. The choice of methods to be used is determined by the conditions encountered and the economic advantage to be gained by using such methods.

The choice of materials is very important. By substituting a more resistant material for one previously used the service life of a structure some times can be increased many-fold. Thus, a thorough knowledge of

the characteristics of materials of construction is important.

Changing the environment so it is no longer corrosive is a much used method. This includes removing the corrodent or providing a protective coating. In either case the corrodent is kept from making contact with the material to cause corrosion. By keeping corrosion prevention in mind during the designing and construction periods many difficult corrosion problems can be avoided.

### 4.1 CHOICE OF MATERIALS

#### 4.101 Cast Iron

Cast iron corrodes at about the same rate as steel under similar conditions but, because of its increased thickness, and sometimes its surface inclusion of sand from the mold, it stands up well in some corrosive environments. The rust coating on cast iron is dense, compact, and adherent when compared to steel. Once formed it tends to retard further corrosion over a long period of time. Numerous examples of this are available in cast iron water and gas mains, cast iron road signs, cast iron sprockets on sludge-collecting mechanisms, etc. Cast iron also resists corrosion at higher temperatures, as are experienced in furnace grates and doors and incinerator parts. In these locations the temperature is usually under 1,000°F (536°C).

Grey cast iron is subject to graphitization when immersed in salt water, acid mine waters, or buried underground in some soils, particularly those containing sulfates. It occurs over a period of time as a result of the ferrite in the cast iron dissolving, leaving the graphite intact. This con-

dition results in porosity of the structure and loss of density and some mechanical strength, but without outward appearance of any damage. White cast iron is immune.

#### 4.102 Malleable Iron

Malleable iron has similar corrosion-resisting properties to cast iron and for that reason it is used for many things, including pipe fittings and chain links on sludge- and grease-collecting mechanisms. It has the added advantage of being less brittle than cast iron and able to withstand greater shock and impact loads without failure.

#### 4.103 Wrought Iron and Low Alloy Steels

Although controversy once existed as to the relative corrosion resistance of wrought iron and low-carbon steel, it now is recognized that in soils and natural waters, their inherent corrosion rates are similar. The composition of iron or steel within the usual commercial limits of carbon and low-alloy steels has no practical effect on

the corrosion rate in natural water or soils. Only when steel is alloyed in the proportions of a stainless steel (> 12 percent Cr) or a high silicon-iron or high nickel-iron alloy, for which  $O_2$  diffusion no longer controls the rate, is corrosion reduced appreciably.

For atmospheric exposures, the situation is changed because the addition of certain elements in small amounts, e.g., 0.1–1 percent Cr, Cu, or Ni, have a marked effect on the protective quality of naturally-formed rust films. The rust film which forms on the surface is more dense and adherent and slows down the corrosion attack. It must be remembered that different atmospheric exposures cause a marked difference in corrosivity, even of low alloyed steels.

#### 4.104 Copper and Copper Alloys

Copper is a metal widely used because of good corrosion resistance combined with mechanical workability, excellent electrical and thermal conductivity, and ease of soldering and brazing.

Copper and its alloys have a low position in the electromotive series. Therefore, as would be expected, they are excellent corrosion-resistant materials in many environments. The corrosion resistance of these metals is due to the formation of a protective coating on their surface and the very slight tendency of the metal to dissolve in most aqueous solutions.

Copper exposed to the atmosphere slowly develops a green coating called a patina. This thin protective coating consists of basic copper sulphate, except at the seashore where it contains some copper oxychloride.

Where there is no oxidizing agent present, copper has very good resistance to corrosion by hydrochloric and cold dilute sulfuric acids; also, to non-oxidizing salt solutions and other fluids which quickly corrode iron and steel. For this reason, it is a good

material to use inside a vacuum filter to convey the filtrate from the sludge cake to the head valve because of the hydrochloric acid used in cleaning the filter surfaces.

Copper and the brasses (Cu–Zn alloys) do not resist hydrogen sulfide and will form a black discoloration rapidly when it is present.

Copper is resistant to seawater, the corrosion rate being about 0.001 to 0.002 in./yr (0.05 cm/yr) in quiet water and somewhat higher in moving water. It is one of the very few metals which remains free of fouling organisms, normal corrosion being sufficient to release Cu ions in concentrations which poison marine life.

Copper is sensitive to corrosion by high velocity water and aqueous solutions, called impingement attack. The rate increases with DO content, whereas in oxygen-free high velocity water up to at least 25 fps (762.5 cm/sec), impingement attack is either small or zero.

In summary, copper is resistant to:

1. Seawater.
2. Fresh water, hot or cold. Copper is suited especially to convey soft waters high in DO, low in carbonic acid and manganese salts.
3. Deaerated, hot or cold, dilute sulfuric acid, phosphoric acid, acetic acid, and other non-oxidizing acids.
4. Atmospheric corrosion.

Copper is not resistant to:

1. Oxidizing acids, e.g., nitric, hot concentrated sulfuric and aerated non-oxidizing acids (including carbonic acid).
2. Ammonium hydroxide (plus oxygen). Substituted ammonia compounds (amines) also are corrosive. These compounds are the ones that cause stress corrosion cracking of susceptible copper alloys.
3. High velocity aerated waters and aqueous solutions. In corrosive

waters (high in  $O_2$  and  $CO_2$ , low in  $Cu^{++}$  and  $Mg^{++}$ ) the velocity should be kept below 4 fps (122 cm/sec); in less corrosive waters greater than  $150^\circ F$  ( $65^\circ C$ ) below 8 fps (244 cm/sec).

4. Oxidizing heavy metal salts, e.g.,  $FeCl_3$ ,  $Fe_2(SO_4)_3$ .
5.  $H_2S$  sulfur and some sulfur compounds.

Copper forms useful alloys with many metals to increase its strength, machineability, and corrosion resistance to different media. In general, alloys of copper and zinc are called brasses, and alloys with aluminum, silicon, tin, and some other metals are called bronzes.

Commercial brasses contain zinc in amounts varying from 5 to 45 percent. Brasses are readily machineable and the compositions can be varied to give a wide range of physical properties.

Although brass is resistant to many types of corrosion, a brass which is in an internally strained condition has a tendency to develop cracks along the grain boundaries when subject to attacks by corrosive agents, even those in the atmosphere. This condition is called season cracking or stress corrosion cracking. Season cracking seldom occurs in brasses containing less than 15 percent zinc.

One of the major corrosion processes of the Cu-Zn alloys (brasses) is dezincification. As the name implies, zinc is lost from the alloy, leaving as a residue, or by a process of redeposition, a porous mass of copper having little mechanical strength. Soft waters especially, may lead to corrosion failures from localized dezincification of the brasses containing much zinc, such as Muntz metal (60 percent Cu, 40 percent Zn), non-inhibited aluminum brass (76 percent Cu, 22 percent Zn, 2 percent Al), and yellow brass (67 percent Cu, 33 percent Zn) containing no dezincification inhibitor. Red brass (85 percent Cu, 15 percent Zn) and other alloys con-

taining less than 15 percent Zn generally resist dezincification, which explains their widespread use as piping materials.

The addition of tin or arsenic (also antimony and phosphorous) to the brasses containing more than 15 percent zinc usually is quite effective in slowing up or inhibiting the dezincification action in fresh and seawater. A few examples are admiralty metal (1 percent tin), naval brass ( $\frac{3}{4}$  percent tin), arsenical aluminum brass (0.04 percent arsenic), and arsenical Muntz metal ( $\frac{1}{4}$  percent arsenic). These are appreciably more resistant than the Cu-Zn alloys free of the inhibiting alloy additions.

The bronzes are more costly than brasses, but have compensating advantages. Bronzes are not subject to a type of corrosion analogous to dezincification, by which one constituent is removed. They also, as a rule, are stronger than the brasses.

The commercial copper-tin bronzes contain 12 percent or less tin. They have higher strength and hardness, are more resistant to impingement attack, and yet have the same high resistance to corrosion as copper.

Aluminum bronze is an alloy of copper and aluminum containing 10 percent or less aluminum. Mechanical properties of aluminum bronzes, particularly resistant to wear, exceed those of the copper-tin bronzes, and their resistance to corrosion is better, especially at high temperatures. They are the most resistant of any bronze to hydrogen sulfide and acids.

Silicon bronzes usually contain one to four percent silicon and in addition, small amounts of either iron, manganese, tin, or zinc. Typical silicon bronzes are those sold under the trade name of Everdur, Type A. Everdur has a composition: Copper, 96 percent, silicon, 3 percent, and manganese, 1 percent. Silicon bronzes as a class, have good mechanical properties, are readily weldable and are resistant to

corrosive compounds, particularly, hydrochloric and sulfuric acid, alkalies, and certain organic compounds. These alloys are used for gates, valves, screens, wire, ladders, bolts, and other structural parts in corrosive environments.

#### 4.105 Stainless Steel

The stainless steels are metal alloys that resist corrosion to a remarkable degree. This resistance to corrosion is due to a property of passivity being induced in the steel by the addition of chromium and nickel as alloys. Steels containing less than 11.5 percent chromium usually are not classified as stainless steel.

There are three main classes of stainless steels designated in accord with their metallurgical structure. Each class contains many types, each of which has somewhat differing alloy compositions, but related physical, magnetic, and corrosion properties.

1. Chromium (11.5 to 17 percent) -iron alloys with carefully controlled carbon content. These may be hardened by proper heat treatment to a martensite structure which is magnetic. They are, therefore, known as martensitic stainless steels. Typical applications include cutlery, steam turbine blades, and tools. The A.I.S.I. type numbers are in the 400 series.
2. Chromium (17 to 27 percent) -iron alloys with low carbon content. They cannot be hardened by heat treatment, but can be hardened somewhat by cold working. Their crystal structure is essentially ferrite, which is also magnetic. They are called ferritic stainless steels. Their atmospheric corrosion resistance is superior to that of the martensite class. Uses include trim for automobiles and as a major material of construction for synthetic ni-

tric acid plants. The A.I.S.I. type numbers are in the 400 series.

3. Chromium (16 to 26 percent) -nickel (6 to 22 percent) -iron alloys with low carbon content. They are not hardenable by heat treatment. Since they have a crystal structure of non-magnetic austenite, this class is called the austenite stainless steels. The basic composition in this class is the 18 Cr- 8 Ni alloy which is the most popular of all the stainless steels produced.

The nickel content contributes to improved corrosion resistance and is responsible for the retention of the austenitic structure. The austenitic class of steel is notable for its ductility.

Some uses of austenite stainless steels include general purpose applications, architectural and automobile trim, and various structural units for the food and chemical industries. The A.I.S.I. type numbers are in the 200 and 300 series.

The highest general corrosion resistance is obtained with the nickel-bearing austenitic types, and in general, the highest nickel composition alloys in this class are more resistant than the lowest. All grades, however, have the same general resistance characteristics. For example, they are all resistant to most concentrations of nitric acid, but the austenite grades usually show the least attack.

All the stainless steels have good resistance to alkaline solution and most organic acids, but are not resistant to halides (Br, Cl, F) in any form, seawater (unless cathodic protection is used), oxidizing chlorides, and some organic acids.

Some stainless steels are subject to pitting and intergranular cor-



rosion. By the selection of proper alloys, the correct heat treatment, and the exclusion of certain chemicals, these faults can be overcome.

Passivity is a state of electrochemical activity which is attained under suitable conditions by certain base metals, notably iron, nickel, chromium, and by some of their alloys. Its nature has been the subject of lively and continuing disagreement for which we have no room here. It is sufficient to state that it is a surface phenomenon between the metal and an oxidizing agent that creates a barrier to corrosion.

Maintenance of passivity requires the continuous replenishment of the oxidizing agent. As an example, DO in seawater is sufficient to maintain passivity on clean surfaces; however, the metal becomes active beneath a barnacle or in a crevice, since the rate of oxygen replenishment is too slow to maintain passivity, and corrosion occurs.

#### 4.106 Nickel and High Nickel Alloys

Nickel is a very important metal for resisting corrosion when used by itself or as high nickel alloy with other metals.

Nickel is a white, malleable, non-corrodible metal, having high strength, relatively high heat conductivity, and good heat resisting properties. These characteristics make nickel desirable for many uses where other metals are not suitable.

The high nickel alloys, i.e., the nickel-base alloys containing more than 50 percent nickel, are in a class by themselves since they have physical and mechanical properties not duplicated readily by other base alloys. These alloys are tougher, stronger, and harder than copper and aluminum alloys, and are as strong as alloy steel. They are highly resistant to corrosion

by most of the normal and special corroding agents found in industries, and they resist oxidation and scaling at elevated temperatures. All the high nickel alloys are characterized by exceptionally high corrosion and heat resistance, good strength, toughness, and high ratios of strength to ductility in all conditions of mechanical and thermal treatments.

The high nickel alloys have been classified into six main groups according to their composition. Most of these alloys have proprietary trade names which are used generally to identify them.

*Group I, Nickel*—93.5 to 99.5 percent nickel (and a maximum of 4.5 percent manganese). There are five specific grades of commercial nickel; namely, "A" nickel, "D" nickel, "E" nickel, "L" nickel, and "Z" nickel.

"A" nickel is the base material and is a commercially pure, malleable material having an average nickel content of 99.4 percent. The other grades contain small amounts of alloying elements that alter the properties slightly for specific purposes.

Nickel combines excellent mechanical properties with good corrosion resistance. It resists hydrogen chloride, chlorine, caustic soda, oxidation, and scaling, and retains its strength at both high and low temperatures. It is free from stress corrosion in atmospheric conditions.

*Group II, Nickel-Copper*—63 percent to 70 percent nickel, 29 to 30 percent copper. These are the so-called monel type alloys, all of which were developed by the International Nickel Company.

Monel is the most important alloy in this group. It is more resistant than nickel in reducing conditions and is more resistant than copper in oxidizing conditions. As a net result, it is

in general more resistant to corrosion than either of its principal constituents. Monel metal often is used in the form of wire mesh behind the filter cloth on vacuum filters. Where lime and ferric chloride are used as conditioning chemicals, the mesh has to be cleaned periodically of a deposit which closes the holes in the mesh. Muriatic acid (hydrochloric), containing an inhibitor, usually is used to clean this mesh.

Monel metal finds its greatest usefulness in seawater involving high velocities as in the case of pump shafts, impellers, and piping. It is not resistant to nitric acid, sulfurous acid, or ferric chloride, except in dilute solutions.

*Group III, Nickel-Silicon*—85 percent nickel, 10 percent silicon.  
The trade name of the best known of these alloys is Hastelloy D.

This metal is strong, tough, and extremely hard. It has properties similar to a high grade cast iron and is not workable. Because of its high hardness, about 360 Brinell, it can be machined only with difficulty, and must be finished by grinding. Its chief characteristic is its exceptional resistance to corrosion in hot or cold sulfuric acid, acetic acid, formic acid, and phosphoric acid. However, it is not resistant to strong oxidizing acids.

These alloys are sometimes used as pump and valve parts where other corrosion resistant materials are not strong or tough enough.

*Group IV, Nickel-Chromium-Iron*—54 to 78.5 percent nickel, 12 to 18 percent chromium, 6 to 28 percent iron.

The most common alloy in this group is called Inconel. It combines the inherent corrosion resistance, strength, and toughness of nickel with the extra resistance to atmospheric and high temperature oxidation that is imparted

by chromium. It resists the attack of many corrosive chemicals, but its chief attribute is exceptional corrosion resistance at high temperatures. Also, the ability to withstand repeated heating and cooling.

*Group V, Nickel-Molybdenum-Iron*—55 to 62 percent nickel, 17 to 32 percent molybdenum, 6 to 22 percent iron.

Two well known alloys fall into this group, Hastelloy A and Hastelloy B. They are characterized by their high resistance to corrosion in hydrochloric acid and wet hydrogen chloride gas. They are expensive and would be used only in exceptional cases of corrosive exposures.

*Group VI, Nickel-Chromium-Molybdenum-Iron*—51 to 62 percent nickel, 15 to 22 percent chromium, 5 to 19 percent molybdenum, and 6 to 8 percent iron.

Hastelloy C and Inconel G are in this group. They are especially characterized by their high corrosion resistance to oxidizing acids and mixtures, such as nitric, chromic, and sulfuric acids, copper sulfate, etc. They are rather hard alloys and difficult to work. They have high resistance to thermal shock.

These alloys are used when a strong alloy is required that will resist strong oxidizing acids and oxidizing agents such as free chlorine, bleaching agents, and the like. They are used for pump and valve parts, spray nozzles, and piping.

#### 4.107 Silicon Cast Iron

Silicon alloyed with iron imparts corrosion resistance to a variety of chemical media, in particular, strong non-oxidizing acids. The alloys are brittle and are, therefore, sensitive to fracture by thermal shock or by impact. These alloys are available only as castings, and usually any subse-

quent forming must be done by grinding.

Optimum resistance for minimum silicon content is about 14.5 percent, and this is the composition of the commercial alloy. Duriron, Corrosiron, and Tantiron are the trade names of the most prominent ones available. Duriron has been used successfully in wastewater treatment plants for piping to convey waste chemicals.

Durichlor is a modified type of 14.5 percent silicon cast iron. It contains about three percent molybdenum and has better resistance to hydrochloric acid than Duriron. Durimet 20 resists hot sulfuric acid up to 180°F (82°C), thus, it is appropriate for handling hot pickling liquor that is being used as a sludge coagulant.

Other uses for this class of alloys are centrifugal pumps, valves, ejectors for chlorine mixing, spray nozzles, and agitators.

#### 4.108 Aluminum

Aluminum has a number of valuable properties. Its lightness, ( $\frac{1}{3}$  the weight of steel) and high strength-to-weight ratio allow significant weight reductions in engineered products. The corrosion resistance imparted to aluminum by the stable oxide coat that forms in air or under special treatment (anodizing) gives it a tremendous advantage over other structural metals.

The properties of aluminum can be varied by alloying, heat treating, and cold working. In actual practice, a good knowledge of the nomenclature and characteristics of each of the many aluminum alloys and tempers is necessary to take advantage of the metal as a construction material.

Hydrogen sulfide, methane, and carbon dioxide have little or no effect on aluminum. Sulfur dioxide as a gas does not attack aluminum, but when oxidized to sulfuric acid, a slight attack is noticeable, which increases with

an increase in concentration and temperature. Aluminum is satisfactory for distilled water or soft water that does not contain heavy metal ions such as copper, iron, etc. It has excellent resistance to rural, urban, and industrial atmospheric exposures with lesser resistance to a marine atmosphere. Lime and fresh concrete are corrosive as well as other strong alkalis. The corrosion rate in concrete is reduced when the cement sets and continues only if the concrete is kept moist or contains deliquescent salts, e.g.,  $\text{CaCl}_2$ .

Aluminum is used at wastewater treatment plants for doors, windows, sash, floor plates, gratings, ladders, hatch covers, etc., where lightness and freedom from painting are important considerations.

Aluminum is high in the galvanic series of metals so one must be careful when coupling it with other metals. Cadmium, zinc, and magnesium in most cases can be coupled without suffering high corrosion rates; but there are special cases for zinc and magnesium in alkalis and seawater, respectively. With steel and other metals below aluminum in the galvanic series, special care must be taken in making couplings to avoid accelerated corrosion.

#### 4.109 Elastomers

Elastomers are the commonly called rubbers such as natural rubber, neoprene, isoprene, butyl, etc. Natural rubber has been used in the past to protect steel piping from chlorine solutions, ferric chloride, and other chemicals. Plastic pipe is being substituted for the elastomers in many of these applications. Where rubber linings were previously used to protect pump impellers and casings, as well as fans, and appurtenances, the plastics are now competing to replace them. One of the big uses of elastomers today is as sealants or gaskets in pipe joints. Neoprene, be-

cause of its resistance to greases and petroleum products, as well as oxidation, is good for this purpose.

#### 4.110 Plastics

The term plastics covers a large group of materials. In general, there are two defined classes or groups of plastics: thermoplastics—those plastics which can be heated to a plastic state and molded, then heated again and remolded. Examples of this group are the vinyl family (PVC, PVA, vinyl, vinylidene chloride), acrylics, Polyamides (nylon), polystyrenes, polyethylenes, and polyterafluorethylenes.

In the second group, called thermosetting, a chemical change occurs, usually at the time of application of heat and pressure during forming. As a result of this chemical change, the material does not soften on subsequent heating; but chars or is destroyed if the heating is carried to excess. Examples of this group are phenolics, polyesters, amino-formaldehyde, and epoxies.

Plastic pipe resists most of the chemicals found in wastewaters and used in the treatment process. These chemicals include ferric chloride, ferric and ferrous sulfate, sulfuric acid, hydrochloric acid, and chlorine.

Plastic pipe does not corrode and form tuberculations like steel and cast iron pipe, thus, they maintain a good value or smoothness factor. Plastic pipe (PVE) is used in chlorination systems and in buried pipe systems, such as for irrigation pipe and sprinklers.

Reinforced polyester pipe is used for submerged aerators in aeration systems. Reinforced polyester sheets are used in construction to cover tanks and as windows. They are translucent, but do not break as easily as glass and are lighter in weight.

Plasticized PVC is used as a lining to protect concrete structures and pipe

from corrosion in atmospheres containing hydrogen sulfide gas.

One of the major disadvantages of plastics is loss of strength and form at high temperatures. The thermoplastics normally are not used above 150°F (65.5°C), while some thermosetting plastics can handle some applications as high as 300°F (149°C). Other disadvantages are high thermal coefficient of expansion (thermoplastics), low strength compared to metals, and costs.

The scope of plastics is ever-widening as they are being fabricated into pump impellers and casings, fans, structural members, and even fasteners, such as bolts and nuts as substitutes for metals and corrosive exposures.

The substitution of plastic for glass in laboratory equipment has been extensive due to their light weight, corrosion resistance, and resiliency.

#### 4.111 Ceramics, Glass, and Vitrified Clay Products

Vitrified clay products, such as clay pipe, are one of the most corrosion resistant materials used in construction. They are resistant to moisture or chemicals in the soil, strong domestic wastes, industrial wastes, and acids formed by oxidation of hydrogen sulfide in the sewer.

Vitrified clay pipe will carry every known chemical, in any state of concentration, without being harmed. The only exception is hydrofluoric acid.

Vitrified clay products are made from blended clays mixed and shaped under pressure. After a period of drying they are burned at a temperature of about 2,000°F (1,090°C). This burning fuses the particles of clay together into a strong, chemical-proof bond.

The major weakness in the use of clay pipe in the past has been the materials used to join them. This deficiency has been overcome recently

with the use of pre-formed plastic joints. Also, clay pipe at the present time is limited in size to about 42 in. (1.05 m) in diam.

Vitrified clay tile liner plates cast in place have been used for many years to protect large concrete sewers and structures from acid attack. The major deficiency in their use has been the jointing material used between the plates and the permeability of the plates to corrodents. The clay products manufacturers have made advances in attempting to overcome the problems of jointing and of permeability; however, both still remain as problems. In an acid corrosion environment, the failure of any of the components making up the clay tile system will lead to the loss of the tile protective cover. Inasmuch as clay tile is a brittle material, any chemical reaction of the concrete backing will result in expansion and the breaking of the anchoring lugs thus causing the tile to be displaced. Tile also have been broken loose by the expansive action of reactive aggregates with portland cement alkalis.

Bituminous joints are emulsified and dissolved by soaps, oils, and greases in the wastewater. Sulfur joints do not adhere well to the clay and are attacked by sulfur bacteria. Acid proof cement joints appear to offer good protection, but they are costly.

Glass-lined steel tanks are used for the handling and storing of corrosive chemicals. Recently, glass-lined steel vent stacks have been used where corrosive vapors were being conveyed.

#### 4.112 Concrete

Portland cement concrete is one of the most widely used materials of construction for wastewater collection systems and treatment plants. Its use in large diameter pipe, tanks, and structures indicates its superiority in corrosion resistance and economy to most other materials. Its resistance

to natural atmospheric corruptions is excellent. Coatings generally are used to cover it for decorative purposes only. In the flowing wastewater, in digesters, aeration, and settling tanks containing domestic wastewater, it has an indefinite life with no protection required. In climates where freezing weather is experienced, concrete is subject to freeze and thaw damage. Generally, this type of damage can be avoided with the use of admixtures and other devices as well as the proper mixing, placement, and curing of the concrete. Steel incased in concrete, being in an alkaline environment, is well protected against corrosion. Cement mortar is used extensively to coat steel and cast iron pipes both inside and outside to protect them from corrosion.

Asbestos cement is a material used extensively in pipe, roofing, and siding for construction. It is composed of Portland cement, fine silica sand, and asbestos fiber mixed with water and then formed under pressure into pipe and sheets. It is usually steam cured. Asbestos cement pipe and sheets are hard, dense, and resistant to oxidizing and weathering conditions, the same as Portland cement concrete.

Portland cement products are subject to severe corrosion in an acid environment. Therefore, in wastewater systems that contain low pH industrial wastes or generate quantities of hydrogen sulfide under conditions where it will be converted to sulfurous and sulfuric acid, Portland cement should not be used without protection.

The properties of concrete may be varied within wide limits. They depend on the quality of the ingredients, the relative proportions of the ingredients, the method of mixing and placing, and the curing or treatment after placing.

The Portland Cement Association is an excellent source of information for all phases of concrete work.

## 4.2 CONTROL OF THE ENVIRONMENT

Since corrosion is the destructive attack on a material by chemical or electrochemical reaction with its environment, it follows that a change in environment, to reduce or eliminate these destructive forces, will prevent corrosion.

An electrolyte, such as water and its dissolved chemicals, is a necessary element for the corrosion of metals. Therefore, any means to prevent contact between the metal and an electrolyte will prevent corrosion.

Sometimes existing structures can be altered to eliminate open wastewater flow and thus reduce exposure to moisture and corrosive gases. These and other methods are discussed in this section.

### 4.21 Ventilation and Heat

The lowering of the humidity so moisture will not condense has a beneficial effect in controlling corrosion. Good ventilation is also of prime importance. These can be accomplished with fans and heaters. Even open windows and natural drafts can be used to advantage.

Detroit reports, "The clearing up of an annoying case of severe corrosion in the wet well of a pumping plan was accomplished by reversing the flow of air into this space. This wet well contained airlines, trolley beams, and an air hoist. The metal parts of this equipment were deteriorating very fast in the damp atmosphere. By forcing fresh air into this area and keeping it under a slight positive pressure, the corrosion rate dropped to ordinary proportions."

Massillon, Ohio, reports, "Forced draft ventilation in all chambers and pump rooms definitely has helped to reduce paint maintenance. Rooms are kept dry. Sweating is reduced or eliminated. Corrosive gases cannot accumulate and condense on damp, cold surfaces."

Winona, Minnesota, reports, "We have reduced our painting maintenance by 50 percent by improving the ventilation at the end of our pipe tunnel."

Circleville, Ohio, reports, "We have found that forced air ventilation had reduced condensation in the non-heated screen and grinder room and that paint life has been tripled."

Pontiac, Michigan, reports, "In the space between the roof and bottom plate of the P.F.T. floating digester cover, rot and rust were prevented by installing two roof-type ventilators."

Providing heat in unheated areas, or more heat where it is inadequate to promote dryness and prevent condensation, will help in reducing the corrosion rate and painting frequency.

Combustion products from gas heaters always should be vented to the outside. Natural and digester gas in burning produces water and harmful gases. The gases would be harmful to personnel and the moisture on condensing would accelerate corrosion.

Baltimore reports, "Installation of heaters in the coarse screen building and in the fine screen building prevents condensation on metal truss, window frames, etc., during cold weather; reducing maintenance."

### 4.22 Cathodic Protection

Cathodic protection by definition is the reduction or prevention of corrosion of a metal surface by making it cathodic, by the use of sacrificial anodes or impressed currents, for example.

Cathodic protection is one of the most important approaches to the control of corrosion of metals in use today. It is used extensively to protect condenser tubes, buried pipe lines, water storage tanks, clarifiers, sludge digesters, aerators, and other metal equipment which contains, or is ex-

posed to, water and other electrolytes. Needless to say, cathodic protection has no effect above the water line.

By the use of an externally applied current, corrosion can be reduced virtually to zero and a metal surface can be maintained in a corrosive environment without deterioration for an indefinite period.

In the usual application of cathodic protection the metal to be protected is connected electrically to the negative terminal of a source of current such as a rectifier, generator, or battery. The positive terminal is connected to an anode in the corrosive electrolyte. Current from the anode passes through the electrolyte to the protected metal, making it cathodic and reversing the current at the anodes of local cells on the protected metal.

The applied voltage needs only to be sufficient to supply an adequate current density to all parts of the protected structure. In soils or waters of high resistivity, the applied voltage must be higher than in environments of low resistivity. The source of current is usually a rectifier supplying low voltage d-c of several amperes.

The voltage required to give protection from corrosion is determined through measuring the potential of the protected structure. This measurement is of greatest importance in practice, and is the criterion generally accepted and used by corrosion engineers. It is based on the fundamental concept that cathodic protection is just complete when the protected structure is polarized to the open-circuit anode potential of local action cells. This potential for steel, as determined empirically, is equal to 0.85v vs. the Cu saturated  $\text{CuSO}_4$  half cell, a survey instrument used for this purpose.

In a cathodic protection system where sacrificial anodes are used as the current source, the anode must be a metal more active in the galvanic series than the metal to be protected.

In the protection of iron or steel, there are three readily available metals, aluminum, zinc, and magnesium, each of which forms reasonably strong galvanic cells when combined with iron. Magnesium forms the strongest cell (highest voltage) of the three, and is, therefore, most often used.

Aluminum operates theoretically at a voltage between magnesium and zinc but tends to become passive in water or soils, with accompanying change of potential, to a value approaching or more noble than steel. Whereupon it ceases to function as a sacrificial electrode. Special methods to combat this have been used but none are too dependable.

Zinc's chemical action, with regard to sulfides and carbonates in wastewater as well as its lower voltage, make it less effective when used as a sacrificial anode than magnesium.

There have been many installations of cathodic protection systems in waste water treatment plants in recent years. Some have been successful and some have not. It is suggested that a competent corrosion engineer be consulted before the design and installation of a cathodic protection system.

#### 4.23 Galvanic or Bimetallic Corrosion

In modern terms, galvanic corrosion may be defined as the accelerated electrochemical corrosion produced when one metal is in electrical contact with another more noble metal, both being immersed in the same corroding medium (electrolyte). Corrosion of this type results, usually, in an accelerated rate of solution for one member of the couple and protection for the other. The protected metal, the one that does not corrode, is called the noble or cathode metal. Note that as galvanic corrosion is generally understood, it consists of the total corrosion which comprises the normal corrosion that would occur on a metal exposed alone, plus the additional amount that is

due to contact with the more noble metal.

With a knowledge of the galvanic corrosion behavior of metals and alloys, it is possible to arrange them in a series which will indicate their general tendency to form galvanic cells, and to predict the probable direction of the galvanic effects.

Some of these metals may be grouped together. These group members have no strong tendency to produce galvanic corrosion on each other and from a practical standpoint they are relatively safe to use in contact with each other. But the coupling of two metals from different groups, and distant from each other in the list, will result in galvanic or accelerated corrosion of the metal higher on the list. The farther apart the metal stands, the greater will be the galvanic tendency.

The relative position of a metal within a group sometimes changes with external conditions, but it is only rarely that changes occur from group to group; however, the stainless steels are in two different places. They frequently change places, depending on the corrosive media. The most important reasons for this are the oxidizing power and acidity of the solutions and the presence of active ions, such as halides. In environments where these alloys ordinarily demonstrate good resistance to corrosion, they will be in their passive condition and behave accordingly in the galvanic coupling.

Some of the more important practical rules that have been derived by corrosion engineers to prevent or minimize galvanic corrosion are:

1. Select combinations of metals as close together as possible in the galvanic series.
2. Avoid making combinations where the area of the less noble metal is relatively small. It is good practice to use the more noble metal for fastenings, and other small parts in equipment,

that are built largely of less resistant material.

3. Insulate dissimilar metals wherever practical. If complete insulation cannot be achieved, anything such as paint or a plastic coating at the joints will help increase resistances of the circuit.
4. Apply coatings with caution. For example, do not coat the less noble material without also coating the more noble, otherwise greatly accelerated attacks might be concentrated at imperfections in the coatings on the less noble metal. Keep such coatings in good repair.
5. If possible, increase the electrical resistance of the liquid path.
6. If possible, add suitable chemical inhibitors to the corrosive solution.
7. If you must use dissimilar materials well apart in the series, avoid joining them by threaded connections, as the threads will probably deteriorate excessively. Brazed joints are preferred, using a brazing alloy more noble than at least one of the metals to be joined. Also, don't use anodic or less noble metals for critical structural material.

#### 4.24 Use of Coating to Prevent Corrosion

One of the most common and widely used methods of preventing corrosion of a material is to cover it with another material which has greater resistance to corrosion. Such a material is called a protective coating.

Protective coatings fall into two main categories: those that act as a physical barrier against the environment, and those that corrode preferentially and save the base metal from attack. Aside from zinc and cadmium coatings, which fall in the sacrificial category, most coatings are of the barrier type.

Protective coatings usually are sub-



divided further into metallic or inorganic and organic coatings.

**4.241 Metallic Coatings:**—Following is a summary of the most important types of metallic coatings available. These coatings can be applied by electro-deposition, flame spraying, hot dipping, cladding, and other techniques.

Zinc and cadmium coatings both are less noble than steel under most conditions. Thus, they are used to cathodically or galvanically protect iron and steel. In the process the coatings are consumed preferentially and the base metal remains intact. A further advantage of these coatings is that they cause little difficulty from the standpoint of dissimilar metal contact when they adjoin aluminum or magnesium.

The zinc coating (commonly called galvanizing) is usually applied by dipping in a molten zinc bath. The resulting coating is measured either in mils (thousandth of an inch) or in "ounces per square foot." An average coating of 5 mils (0.005 of an in.) is approximately  $2\frac{1}{2}$  oz/sq ft (0.07 g/sq cm).

Past experience indicates that the effective service life of a galvanized coating varies directly with its thickness.

The service life of a galvanized coating varies greatly with the exposure. In heavy industrial areas containing smoke, soot, acid fumes, etc., a 5- to 10-yr life can be expected while in a rural area 20 to 25 yr can be expected.

Sherardizing is another method of applying a zinc coating in which the material to be coated is packed in zinc dust in an airtight revolving container and heated to a temperature close to the melting point of zinc. This causes an alloying of the zinc with the steel. This method is more suitable for small pieces and does not produce as thick a coating as the hot-dip method.

For specifications and standards on hot-dip galvanized coatings refer to

A.S.T.M. Standards which have been compiled by the American Hot-Dip Galvanizers Association into one book.

Nickel coatings, unlike cadmium and zinc, are more noble than iron and steel and do not provide sacrificial protection. To protect the base metal they must provide an impervious, non-porous barrier. Electropolated nickel coatings vary in thickness from 0.5 to 10 mils, the thicker coating being used in the chemical industry. For added adhesion, they usually are applied over a very thin layer of copper. Nickel also can be applied by electroless plating and by cladding. The electroless coatings are particularly useful in areas that cannot be reached by electrodeposition and where a heavy-duty coating is needed, as for tank cars handling corrosive liquids.

Chromium electroplates are especially useful where tarnish resistance combined with hardness, wear resistance, or a low coefficient of friction is needed. They are used most frequently to preserve the appearance of nickel electroplates.

Silver electroplates can be useful in some corrosive applications. They are immune to attack by most dry and moist atmospheres and although attacked by ozone, they resist the effects of oxygen at high temperatures. Most halogen gases will attack silver plate but the initial film that is formed inhibits further attack. However, as is well known, the coatings will tarnish when subjected to moist sulfur-bearing compounds.

Other metal coatings such as aluminum, tin, lead, monel, stainless steel, and various hard facings are used frequently to protect iron and steel against corrosion. Hot-dipped aluminum coatings are especially useful where a combination of heat and corrosion is encountered and they have high resistance to corrosive condensates which form when a heated part cools down. Tin, of course, is widely known for its use on corrosion re-

sistant food containers. Lead coatings are noted for their ability to form a film of environmental reaction products, such as lead sulfate, which are highly resistant to corrosion.

A recent newcomer to the coatings field is the inorganic zinc coating, which probably belongs in the metallic coatings classification. It is composed of metallic zinc particles and a vehicle of sodium silicate. A curing agent or hardener is used to complete the chemical action of the formation of the coating. Inorganic zinc coatings perform well because they are bonded tightly to the metal surface through reaction with iron base and are basically conductive, permitting the zinc to corrode preferentially to protect underlying steel. Much of the corrosion-protective value of the zinc is thought to be related directly to formation of relatively stable insoluble corrosion products, such as oxides, hydroxides, and basic carbonates.

**4.242 Non-Metallic or Inorganic Coatings:**—The inorganic coatings are used to form a physical barrier between the corrosive environment and the material to be protected. They get the name organic from the use of organic vehicles, thinners, drying oils, and resins in their compounding. The pigments for these coatings usually consist of metallic oxides, e.g., titanium oxide, chromate, lead carbonate, etc. Synthetic resins now are used quite often as vehicles or components of vehicles to enhance the ability of the coating to resist acids and alkalis.

Vinyl resins have good resistance to penetration by water. Silicone resins are used at elevated temperatures. Epoxy resins show resistance to many chemicals as well as excellent adhesion.

It is sufficient to say that organic coatings cover a tremendous field from the linseed oil paints through the coal tars and asphalts to the newer synthetics such as vinyls, epoxies, and

urethanes. This field includes the primers that are used in conjunction with many of these coatings. The detailed uses of these coatings are covered in the chapter on Paints and Painting.

#### **4.243 Chemical Conversion Coatings:**

—Inorganic films produced through a chemical reaction are classed as chemical conversion coatings. Such films actually become an integral part of the surface of the base metal being processed. These films vary in physical characteristics such as durability, appearance, and cost, depending on the processing compound selected to produce the desired end result.

Chemical conversion coatings may be employed to produce a decorative effect on a finished product, act as a conditioner or an adherent base for an organic finish, protect against corrosion, provide wear-resistant properties, assure lubricant adhesion, insulate, reflect heat, or form a dielectric film.

Typical inorganic chemical conversion films used today include coatings produced with phosphate, chromate, various strongly alkaline-oxidizing solutions, fused dichromate, and anodic or electrolytic immersion.

Two of the most widely used are the phosphate coating and the controlled oxidation method of applying a black finish to metal parts.

A phosphate coating is a crystalline non-metallic layer formed on the surface of a metal by the chemical reaction of phosphoric acid and the metal. The solutions used most commonly contain zinc and iron or manganese along with iron phosphates. Small articles such as bolts, nuts, etc., are coated by dipping them in the phosphate solution. Large pieces are sprayed.

The phosphate coating depends on the attack of the base metal to form the coating. Consequently, anything which interferes with this attack will influence the coating. This fact ex-

plains the great importance of cleaning in the proper deposition of a quality phosphate coating.

A phosphate coating is not intended to prevent corrosion by itself, but finds its greatest use as a base on which to apply subsequent coats of paint. Paints adhere much better to a phosphate-treated metal surface than to an untreated one.

Corrosion under a paint film that has been scratched is retarded effectively by the phosphate coating. This characteristic is particularly valuable on the edges of articles where corrosion tends to start.

The adhesion of paint to new zinc or zinc alloy surfaces is usually very poor. A phosphate coating not only provides the necessary bonding layer but also increases the durability of the subsequent paint coatings.

Parkerizing and Bonderizing are trade names applied to commercial phosphate coatings. They are used widely for refrigerator cabinets, office equipment, and automobile panels.

The black oxide finish process was originated as an alternate or substitute process for plating during the war. At that time, the scarcity and high cost of plating material turned manufacturers to other sources for an attractive, durable, and protective finish. Blackening, obtained with the controlled oxidation process, was employed widely because of its ease of use and excellent protective qualities and continued to be popular even after chrome again was available.

Typical applications for such blackening include modern metal furniture, machine parts, guns, tools, spark-plug bodies, gears, typewriter parts, hinges, screws, nuts, bolts, washers, and similar items.

The black chemical conversion coatings usually are obtained by exposing the metal parts to hot, oxidizing solutions or gases. These coatings are very thin, normally ranging from 0.02 to 0.2 mils and have little, if any,

effect on dimensional accuracy. Basically such coatings are used to improve the appearance of the finished item, to provide protection from corrosion, or a base for painting.

One of the most commonly used methods of blackening ordinary steel is the immersion of the metal in a hot strongly alkaline solution. Here, as with the phosphate solution, the metal must be cleaned before immersion for a good protective surface to develop.

#### **4.25 Treatment of Water Systems to Prevent Corrosion**

The use of water as a heating and cooling agent is widespread. To prevent corrosion in the process equipment and operate at peak efficiency, treatment methods have been developed to alter the corrosive characteristics of the water used.

**4.251 Cooling-Water Systems:**—In general there are two types of cooling-water systems, the once-through and the recirculating system.

The once-through system usually is not treated chemically because of the large quantities of inhibitors required and the problem of water pollution. Sometimes additions of about two to five mg/l sodium or calcium polyphosphate are added to help reduce corrosion of steel equipment. In such small concentrations polyphosphates are not toxic and water disposal is not a problem. Otherwise use must be made of a suitable protective coating or of metals more corrosion resistant than steel.

Recirculating cooling waters, such as engine-cooling systems, can be treated with sodium chromate,  $\text{Na}_2\text{CrO}_4$ , in the amount of 0.04 to 0.1 percent (or the equivalent amount of  $\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$  plus alkali to pH 8). Chromates inhibit corrosion of steel, copper, brass, aluminum, and soldered components of such systems. As chromate is consumed slowly, additions must be made at long intervals in order to maintain the concentra-

tion at the right level. For diesel or other heavy-duty engines, 2,000 mg/l sodium chromate (0.2 percent) is recommended in order to reduce damage by cavitation erosion as well as by aqueous corrosion.

Chromates should not be used in the presence of anti-freeze solutions because of their tendency to react with organic substances. There are many proprietary inhibitor mixtures on the market which usually are dissolved beforehand in methanol or in ethylene glycol in order to simplify the packaging problem. Borax ( $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$ ) is a common ingredient, to which sometimes is added sulfonated oils which produce an oily protective coating, and mercaptobenzothiazole which specifically inhibits corrosion of copper and at the same time removes the accelerating influence of dissolved copper on corrosion of portions of the system.

The treatment\* of the water used at the Hyperion Sewage Treatment Plant of the City of Los Angeles in the diesel dual-fuel engines with vapor-phase cooling and steam-recovery system, is as follows.

First the water is put through a Zeolite-Nalcite softener and sand and gravel filter. It is softened to zero hardness as indicated by tests with the Boutron-Boudet soap solution. Then the following chemicals are added:

Sodium Sulfite (Santosite)	104 mg/l
Sodium Hexametaphosphate (Calgon)	47.5 mg/l
Hagan Dispersive (Haganite)	47.5 mg/l
Sodium Hydroxide (Caustic Soda)	9.5 mg/l
Cobaltous Chloride	0.24 mg/l

Hot water heating systems normally are closed steel systems in which the initial corrosion of the system soon uses the dissolved oxygen; thereafter, corrosion is negligible so far as life of the metal equipment is concerned.

\* This is a once-through system; therefore, this particular treatment might have to be modified where steam was condensed for reuse as feed water to the system.

Medium or hard waters are relatively non-corrosive and do not require treatment of any kind for corrosion control in municipal water systems. Soft waters on the other hand cause rapid accumulation of rust in iron piping, are contaminated readily with toxic quantities of lead salts on passing through lead piping, and cause blue staining of bathroom fixtures by copper salts originating from slight corrosion of copper and brass piping. Vacuum deaeration of such waters would be ideal as a corrosion control measure. The expense is high for treating the large quantities of water involved and no practical installations apparently have been constructed as yet for community water supplies.

Chemical treatment of potable waters is limited to small concentrations of inexpensive, non-toxic chemicals, such as alkali or lime. Some water supplies are treated with about two mg/l sodium polyphosphate which helps reduce the red color originating from ferric salts or suspended rust in water. This treatment also reduces the corrosion rate to a modest extent wherever water moves with some velocity and is aerated fully. In stagnant areas of the distribution system, however, there is probably no practical benefit.

#### 4.26 Preventing the Corrosion of Portland Cement Concrete by Hydrogen Sulfide

##### 4.261 Nature of Concrete Corrosion:—

**4.2611 General:**—The concentration of dissolved sulfide in wastewater is indicative of the corrosion potential. Dissolved sulfide itself is not corrosive to the concrete below the surface of the wastewater in the concentrations normally present. It evolves, however, from the wastewater flow in the form of hydrogen sulfide and, by bacterial action, is oxidized on the interior surfaces of the sewers and ap-

appurtenant structures, above the wastewater level, to form sulfuric acid. The resultant sulfuric acid then will react with any non-resistant material resulting in surface deterioration. On a concrete surface the sulfuric acid will be neutralized by the basic constituents of the concrete. Complete neutralization usually is not achieved, however, because of the interfering film of the reaction products. On an acid-resistant surface free acid may concentrate to as much as 25 percent. Thus, when the concrete is protected by tile or other jointed resistant material, the joints must be sealed with acid-proof material. The porosity of both the protective material and the joints also must be kept to a minimum. If this is not done, the acid will penetrate and react with the concrete behind the protective material. Behind bonded ceramic tile or similar materials, such reaction, accompanied by the greater volume of the reaction products, will break the bond and cause the protective surfaces to fail. When the protective membrane and jointing remains sound, the concentrated acid tends to collect and run down the walls. If wastewater does not reach the level of the protective membrane for most of the time, the unprotected surfaces below the membrane can be corroded rapidly and severely.

**4.2612 The Corrosion Cycle:**—The corrosion cycle, as it applies to sewers and appurtenant structures, can be described as follows:

First, the formation of sulfides in the wastewater results from the bacterial reduction of compounds containing organic sulfur, such as homocystine, cysteine, methionine, and jenkolie acid; or from the reduction of inorganic sulfur-containing compounds such as sulfates, sulfites, and thiosulfates. All of these reductions are anaerobic in nature and take place only in the absence of free or dissolved oxygen. In the sewer sulfide production may occur in the anaerobic invert

slimes even though dissolved oxygen exists in the flowing wastewater.

Second, the release of hydrogen sulfide into the sewer atmosphere occurs. This rate of release, and to some extent the formation of hydrogen sulfide, is dependent on both the characteristics of the wastewater and the geometric design of the sewer and appurtenant structures. Temperature and hydrogen ion concentration are the wastewater characteristics effecting the proportion of the dissolved sulfides available as hydrogen sulfide. Flow velocity and turbulence are the design considerations most effecting the release of hydrogen sulfide gas.

Third, the oxidation of hydrogen sulfide to sulfuric acid takes place on moist, exposed surfaces as a result of bacteriological or non-biological actions. An intermediate oxidation product may appear in the form of elemental sulfur accumulation on the surface. A portion of the hydrogen sulfide may escape from the sewer as an odorous gas.

Finally, the reaction of sulfuric acid with the calcium compounds of portland cement concrete forms calcium sulfate. The calcium sulfate reacts with the tricalcium aluminate in the cement to form an expansive, complex salt (tricalcium aluminosulfate hydrate). This and other expansive corrosion products cause the concrete to soften and spall.

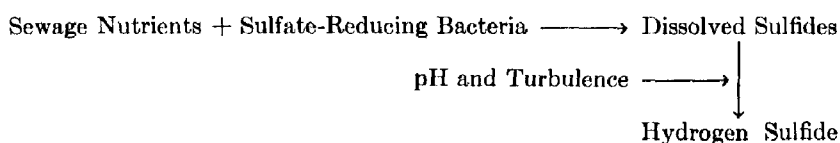
The bacteria primarily responsible for hydrogen sulfide formation are the sulfate-reducing bacteria, *Desulphovibrio desulfuricans*. These bacteria, in deriving their necessary energy, reduce sulfates to sulfides. While the sulfur-oxidizing bacteria (*Thiobacillus thio-parus*, *Th. thiooxidans*, and *Th. concretivorus*) act as the biological intermediaries in the formation of sulfuric acid from hydrogen sulfide, sulfur, and thiosulfate. It is not clear at this time if these are the only species involved in these reactions. They have been isolated by certain workers in the

field and have been found either to reduce or oxidize sulfur compounds. Other species also may function just as efficiently.

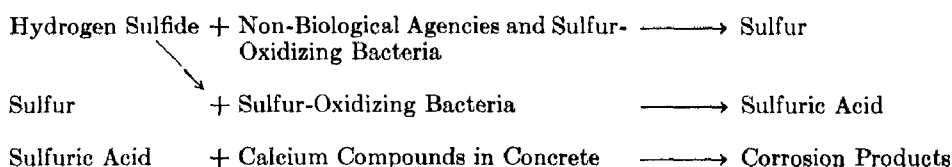
The manifestation of the "Corrosion Cycle," as relating to concrete corrosion, is schematically shown as follows:

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In the Sewer Flow—



Above the Wastewater Flow—



#### 4.262 Control Methods:—

##### 4.2621 Method of Presentation:—

The control methods, which are applicable to the sulfur cycle and its products as it applies to sewers, have been separated as to principal effect into bacteriological, physical, and chemical categories for purposes of presentation.

##### 4.2622 Bacteriological Control:—

###### 1. General

In a manner analagous to that of all other forms of life, the growth and activity of wastewater bacteria will be affected by changes in their environment such as sudden changes in temperature, pH, presence of toxic material, or the supply of nutrients. Bacteria, too, are subject to destruction by other forms of living organisms.

Bacteria stabilize organic matter as a function of their metabolic activity. This stabilization, which consists basically of hydrogen removal and its transfer to an appropriate hydrogen acceptor, will proceed so that the higher energy-yielding reaction takes place first. These hydrogen acceptors, in order of descending energy yields, are

DO, nitrates, sulfates, oxidized organic matter, and carbon dioxide.

###### 2. Sterilization of Sewage

(a) **Treatment with Bacteriostatic Agents:—**In most systems sterilization of the wastewater cannot be achieved economically. However, certain chemicals possessing bactericidal action have been used. These include chlorine, trichlorophenol, phenol, pentachlorophenol, orthodichlorobenzene, quaternary ammonium compounds, heavy metallic salts, and a number of commercial materials with claimed bactericidal properties. Except under special conditions, only chlorine has been effective in quantities economically feasible. Chlorine is a strong oxidizing agent; therefore, it is utilized in many side reactions before acting as a bactericide. Since wastewater contains large amounts of ammonia, much of the chlorine is utilized in forming chloramines. These are weaker than free chlorine as bactericides.

(b) **Lime:—**Lime in sufficient concentrations is a bactericide

which can be both inexpensive and effective. If enough lime is added to wastewater to boost the pH to 12, a dosage rate of 6,000 to 8,000 mg/l for a period of at least 45 min, the bacteria in the slimes below the surface of the wastewater are destroyed. Sulfide generation then will be reduced materially until the bacteria and slimes build up again. A period of two to four weeks is usually required for this build up. If lime dosages are not sufficient to hold the required pH over the required time, little benefit occurs.

### 3. Oxidation of Wastewater

- (a) Methods:—One or all of the following physical methods of increasing the DO content of the wastewater may be used; compressed air or oxygen introduced into the wastewater flow, wastewater diluted with oxygenated fresh water, or turbulence in high velocity of flow utilized for surface absorption.

The demand for oxygen also may be met through the use of chemical additives. Chemicals, which have been used with various degrees of success, are chlorine nitrates, hypochlorites, hydrogen peroxide, and hexavalent chromium.

As an alternate to the physical and chemical means, the oxygen demand may be reduced by partial purification of the wastewater at some intermediate point in the sewer system. This could include the biological use of algae in treatment lagoons.

- (b) Chlorine:—It has been shown by investigations that chlorine oxidizes sulfide to sulfate, not to free sulfur, and that the ratio of chlorine demand to sulfide is 8.87:1. Chlorine also

will raise the oxidation-reduction potential of the wastewater and has germicidal action on the sulfide-producing bacteria. In actual operational use between 12:1 and 15:1 parts of chlorine per part of sulfide have been found necessary in gravity sewers and 15:1 to 20:1 parts in force mains for odor and corrosion control.

- (c) Nitrate:—Nitrate addition to relatively fresh wastewater is sometimes an effective means of providing the wastewater with a reserve oxidizing capacity. The nitrates are depleted only after the DO has been exhausted. If septicity already exists in the wastewater, this method is not as applicable because the required nitrate concentration becomes extremely high. The effective dosing rate is 7.3 lb nitrate/lb of expected sulfide generation. As with all chemical dosages, if not enough nitrate is added the treatment is generally useless. Nitrate appears to be most effective under ponding conditions.

- (d) Compressed Air:—Compressed air is most applicable to force mains where it is desirable to maintain the maximum solubility of air under the given conditions without adding an excess of air. Too much compressed air will increase pumping costs by causing air pockets which increase friction head and may constitute a potential danger. Small amounts of hydrogen sulfide can collect in the air pockets and be oxidized biologically to sulfuric acids. This in turn can cause severe localized corrosion. The proper amount of air to be added may be calculated as follows:  
cfm of air needed to saturate the wastewater flow = (cfm of

wastewater) (absolute pressure in main) (solubility of air at the particular temperature)  $\div$  atmospheric pressure. In practice a minimum of 1 cfm/1 in. of pipe diam (0.011 cu m/min/cm) is recommended for trial. Efficacy of injected air is affected by the pressure. If the sewer main operates under high pressure, the injected air dissolves more readily and more effective control is obtained.

- (e) Reducing Oxygen Demand:—As an alternate to providing a method for increasing the DO content of the wastewater, a partial purification of the waste-

water to reduce the oxygen demand may be undertaken. With the development of small, compact wastewater treatment plants, the use of these plants for an in-line system of wastewater treatment at intermediate points in the sewerage system appears possible.

- (f) Dilution with Water:—In the early years of a sewer system when small flows exist, it may be feasible economically to control sulfide production by diluting the wastewater with oxygenated water. The amount of water to be added may be calculated by the formula:

$$Q_w/Q_s = (\text{EBOD}/\text{Marginal BOD})^{\frac{1}{n}} - 1$$

Where

$Q_w$  = Quantity of water;

$Q_s$  = Quantity of sewage; and

EBOD = Effective BOD, or  $\text{BOD} \times 1.07^{\circ\text{C}-20}$ .

Marginal BOD = BOD limit a sewer can carry without sulfide buildup.

#### 4.2623 Physical Control:—

##### 1. Wastewater:—

- (a) Factors:—The buildup of sulfides in gravity sewers can be related to the temperature, pH, BOD, DO, velocity, slope, and area of wetted surface in any section under consideration.

Sulfide generation will occur during long detention periods in force mains and gravity sewers. If there is no loss to the atmosphere or no oxidation, buildup will result. Force mains, since they run full, will not be subjected to corrosion; however, when the wastewater is discharged into partially full gravity sewers and wet wells, the sulfide generated in the force main will be released as hydrogen sulfide and, where conditions are favorable, cause corrosion and odors.

The addition to fresh wastewater of cesspool and septic tank cleanings and industrial wastes may bring about a loss of DO and the establishment of anaerobic conditions with a rise in sulfide production.

The rate of sulfide generation virtually is independent of sulfate concentration as long as the sulfate concentration is greater than about 50 mg/l; therefore, under normal wastewater conditions the concentration of sulfates is not considered an appreciable factor.

- (b) Interrelationship of Factors:—Attempts have been made to relate the various factors which affect sulfide generation into expressions which will give a marginal value, or upper limit, for the BOD of the wastewater



which can be conveyed by a particular gravity sewer with

little or no sulfide buildup. Such an expression is as follows:

$$\text{Marginal BOD} \times 1.038^{(t-65)} = 7,500Q^{\frac{1}{2}}S^{\frac{1}{2}}f(Q/Q_f)$$

where

$t$  = temperature, °F;  
 $Q$  = actual flow, cfs;  
 $Q_f$  = flow capacity of full pipe, cfs;  
 $S$  = slope; and  
 $f(Q/Q_f)$  = a function of relative flow.

Expressions also have been proposed for the calculation of sulfide generation on submerged surfaces as shown below.

Gravity Sewers:

$$S = \text{EBOD} \times A \times K$$

where

$S$  = sulfides, lb/day;  
 $\text{EBOD}$  = Effective BOD, mg/l;  
 $A$  = area of submerged surfaces, sq ft; and  
 $K$  = constant,  $5 \times 10^{-6}$ .

Force Mains:

$$S = Kt(\text{EBOD}) \frac{(1 + 0.01d)}{d}$$

where

$S$  = sulfides, mg/l;  
 $K$  = constant = 0.0026;  
 $t$  = time of passage, min;  
 $\text{EBOD}$  = Effective BOD, mg/l; and  
 $d$  = diam of force main, in.

The above equation is based on an assumption of no absorption of oxygen at the free wastewater surface in a gravity sewer. When such oxygenation exists the sulfides buildup in the wastewater will be less than calculated.

Earlier work indicated that the buildup of sulfides, where slimes existed, was in the range of 0.3 to 0.6 lb/day/1,000 sq ft (1.5 to 2.9 g/day/sq m) of slime surface per 100 mg/l of BOD.

A relationship of wide application, taking into consideration all variables of the control problem, remains to be formulated.

(c) Velocity:—By increasing velocity in the wastewater stream the

internal partial pressure is decreased thus increasing the rate of oxygen absorption at the surface and limiting the sulfide buildup. It has been shown that the rate of oxygen absorption by a flowing stream is proportional to the velocity to the 1.75 power. The amount of dissolved sulfide existing in a sewer tends toward a dynamic equilibrium between the sulfides oxidized by oxygen diffusing into the stream, the sulfides lost as hydrogen sulfide, and the sulfides being generated from sulfur compounds in the anaerobic slimes. The loss of sulfides, as hydrogen sulfide, to the sewer atmosphere is dependent on the internal pressure, pH, tempera-

ture, and turbulence. It has been proposed, however, that the minimum velocities required

to prevent sulfide buildup for various values of Effective BOD may be calculated by:

$$V = 0.137(\text{EBOD})^{0.496}$$

or

$$N_{Re} = 5,700 \times \frac{A}{b} (\text{EBOD})^{0.89},$$

where

- $V$  = velocity, fps;  
 EBOD = Effective BOD;  
 $N_{Re}$  = minimum Reynold's modulus for no buildup of  $\text{H}_2\text{S}$ ;  
 $A$  = cross-sectional area of flowing wastewater, sq ft; and  
 $b$  = width of surface of flowing wastewater, ft.

These equations are limited in use to sewers operating under "normal" flow conditions. They do not provide for the effect of numerous other variables and can be considered only as an approximate guide in corrosion calculations.

- (d) Temperature:—A high wastewater temperature will influence biological action resulting in increased sulfide production. Within the temperature range found in sewers an increase of  $15^\circ\text{C}$  may double biological metabolic rate. High temperatures, by reducing gas solubility, also will cause the un-ionized hydrogen sulfide to escape into the sewer atmosphere. The production of sulfides is negligible below a wastewater temperature of about  $60^\circ\text{F}$  ( $15^\circ\text{C}$ ). At wastewater temperatures between  $60^\circ$  and  $70^\circ\text{F}$  ( $15^\circ$  and  $21^\circ\text{C}$ ) sulfide buildup generally will be moderate; however, severe corrosion can occur. By adding cool, unpolluted water, wastewater temperature will be reduced and sulfide production lessened. For sewers this is not recommended generally since useful capacity will be used by the unpolluted water.

- (e) Alkalinity:—Decreasing the wastewater's pH causes hydrolysis of the hydrogen sulfide. Hydrated lime or caustic waste are considered to be the most economical chemicals for pH-control treatment. Except for the use of certain industrial wastes, such pH control would be uneconomical. Chemicals containing sulfides should not be added to the sewers.

- (f) Cleaning:—Mechanical cleaning should be done periodically in order to remove sludge deposits from the bottom and slimes from the submerged walls. It appears that cleaning is the least expensive and the most effective method of sulfide control. Sewers with heavy sludge and slime deposits can generate more sulfides than the theory states. Regular cleaning should be the foundation of any system-wide sulfide control program. Sewer design should provide for easy cleaning.

- (g) Ponding and Flooding:—Only that concrete exposed to the sewer atmosphere is subject to rapid corrosion. Corrosion of concrete in sewers, therefore, can be eliminated by restricting the wastewater flow to main-

tain a full pipe at all times. This method of corrosion control has been referred to as ponding and can be accomplished by using adjustable gates built into the sewer line at appropriate locations to maintain the required liquid level. Properly weighted flat gates can be installed in manholes to accomplish ponding in sewer lines where gates do not exist and where the installation of sluice gates and appurtenances would be difficult and expensive. Ponding, however, may increase sulfide buildup in the wastewater since wall slime area is increased. Ponding, therefore, may increase severely the odor and corrosion problem downstream of the sewer being protected. In addition, ponding will increase the cleaning job by allowing sludge deposits and heavy slimes to build up.

Periodic washing of the sewer walls by flooding with wastewater or fresh water may lessen corrosion of the concrete by preventing the buildup of heavy sulfuric acid concentrations. This practice also tends to retard the activity of the sulfur autotrophes proliferating on the sewer walls above the flowing wastewater. Such flooding robs these organisms of the required nutrients, such as oxygen, hydrogen sulfide, carbon dioxide, nitrogen compounds, and an acid environment. The necessary frequency and duration of the wetting for corrosion control depends on the intensity of the corrosive gases in the sewer atmosphere.

- (h) Turbulence:—Hydrogen sulfide is soluble in water to the extent of 3,850 mg/l at ordinary temperature and dynamic equilibrium with 100-percent hydrogen

sulfide in surface contact. Its evolution from the wastewater is not visible to the eye. At points of higher than normal turbulence, rates of release are far greater than from smoothly flowing wastewater. Turbulence can be caused by high velocities, obstructions in the line, or as a result of improper design of structures including junction manholes which permit sewer lines to intersect at right angles or at different elevations. Turbulence also is found at the outlet end of force mains where free fall exists, at sudden grade changes, at weirs, and at sharp bends. These conditions should be avoided in locations where hydrogen sulfide cannot be tolerated. Even where wastewater contains but 0.1 mg/l of dissolved sulfides, turbulence can cause excessive release of hydrogen sulfide gas. By undertaking structural alterations it may be possible to reduce substantially the emission of hydrogen sulfide into the sewer atmosphere.

The mass transfer of hydrogen sulfide from wastewater into sewer atmosphere also depends to some lesser degree on the liquid surface tension and the vapor pressure. The surface tension of a liquid decreases as the wastewater temperature rises resulting in increased molecular motion. An increased turbulence in the wastewater also will cause a corresponding increase in the kinetic energy of the liquid. Any increase in the average kinetic energy of the molecules of the liquid, therefore, results in a decrease in surface tension.

The concentration of  $H_2S$  in an atmosphere in equilibrium with a  $H_2S$ -containing liquid

may be found by multiplying the concentration in the liquid by a factor which varies with the temperature. At 68°F (20°C), this factor is 286, giving the concentration at equilibrium in mg/l by volume. The pH and turbulence have more effect than temperature on the evolution of hydrogen sulfide from the wastewater.

#### 4.263 Sewer Atmosphere:—

**4.2631 Methods of Control:—**When odorous and corrosive gases already are present in the sewer atmosphere, they can be withdrawn and certain components eliminated by properly designed scrubbing or incineration equipment.

Other methods of treating this withdrawn air are the passing of the air through activated carbon, earthen beds, activated sludge cultures, and trickling filters.

In order to prevent an offensive odor condition, control should be considered when the concentration of hydrogen sulfide in the atmosphere reaches 0.7 mg/l.

Tile, plastic sheet, stainless steel sheet, or protective coatings will give various degrees of surface corrosion protection to sewer structures in contact with such contaminated atmospheres prior to treatment. Sewer ventilation also may be used to supplement physical protection.

**4.2632 Ventilation:—**The oxidation of hydrogen sulfide on the sewer walls depends on conditions favorable to sulfur bacteria, including a moist surface. A flow of unsaturated air tends to remove the moisture from the walls and would therefore retard bacterial growth and resultant conversion of hydrogen sulfide to sulfuric acid. Ventilation has a secondary effect in that it can help prevent the accumulation of toxic or explosive gases. Ventilation may, however, result in a serious odor problem since large quan-

ties of odorous air have been concentrated into a point source.

Effective drying of the sewer walls is related to the quantity and relative humidity of the air being drawn through the sewer. The distance that a given fan can provide the required drying must be determined by full-scale field tests under normal operating conditions.

If, however, it is necessary only to maintain negative pressures at the manholes for odor control, then it would be possible to determine unit pressure losses in the sewer for application to the design problem. Theoretically this could be accomplished by measuring the static pressure at two consecutive manholes in the line during ventilation test periods for different conditions of flow. This pressure or head loss then would be used with other known or measured data in Darcy's equation in order to determine a factor "*f*," thus:

$$H_f = f(L/4r)(v/4,005)^2$$

where

$H_f$  = head loss between manholes in in. of H<sub>2</sub>O;

$L$  = distance bet. manholes, ft;

$V$  = air velocity, fpm;

$r$  = hydraulic radius, ft; and

$f$  = factor.

#### 4.264 Sewer and Sewer Appurtenances:—

**4.2641 Consideration:—**The protection of the sewers and appurtenant structures from hydrogen sulfide by the use of protective coatings and liners needs to be considered where the presence of the gas is anticipated and where it is impractical to fully control its generation.

**4.2642 Coatings:—**Protection of concrete from corrosion may be obtained by applying protective coatings to the sewer walls. Three factors affect the ability of the coating to protect the concrete: (a) chemical resistance of the coating, (b) permeability

of the film, and (c) adhesion of the film to the concrete. A successful coating must have these properties and retain them over a long period of time.

Many coating materials have suitable chemical resistance but when brushed, sprayed, or rolled on seldom give complete protection. Such coatings are likely to have minute perforations or pinholes. When this happens the imperfections rapidly increase in size until failure occurs. Abrasion of the coating from floating objects occurs between high and low wastewater levels leading to corrosion of the exposed concrete. Few if any presently known coatings, therefore, have been effective in preventing concrete attack under highly corrosive or abrasive conditions. The epoxies show the most promise, primarily due to their good adhesive properties. Coal-tar epoxy coatings over aluminous or Portland cement concrete have been used with some degree of success. A silica loaded coal-tar epoxy liner material has been developed and can be factory applied to new concrete pipe.

**4.2643 Plastic Liner:**—Flexible polyvinylchloride (PVC) sheeting, either cemented to the concrete or cast in place using integral "T" shaped PVC projections on the back of the sheet, has proved to be a very successful lining material. PVC has been shown to be safe from degradation under microbial attack. Some authorities consider it to be the only proven sulfide barrier. Data on long-time exposure of PVC to sewer atmospheres are limited and in view of its known water absorption characteristics, slow hardening, and sensitivity to some solvents, length of service is not known now. Except for a tendency to mechanical damage when subjected to high velocity wastewater flows, with a subsequent repair problem, PVC protection has an excellent record.

**4.2644 Stainless Steel:**—In structures where PVC sheet liner protection may be subject to mechanical

damage, the use of stainless steel is recommended. Sheets of the type 316L with a thickness of  $\frac{3}{16}$  to  $\frac{1}{4}$  in. (0.5 to 0.6 cm) are providing excellent protection.

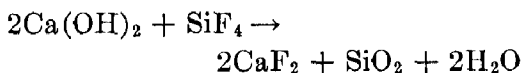
**4.2645 Tile Liner Plates:**—Clay tile liner plates have been used for many years and glass plates have been proposed. The clay product manufacturers have made advances in attempting to overcome problems of jointing between plates and of permeability of the plates; however, both remain as major problems. To find a satisfactory jointing material is quite difficult. Bituminous joints are emulsified and dissolved by soaps, oils, and greases in the wastewater and sulfur joints do not adhere well to the clay and are attacked by sulfur bacteria. Acid-proof cement joints appear to offer good protection, but they are costly.

The failure of any of the components making up the clay tile system will lead to the loss of the tile protective cover. Inasmuch as clay tile is a brittle material, any chemical reaction of the concrete will result in expansion and the breaking of the anchoring lugs thus causing the tile to drop. Tiles also have been broken loose by the expansive reaction of concrete aggregates with the alkalis of Portland cement.

**4.2646 Impregnation:**—Any measure that will reduce the quantity of free lime and other reactive compounds present in concrete would greatly improve its chemical resistance. One method was the so-called "fluating" process. This involved treating the surface of the concrete with a water solution of a fluoride, usually magnesium fluoride, which reacted with the free lime to form a layer of calcium fluoride of high chemical resistance. The main disadvantage of this method was the very thin and easily broken layer of protection obtained.

The same principle is used for a newer method called "ocrating." The

only difference between the two processes is that the free lime in the curing process is converted into hard, insoluble calcium fluoride by means of a fluorine-containing gas, silicon tetrafluoride. The chemical action is said to be as follows:



**4.2647 Lime Coating:**—A thin coating of dry lime,  $\frac{1}{8}$  to  $\frac{1}{4}$  in. (0.2 to 0.3 cm) thick, can be applied to the walls and soffit through the manholes by means of large-volume blowers. One blower is set to direct the discharge of lime into the sewer at one manhole and the other is set to exhaust the air from the next manhole downstream. Some of the lime is deposited from the air flow on the moist surface of the sewer and forms a semi-hard coating. This coating tends to absorb moisture and neutralize any acid which may be formed. Depending on the rate of acid generation, the lime may be effective for a period of up to three months provided it is not removed by high flows.

**4.2648 Cement and Aggregates:**—

(a) Portland Cement:—There are various kinds of cement, each of which differ in their resistance to acid attack. The most economical is Portland cement. Portland cements, according to type, may vary in the degree of susceptibility to corrosion depending mainly on the proportion of tricalcium aluminate they contain.

Portland cements are available in which the amounts of this constituent are kept below the normal average. ASTM Type II and ASTM Type V Portland cements have a tricalcium aluminate content of approximately eight and five percent, respectively. It appears, however, that a high degree of resistance to sulfate attack alone

will not prevent destruction of the concrete by sulfuric acid.

Pozzolans when added to Portland cement concrete, without reduction of cement content, may increase its resistance to corrosion. The pozzolans combine with the free lime in the cement to form a cementitious compound, monocalcium silicate. The use of pozzolanic cements for sewer construction, however, has been very limited.

(b) Aluminous and Supersulfated Cements:—The basic constituent of aluminous cements is alumina and, after hydration, free alumina is present rather than free lime. The alumina does not react readily with acids in a pH range above three and thus may provide better short-term protection against corrosive attack. High aluminous and supersulfated cements contain approximately 40 and 13 percent, respectively, of  $\text{Al}_2\text{O}_3$ .

Aluminous cement is being used for sewer construction in several cities of the world where concrete corrosion exists. In Southern California its use, until recently, has been limited to repair of corroded concrete surfaces. It is found that extreme care must be exercised in mixing, placing, and curing to insure that the aluminous cement concrete will provide the desired dense, adherent, and corrosive resistance surface.

(c) Calcareous Aggregates:—The use of calcareous aggregate provides additional mass of an alkaline material for neutralizing the acid, thus requiring more acid to effect a given amount of corrosion. The rate at which corrosion penetrates is directly proportional to the amount of acid available and inversely proportional to the exposed sur-

face area of reactive material. Other factors which also will determine this rate, however, are compressive strength, specific gravity, abrasion resistance, soundness, and absorption. The physical characteristics of limestone aggregate vary over a wide range, even in the same quarry; therefore, careful testing and control methods must be exercised when such an aggregate is used. Dolomite containing magnesium carbonate should not be used due to the reactivity of magnesium salts with cement alkalies. It is questionable that calcareous aggregate concrete, without extra thickness, will provide the necessary protection where the attack by acid is severe and concentrated in one location. The cost of sacrificial calcareous aggregate concrete, in any case, must be considered against the cost of other protective methods.

#### 4.265 Chemical Control:—

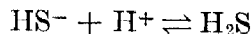
**4.2651 General:**—The sulfide generated in the sewers is in the equilibrium  $H^+ + HS \rightleftharpoons H_2S$ . Whether the  $H_2S$  or the  $HS^-$  ion predominates depends on the pH of the solution. The equilibrium proportions are constant and unchangeable except by a change in pH. The total mass of material in each of these forms is affected by the loss of  $H_2S$  from the wastewater phase. At points of extreme turbulence, the diffusion of  $H_2S$  is accelerated and the reaction is driven strongly toward the  $H_2S$  component. Normally the wastewater is near neutral and possesses a strong buffering capacity so that the ratio of  $HS^-$  to  $H_2S$  is about three or four to one. When a soluble metal salt, which will react with sulfide is added, the action is toward the removal of all sulfide ions and, thus, the prevention of  $H_2S$  release to the atmosphere.

**4.2652 Zinc:**—Zinc salt solution has been found to be very successful in the removal of sulfide ions. Although the zinc will react with other materials present in the wastewater, the desired reaction is satisfactory and the  $ZnS$  formed is insoluble. In addition, relatively inexpensive zinc salt solutions, in the form of industrial waste, are available as a result of certain industrial processes.

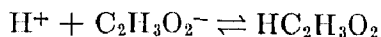
Zinc ions have been investigated in their reaction with the four anions usually considered most important in wastewater applications. These are  $OH^-$ ,  $S^{2-}$ ,  $CO_3^{2-}$  and the  $NH_3$  complex. The solubility product constant of  $ZnS$ ,  $Zn(OH)_2$  and  $ZnCO_3$ , are  $1 \times 10^{-20}$ ,  $5 \times 10^{-17}$  and  $2 \times 10^{-10}$ , respectively. Therefore, the  $ZnS$  should precipitate first. When hydrogen sulfide is passed into a zinc chloride solution, precipitation takes place as



The precipitation of  $ZnS$  soon ceases. The  $H^+$  ions produced reach a high enough concentration to establish an equilibrium.



If the  $H^+$  ions are buffered with a salt, such as sodium acetate ( $NaC_2H_3O_2$ ), the reaction forming  $ZnS$  can be driven to completion



The wastewater generally contains buffering materials adequate to maintain pH levels near neutral at the normal zinc salt dosage rate.

In the presence of hydrogen ions the concentration of sulfide in equilibrium with the hydrogen sulfide is smaller than in a neutral solution. As the pH increases, the fraction of the dissolved sulfides existing as sulfide ions becomes so small that a very high concentration of zinc ions would be necessary to exceed the value of the solubility product of zinc sulfide. Such

a condition would not be expected in the outfall sewers unless a heavy acid spill was present. The theoretical ratio of zinc metal to sulfide content for complete reaction is 2.04 lb to 1 lb, respectively.

**4.2653 Copper and Other Heavy Metals:**—The salts of copper and most of the other heavy metals, such as lead, trivalent chromium, and cadmium, also will precipitate sulfides as insoluble metal sulfides. The use of these metals is generally too expensive for routine sulfide control. In a large city, however, certain amounts of such heavy metals will reach the sewers as industrial waste and aid in sulfide control. Copper and other heavy metals also can exhibit strong bacteriostatic and bactericidal action and, although presenting a problem during treatment when such metals are present in high concentrations, will inhibit the action of bacteria in the sewers.

**4.2654 Iron:**—It would be expected that the ferric salts would be more effective than the ferrous compounds. The principal effect of the ferric salt, when added to wastewater of low sulfide content, seems to be oxidation of sulfide at the time of mixing; very little precipitation occurs unless the initial sulfide concentration exceeds 10 mg/l.

A large excess of iron is, therefore, required when the concentration of the

dissolved sulfides is below 1.0 mg/l. It has been found that a mixture of iron containing about two-thirds  $\text{Fe}^{+++}$  and one-third  $\text{Fe}^{++}$  is more effective than either alone.

In contrast to iron, zinc has the advantage of a practically complete reaction with dissolved sulfides. Experimental results indicate that the  $\text{Fe}^{+++}$  has only 12 percent of the effectiveness of  $\text{Zn}^{++}$ . This difference in effectiveness between the two ions is due apparently to the hydrogen concentration. The addition of  $\text{Fe}^{+++}$  ions can make the mixture strongly acidic due to the hydrolysis of the ferric ion. The  $\text{HS}^- + \text{H}^+ \rightleftharpoons \text{H}_2\text{S}$  equilibrium then is shifted to the right. For large outfall sewers, however, the buffering capacity is so great that the acid shift does not become apparent until 100 to 200 mg/l of  $\text{Fe}^{+++}$  is added. For normal dosage rates,  $\text{Fe}^{+++}$  would, therefore, be preferable to  $\text{Fe}^{++}$ , with zinc better than either.

**4.2655 Ammoniation:**—It has been theorized that ammonia gas, when added to the sewer atmosphere, would dissolve in the moisture on the exposed wall surfaces and neutralize the sulfuric acid being formed. Application of this proprietary method has certain technical difficulties arising from losses and dilution of the gas as well as the high cost of maintaining the distribution system.

### 4.3 SUMMARY

It generally is considered that the dissolved sulfide level in the flowing body of wastewater represents an equilibrium between the production within the subsurface slimes and sludge deposits, the oxidation by the oxygen being absorbed continually from the surface, and the evolution of hydrogen sulfide to the atmosphere. It is believed that little sulfide production occurs in the flowing wastewater.

Sulfate is considered the chief

source of sulfides; however, other organic sulfur compounds also contribute to sulfide formation. Sulfates are reduced easily by microbes; moreover, with the large amount generally found in the wastewater, the rate of sulfide production would be little affected by any attempt to control the sulfate concentration.

Due to the rapid conversion of hydrogen sulfide to sulfuric acid on the exposed sewer walls, the concentration



of hydrogen sulfide in the sewer atmosphere generally is far below the expected value for equilibrium with the wastewater. Concentrations of 5 to 10 percent acid generally are found on acid resistant surfaces where this conversion is taking place.

In the design of branch or local sewer systems, consideration should be given to the proper velocities required to maintain the generation-oxidation equilibrium at a level to prevent a sulfide buildup. Turbulence should be minimized to prevent hydrogen sulfide release in large interceptors and land outfalls where odor and corrosion problems are most common. Large concrete sewers probably can be protected most positively from corrosion by PVC sheet liner where normal flow velocities exist. Because of the danger of mechanical damage to the PVC lining high velocity lines should be constructed of clay pipe.

Rate of production of sulfide in sewers may be diminished by diluting the wastewater with unpolluted water, by removing industrial wastes of high temperature or with high content of organic matter, by restricting the addition of septic tank and cesspool pumpings, or by partial treatment of the wastewater to lower the BOD. Regular and thorough cleaning also will aid materially in limiting sulfide production.

Air or oxygen may be injected into force mains in order to prevent the sulfide generation. A controlled withdrawal of air, however, should be considered to prevent air pockets in the top of the sewer to avoid corrosion and increase in pumping head.

Chlorine is considered useful in the control of sulfides. When an adequate amount of chlorine is applied, it leaves the wastewater in an oxidized state, and existing sulfides may be oxidized to sulfate.

Zinc and other heavy metal salts are effective in the treatment of wastewater containing dissolved sulfides.

#### 4.31 Designing and Building to Prevent Corrosion

Many instances of corrosion could be corrected by better design and construction methods. The case for dissimilar metals or galvanic corrosion has been mentioned previously and is very important. Corrosion of an aluminum rivet can be expected when it is used to fasten steel sheets together. Similarly if a steel rivet is used to fasten aluminum sheets, then undercutting galvanic corrosion of the aluminum sheet will result in loose rivets, slipping, and possible structural damage. Corrosion of this type can be prevented by applying a non-hardening insulating joint compound in the area where the sheet and rivet or bolt are in contact. Another approach is to apply a zinc chromate primer to all contacting surfaces and then coat the primed area with an aluminum paint.

Another cause of galvanic corrosion that should be avoided is the use of steel and brass or copper pipe in the same system.

In the use of structural steel avoid sections that are hard to clean and coat such as back-to-back angles, beams, etc.; also flat and dished sections that will collect and retain moisture.

Whenever possible sharp features where moisture, liquids, and solids can accumulate should be avoided and all corners and contours should be rounded.

Construction of angles, channels, and beams should be arranged so as not to leave catchment areas for liquids. If this is not possible the appropriate size and number of drainage holes should be provided. These should not only be kept clean from blockage but also should be sited carefully and attention paid to disposal of the drainage.

The various methods of joining should be considered. For ease of protection butt-weld joints are preferable

to those that are lap-welded. If, however, it is essential to use the latter, all exposed edges should be treated in such a way as to prevent the access and retention of liquids and dirt in the crevices.

Any storage containers and tanks should be supported on legs so that free circulation of air is possible and condensation is prevented. Condensation also can be prevented by the use of insulation.

Evaporation of condensed moisture often is retarded on sheltered horizontal surfaces such as those under the eaves of buildings. Such features should be provided with breathing holes or given additional protection such as a coat of water-resistant finishing paint.

Where the coating to be used will

not be harmed by fabrication or can be touched up easily after such fabrication, surface preparation and coating applications should be done in the shop where controlled conditions such as temperature and humidity exist and good inspection is available. An example of the above is in the shipbuilding industry. Many prefabricated parts of ships are stored in the open, subject to corrosion for as long as two years without protection. Some ship builders are now coating these sub-assemblies with inorganic zinc coatings over a shot-blasted or sand-blasted surface. This provides protection during the building period and a good base for a top coating after completion. If welding is used to join the parts, only a small area of coating is destroyed and it can be retouched.

## 5. ACTION OF DESTRUCTIVE AGENTS ON PAINT FILMS

### 5.1 GENERAL

The slogan of the Paint Manufacturers' Association, "Save the Surface and You Save All," is most appropriate advice. Corrosion begins on the surface of the metal and works inwardly. Destructive action on the paint film normally begins on the surface of the paint and works inwardly.

If it were possible to provide a coating over the surface of metals which would cover them completely and remain that way, adhere tenaciously to

the base material, be impervious to all liquids and gases, be inert to chemical union with the metals and its environment, be a non-conductor of electricity, and stand up under abrasion and exposure to sunlight, there would be no serious corrosion problem. However, since it is not possible or even practical to isolate metals in this way, it remains to investigate the agents which destroy or make ineffective the surface protection afforded by paint films.

### 5.2 DESTRUCTIVE AGENTS

#### 5.21 Water

Water, with its property of dissolving more materials than any other single liquid, and its capillary attraction, provides the close contact between the paint film and other destructive agencies. Water will find imperfections in the coating and filter through which to reach the metal beneath. The products of corrosion, or merely the expansion of the water at the metal surface, tend to separate the paint film from the metal. This action first may be noticed as a series of isolated spots. If left to run its course, the spots enlarge until their circumferences meet, thus lifting more and more paint and exposing progressively larger areas to metallic corrosion (see Figure 4).

Water will dissolve or soften many paints making the film more vulnerable to their destructive agents. Water will carry acids and alkalis from other areas into direct contact with the paint surface.

The painting of a metal surface that is wet, or painting on a day when the relative humidity of the air is high,

is certain to retain enough moisture in the film or beneath it to cause early paint failure and incipient corrosion. The inclusion of water in an oil paint will have the same effect.

The presence of an excessive amount of moisture in wood that is painted will result in the water vapor forming blisters with a subsequent lifting of the coating.

#### 5.22 Air and Gases

The air is another agency that deteriorates paint films. The oxygen of the air unites with the pigments or vehicles of the paint, causing them to form products which may be granular and porous. It also may produce combinations which require less volume than the original coating, thus producing many tiny cracks or checks in the film. It may dry out the coating to the point where it is no longer flexible, causing it ultimately to crack and peel. The aging of paint is a gradual oxidizing of the vehicle and the pigment, resulting in a brittle and chalky surface.

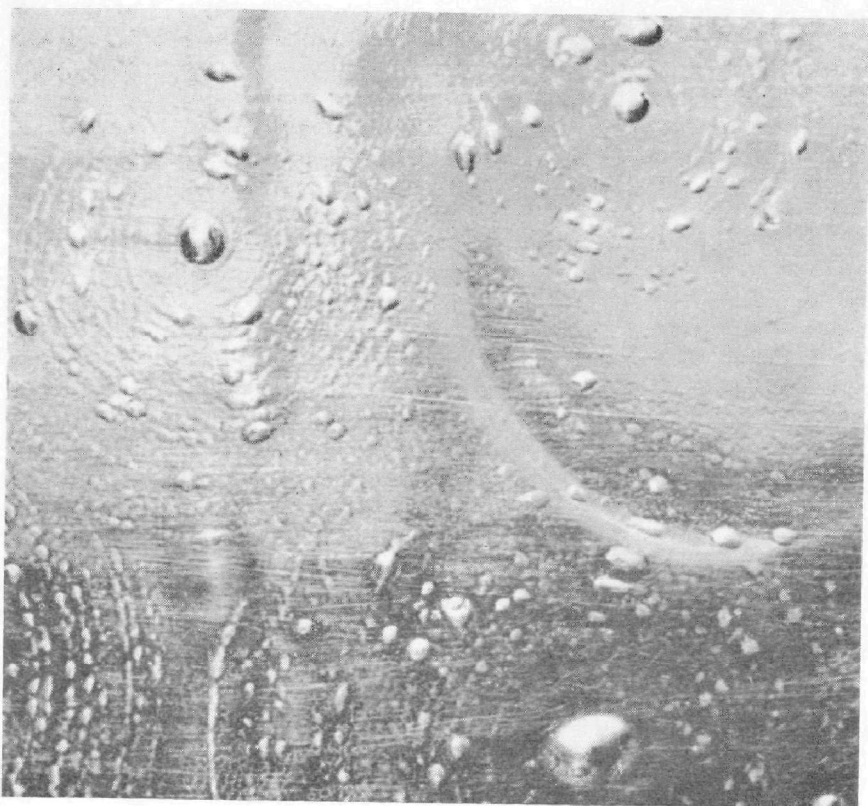


FIGURE 4.—Results of water vapor penetration of a coating thus forming a concentrated solution which blisters at the coating-steel interface. (Courtesy Amercoat Corporation.)

Certain gases in the air which are prevalent in industrial areas are very injurious to ordinary paint films. The two most important of these are hydrogen sulfide and sulfur dioxide. As mentioned under metallic corrosion, they attack metals readily because of the acids they form in their union with water and oxygen. Many paint pigments are metallic derivatives and their reactions with the two gases, directly or with the acid forms, produce substances which no longer protect the metal beneath.

Another result is the discoloration of the paint film. A familiar example of this is the darkening of white lead paint by the action of hydrogen sulfide in the air. In this instance the white lead carbonate is changed slowly to the black lead sulfide. As little as 1 to 10 mg/l of hydrogen sulfide in the atmosphere will be enough to make a noticeable change in the whiteness of white lead paint.

### 5.23 Chemicals

The acids and alkaline substances used in wastewater treatment processes and those which are sometimes brought in with the wastewater as industrial waste are very destructive to ordinary paint films. This usually is brought about by the direct action of the chemical on the paint coating, causing it to form another compound which has no protective value or one that loses its bond to the metal beneath.

### 5.24 Sunlight and Heat

The ultra-violet light in the sun's rays causes some paint films to change their chemical composition, which results in fading of colors, drying out, and cracking.

Heat above the ordinary range of temperatures produces disintegration of paint films by the breaking down or drying out of the vehicular oils.

This is particularly noticeable on boiler fronts, breechings, and stacks where a heat-resistant paint has not been used.

### 5.25 Oils and Greases

The mineral oils and greases used around a wastewater treatment plant for lubricating purposes and the fats and organic greases brought in with the wastewater have a deteriorating effect on ordinary paint films.

The mineral oils and greases damage paint coatings by softening or dissolving them. These lubricants sometimes contain traces of sulfur which may have been in the original crude oil or left from the refining process. They also may contain small portions of the lighter ends of the fractional distillation process, such as kerosene and gasoline.

Greases are made by adding a lubricating oil to a soap base to get the desired consistency. These soaps are

a mixture of fats and an alkali, usually lime or soda. The presence of any free alkali in the grease explains their damaging effect on paint films.

The fats and organic greases usually found in wastewater oxidize readily on contact with the air. As oxidation proceeds, fatty acids are produced. These acids dissolve and soften paint, or destroy its bond with the metal beneath, causing it to slough off in large pieces. On metal parts of sludge and grease-collecting equipment, such as chains, sprockets, troughs, etc., which usually are not painted, these acids may attack the iron.

### 5.26 Paint Cleaners

Paint-cleaning compounds can be especially injurious to the ordinary paint coatings if not used properly. Many of these compounds are strongly alkaline while others contain solvents which

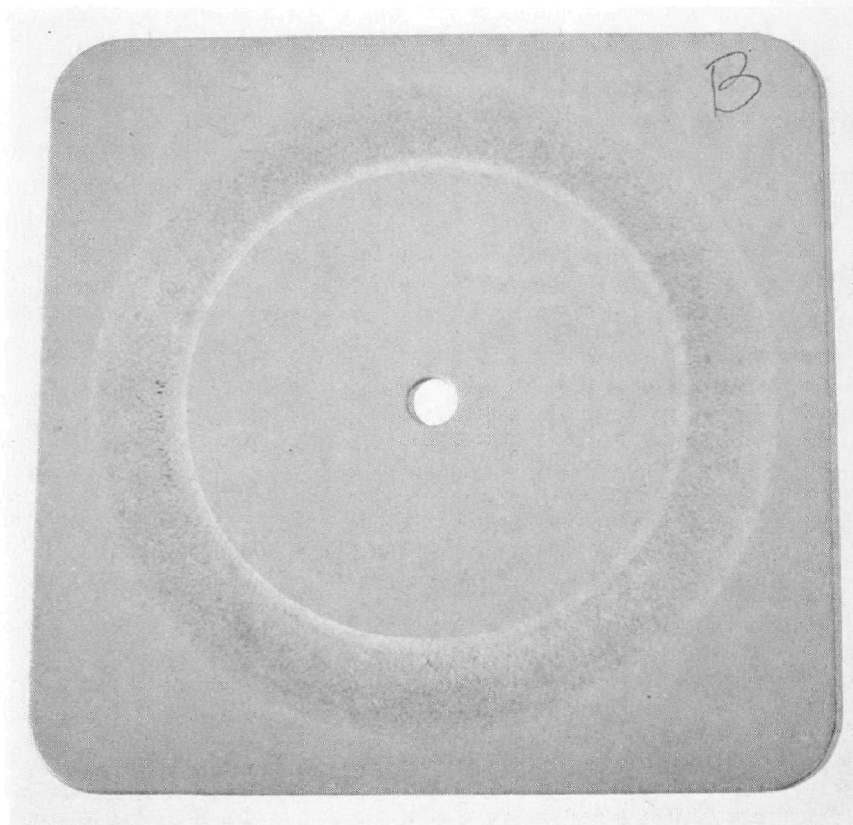


FIGURE 5.—Abrasion test result. Circle shows path of abrasive wheels on coating. (Courtesy Amercoat Corporation.)



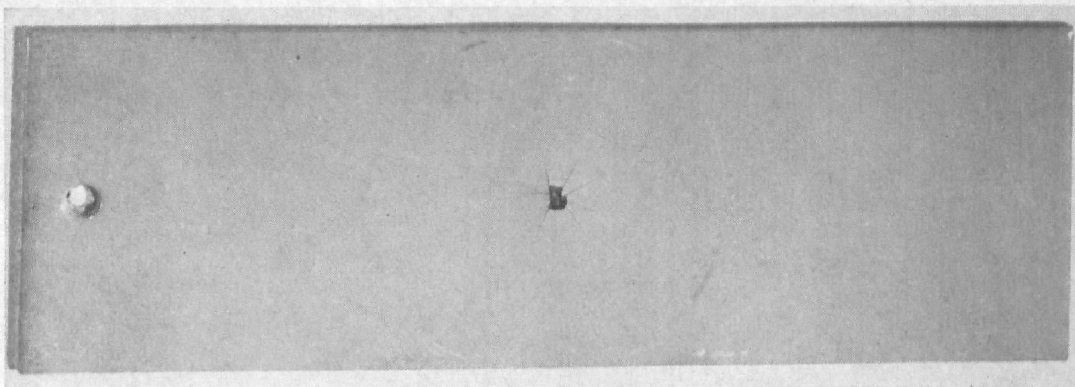


FIGURE 6.—Chipping causes cracks in coatings resulting in more extensive damage.  
(Courtesy Amercoat Corporation.)

soften paints. Each type cleans by removing the thin outer layer of the paint film which has become chalky and rough. The rough, uneven surface provides the tooth to which dirt can cling.

A too-concentrated solution of either kind of cleaner will remove more than the top layer and shorten the normal life of the coating. For average cleaning jobs a mild soap-and-clean-water mixture should be sufficient. Abrasive cleaners should be avoided.

### 5.27 Abrasion

The damage to paint films by frictional abrasion (see Figure 5) is due in most cases to ordinary wear. The familiar examples are the worn spots that show up in areas of concentrated traffic on painted floors, stairs, and handrails. When it is considered that the average paint film is about 1/500

in. (0.0051 cm) thick, it is quite remarkable it stands up as well as it does under this type of use.

Mechanical damage to paints, aside from abrasive wear, consists of chipping, scratching, loss of luster, etc. Chipping usually occurs to paint films that have become too thick from repeated coats or have become dry and brittle (see Figure 6). Scratches remove a portion of the paint film, or all of it, depending on the severity of the scratch (see Figure 7). This reduces the protection to the metal if the scratch is light. If the scratch goes entirely through the paint coating, the door is open for corrosive action.

The loss of luster may be due to several causes, but under the heading of mechanical damage it usually is due to repeated wiping of the paint to keep it clean. Even though the wiping is done with a soft rag, the luster gradually is worn off.

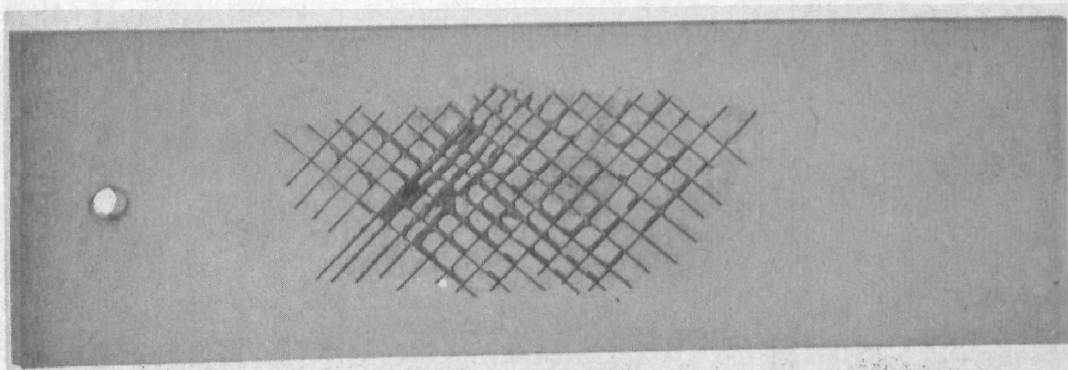


FIGURE 7.—Scratches cause further flaking away and further damage.  
(Courtesy Amercoat Corporation.)

## 5.3 METHODS OF PAINT TESTING

### 5.31 General

Laboratory or field tests are only approximations of the conditions expected to be encountered in actual service. The test for quality is durability, and no test or group of tests can replace actual exposure. However, good laboratory or field tests intelligently applied usually can be depended on to give reliable data on the physical properties of different coatings.

### 5.32 Laboratory Tests

There are three general types of tests performed in the laboratory:

1. Package and fluid properties which measure such properties as settling, floating, viscosity, specific gravity, reducibility, spraying properties, and odor.

2. Chemical and physical properties—includes chemical analysis on pigment, binder, solvent, determination of pigment volume, ash, suspended matter, etc.

3. Panel performance tests—includes tests which are based on the dry film characteristics of the material such as color, water resistance flexibility, hardness and adhesion and is conducted under accelerated test conditions. This test is considered the heart of the performance test. To be of value, it must simulate as nearly as possible actual service conditions.

The performance of a paint film will vary with the substrate used. A paint which tests well on glass or metal may be destroyed quickly on concrete. The substrate used should be the same as the substrate in actual service.

The finish used on the test panel should be exactly the same as used in actual service. Test panels should be treated physically (scraped, sanded, buffed, polished, etc.) as in actual service. The condition of the surface will affect the mechanical adhesion.

The life of a paint applied to iron and steel is determined primarily by the surface condition of the metal.

Paints are applied by spraying, dipping, brushing, roller coating, etc. The method of application to the test panel should be the same as in the field. The temperature of the substrate and the paint, the use of thinner, etc., all play a part in the rate of drying and in the appearance of the finish. They should correspond to field practices.

Film thickness is very important and must be controlled and measured. Top coats and primers should be tested together according to the paint system to be used.

The principal factors which are evaluated in panel testing of paints are hardness, adhesion, blistering, brittleness, wrinkling, softness, fading, darkening, chalking, checking, cracking, rusting, and discoloration. These are rated as slight, moderate, and extensive, or good to excellent, fair to good, and bad to poor.

It is important in estimating outdoor durability to determine resistance to moisture. Moisture can affect paint both chemically and physically. The chemical reaction is principally hydration. This is a slow reaction generally not measurable in laboratory tests but may become important in the field where the paint is immersed for long periods of time. The physical effects are colloidal, electrical, and mechanical, and largely are dependent on the nature of the paint film and the substrate. The colloidal effects are generally inhibiting. The electrical effects are caused by potential differences and mechanical effects are caused by the penetration of the water through the film. The effect of each separate reaction generally is not known, only the net effect of all three is determined.

For comparative purposes, water testing should be carried out within plus or minus 2°C in distilled water.

As a general rule, the longer the immersion period, the more severe the test.

### 5.33 Field Tests

Outdoor exposures are regarded by paint chemists as the ultimate test. Yet outdoor exposure is in itself a highly variable test. Florida exposure is used widely by paint laboratories. There is less month-to-month weather fluctuations than in other locations, and in addition the rate of destruction is much greater.

The angle of inclination of the panels is difficult to select. Exposures at 45 deg do not give the same results as vertical exposures. The angle needs to be selected to correspond with the field use.

Panels that receive dew followed by sunshine show more rapid failure than others where there is no dew. Water plays an extremely important part in the destruction of finishes even exceed-

ing that of light. Fumes and gases in the air particularly can be destructive. These observations all point to the need of locating the test panel in the same atmosphere where the use will be.

Because of the variable conditions encountered in field testing, it is important to conduct numerous tests so the results can be evaluated statistically.

### 5.34 Test Standards

Laboratory testing of paints remains an art and subject to personal interpretation despite the many instruments and scientific tests that are available. The fundamental properties of hardness, adhesion, cohesion, flexibility, etc., when judged by a trained expert generally is more useful than the results of mechanical tests. The fingernail and the trained eye become the tools of the expert to make the evaluation.



## 6. PREPARATION OF SURFACE FOR PAINTING

Too much emphasis cannot be given to the manner of preparing the surface as the most important phase of the operation of applying paint. Proper surface preparation easily can account for the major proportion of the manhours for the whole paint job. In fact, it may account for a major portion of the total cost of the job. It is most important that the surface preparation be done properly or all may be lost.

The performance of any paint application is affected profoundly by water, grease, oil, mill scale, rust, alkalies, hydrogen sulfide, sunlight, air, micro-organisms, DO, and other items including the physical qualities of the cleaned surface. Surface preparation for painting in wastewater treatment plants must take most of these enemy agents into account. The types of surfaces needing protection are more

varied than found elsewhere. Every type of construction material is involved, submerged both in wastewater and cleaner waters as well as those exposed to the elements.

The quality of the prepared surface must be judged from the standpoint of both its freedom from contaminating substances as well as its ability to provide firm anchorage for the paint applied. Since the many kinds of surfaces needing protection are common to both the large and the small plant it will at times be difficult for the operator of the smaller plant to select and use the best methods of surface preparation due to the restrictions of manpower, equipment available, and money resources. Considerable thought and ingenuity may be required, therefore, to balance resources and cost against satisfactory results.

### 6.1 TOOLS FOR SURFACE PREPARATION

Tools available for the preparation of surfaces for painting are many and of varied types. They can be divided into two basic groups, hand tools and power tools.

#### 6.11 Hand Tools

The steel wire brush is available universally in a variety of sizes and shapes to fit the need.

Scrapers also are available in many sizes and forms. Many have blades that can be resharpened. An excellent scraper can be made by reforming large flat files. The end is turned, widened, edged, and tempered. They are effective and long lasting.

The chipping hammer is available at hardware and mill supply stores.

Sand and emery paper are available almost everywhere. The so-called

aluminum oxide open-coat production papers are well suited for good abrasion and longer life. A cloth-backed emery also is available and can be used wet.

Steel wool is available in various grades. It is used normally on a smooth surface and quite often in conjunction with a cleaner.

The blowtorch or similar device often is used for intense heat application and for scale or paint removal.

There are various chemicals available that might be classified as hand tools. They are washing powders, detergents, and trisodium phosphate (TSP).

Solvent cleaning, although the least efficient of the chemical removal methods, still is used commonly to remove grease, oil, and films prior to a more

effective cleaning method. Some of the solvents are naphtha, Stoddard solvent, toluene, trichlorethylene, and mineral spirits.

Steam and water jets are used where conditions so indicate and when the apparatus is available.

Effort and patience are of prime importance and are required for all of the above tools. The workman must have had proper instruction in the use of the tools for cleaning and the work must be inspected to see that it was done properly.

### 6.12 Power Tools

The ever increasing cost of hand labor finds the use of power tools essential. If they are not a part of the plant equipment inventory, they can be leased or rented in most areas. It would be well to evaluate their cost vs. hand tools and labor.

The air or electric motor with flexible shaft is used with a disc or wheel-type steel wire brushes. There is a large range of sizes and shapes available. One company recommends a speed of 450 rpm using a working pressure of 150 psi (10.5 kg/sq cm) for thorough, fast, and economical work. The wire brushes specified were austenitic chrome nickel steel wire bristles.

Air or electric motors with rotating

heads using disc, wire brushes, or rotary impact cleaning tools are used often on steel surfaces for removal of some mill scale and rust.

Air driven paint scrapers and special chisels are available and used effectively.

Motor-driven power sanders are adapted to use discs, drums, or cones of varied sizes to suit the need. Aluminum oxide open-coat papers are used on this machine.

Sand and shot blasting equipment are efficient and effective when properly used. Blasting of steel surface will remove rust, mill scale, and old paints along with some of the base metal. There are three types of blast cleaning: (a) abrasive in a stream of high-pressure air, (b) abrasive in a stream of high-pressure liquid, such as water, and (c) the abrasive discharged from the periphery of a rotating paddle wheel traveling at high peripheral speed. The first two are known as nozzle blast cleaning. There are several types of abrasives used in blast cleaning such as metallic, siliceous, synthetic non-metallic, and nut shells.

Flame priming and descaling equipment also are used. This is a method for preparing ferrous surfaces by passing high velocity oxyacetylene flames over the surface. Flame tips are provided for the particular type of operation in which they are used.

## 6.2 PREPARATION OF STEEL SURFACES

### 6.21 Justification for Cleaning

It is fundamental that paint on steel surfaces will not adhere permanently nor prevent corrosion unless placed in intimate contact with sound, clean metal when that metal is dry.

Ferrous surfaces present the most complex problems for paint protection of all surfaces. This is due to the well-known tendency of iron surfaces to be attacked by chemical and electrochemical reactions in the presence of moisture, oxygen, and other corrosion ac-

celerators. The two main problems to be dealt with are rust and mill scale.

**6.211 Rust:**—Iron and steel products are never homogeneous in structure. Therefore, their surfaces present innumerable points of differing electrical potential. Electric currents, carried by moisture laden with soluble salts, attack the metal. At the anode, the positive pole, iron goes into solution forming ferrous hydroxide by combining with the moisture present. Simultaneously, hydrogen is released

at the cathode, or negative pole, of this minute battery. At the anode, the ferrous hydroxide formed is changed to ferric hydroxide by the oxygen present in the air. This compound is rust. The rust is insoluble and deposits onto the metal surface. Rust is hygroscopic and, therefore, tends to retain moisture to continue the battery action. Hence, the old saying, "rust begets rust." Rust has bulk and tends to create a heaving action on mill scale and paint films.

**6.212 Mill Scale:**—Mill scale is essentially an oxide of iron ( $\text{Fe}_3\text{O}_4$ ). It is formed on the surface of steel during the process of rolling the steel. It is brittle and subject to cracking and scaling. Since its coefficient of expansion differs from that of the base metal, temperature changes affect the uniformity of its adherence. Moisture then tends to seep under seemingly tight scale to form rust. Mill scale is cathodic to steel so that electrochemical action causes an accelerated local corrosion in the presence of moisture. Complete removal of mill scale immediately before prime coating is the best method of protection from its presence.

It is obvious that the presence of rust and mill scale presents a difficult mechanical problem particularly on old equipment and where angles, rivet heads, and gusset plates complicate the surface. The usual specification for the preparation of a ferrous metal surface for painting states that the surface shall be dry, free from mill scale, rust, oil, grease, paint films, and all other deposits.

## 6.22 Mechanical Cleaning Methods

Effective mechanical methods to accomplish cleaning include wire brushing, chipping and scraping, sanding, sand or shot blasting, and flame conditioning.

Hand or power steel-wire brushing is the most widely used method. The method, however, tends to remove only

the more loosely adherent scale, rust, and paint films. Power wire brushing is by far the more effective. Wire brushing in general, is considered to be a "high-spot" hitting method. It should be followed by scraping.

Chipping and scraping offers one of the least effective methods. Hand scraping removes only loosely adhering scale and paint. Power chipping hammers are not recommended since they tend to beat corrosion products into the metal and leave ridges and a roughened surface that cause the subsequently applied paint films to vary in thickness.

Sanding is only useful on small and slightly corroded surfaces that are not too irregular in shape. Sanding would be incapable of removing mill scale.

Sand or shot blasting are methods generally used for thorough cleaning of steel, both in the shop and in the field. With this method there are three degrees of cleanliness of steel which can be had.

(a) White metal blast described in Steel Structure Painting Council specifications SSPC - SP5 - 52T. This classification calls for the complete removal of all corrosion products, all mill scale, all paint, and all other foreign matter. The metal after cleaning has a light gray uniform surface with a good anchor pattern for excellent adhesion by the paint coating.

(b) Commercial blast as is described in Steel Structure Painting Council specifications SSPC - SP6 - 52T. This classification calls for a good blast but not perfect as in the case of white metal. Practically all mill scale, paint, and rust will have been removed. The surface will not necessarily be uniform in appearance. This grade of blasting also will give a good anchor pattern.

(c) Brush-off blast cleaning is described in the Steel Structure Painting Council specifications SSPC - SP6 - 52T. This classification calls for the removal of loose rust and loose mill

scale. The blast should clean the surface sufficiently to give an anchor pattern for paint coatings.

The type of protective coating to be used often dictates the type of blast to be used. The operator should be sure he provides the best blast surface he can afford economically. The blasting should be performed on days of low humidity, and it is very important that the compressed air be dry and free of oil vapor. Dry sand free of dirt is a prerequisite for good work. The blasted surface should be brushed or cleaned with dry air just prior to applying the paint. It is essential that the clean metal be painted that same day or as soon as possible for the clean metal will begin to rust and defeat the purpose of blasting.

Flame cleaning is effective for preparing steel surfaces for painting. In addition to its cleaning action, flame cleaning leaves the surface dry, warm, and in good condition for receiving paint. The flame loosens the scale and rust. As soon as the flame head has passed, the steel surface is wire brushed to remove the loose material. It is an advantage then to apply the paint while the steel is still warm. In this way, painting sometimes can be done under cold or damp conditions which otherwise might cause delay. Multiple flame-in-line heads are used ranging in width from 1 to 12 in. (2.54 to 30.5 cm) and attached to standard welding blow pipes. With a 6-in. (15.3-cm) flame head, relatively clean surfaces can be treated at the rate of 1,000 sq ft/hr (93 sq m/hr) while on heavily rusted riveted sections the rate will drop to about 200 sq ft/hr (18.6 sq m/hr). There may be considerable danger connected with the use of flame cleaning at a waste-water treatment plant, especially in confined spaces where gasoline fumes, methane, etc., may be present or where the paint itself may contain explosive types of volatiles. This method is not recommended for submerged metals.

## 6.23 Chemical Cleaning Methods

An alternate approach to the preparation of ferrous metal surfaces for painting involves chemical methods, such as pickling, weathering, phosphatizing and chromating, alkali primers, and the use of solvents for degreasing.

**6.231 Pickling:**—This method need not be considered for use in waste-water treatment plants. This process as well as bonderizing and parkerizing are strictly factory methods.

**6.232 Phosphatizing-Chromatizing:** — If a rusted surface is free from mill scale, it may not be desirable or practical to remove all the rust. The alternate method of phosphatizing depends on the principal that the normal electrochemical action can be slowed down or arrested by passivating the metal by forming an oxide layer on its surface. The Metropolitan Sanitary District of Greater Chicago recommended a solution for this purpose carrying 15 percent of phosphoric acid ( $H_3PO_4$ ) by weight of the total liquid. The liquid is also to contain a wetting agent in sufficient amounts to make the acid miscible with the water. This acid solution is to be used at the rate of 1 gal/1,500 sq ft (0.3 l/sq m) of surface. The solution is to be scrubbed thoroughly into the prepared surface and allowed to dry over night. Pools of excess liquid should be avoided or removed. No water should be allowed to contact the treated surface. When ready to apply the paint, the surface should be dry and present a sprinkling of hard, dry, white phosphate crystals. Military specifications have been written for a conditioner similar to the above and carry the number MIL-M-10578A Type II.

Chromic acid is used in a similar manner. Some of the acid inhibiting solutions offered for sale contain both phosphates as well as chromates.

**6.233 Alkali Primers:**—Another method of checking rust formation by slowing down the electrochemical ac-

tivity is to create an alkaline atmosphere at the metal surface. This procedure is based on the acid reaction of the rusting process. Red lead has an alkaline reaction which partly accounts for its long and favored use as a metal priming pigment. The suggestion of applying a preliminary coating of raw linseed oil ahead of the primer coat to drive moisture out of the pores of the metal appears to have merit.

One well-known paint manufacturer offers a metal primer whose pigment is Portland cement suspended in a linseed oil vehicle. Here again, a strong alkaline reaction is produced

at the metal surface. Zinc chromate pigments offer similar properties.

**6.234 Other Methods:**—When painting metal surfaces in damp places, such as wet wells, where it is quite impossible to attain dry surfaces, the Chicago Metro District directs that after proper cleaning of the surface it shall be washed with rags soaked in alcohol, mineral spirits, or turpentine. The surface shall be well scrubbed so as to get penetration into all cracks and crevices to drive out the moisture. The surface then shall be wiped with dry, clean cloths and the primer coat immediately applied.

### 6.3 PREPARATION OF CONCRETE SURFACES

In addition to the general and fundamental rule that surfaces shall be free from all loose dirt, scale, grease, oil, etc., concrete surfaces, especially if new, need to be "cured."

#### 6.31 Concrete Walls

When Portland cement hardens, a considerable amount of calcium hydroxide ( $\text{Ca}(\text{OH})_2$ ) is formed. If this compound is not neutralized properly, the alkaline calcium hydroxide in contact with linseed oil vehicles tends to saponify the oil, producing soaps that destroy the values of the coatings applied.

The usual remedy is to wash the surface with a solution of zinc sulfate ( $\text{ZnSO}_4$ ), using a solution of 2 lb of the zinc salt/gal (0.24 kg/l). The zinc sulfate combines with the calcium hydroxide to form zinc hydrate ( $\text{Zn}(\text{OH})_2$ ) and calcium sulfate ( $\text{CaSO}_4$ ), both of which are used as pigments in paint. This process constitutes the "curing" of the wall. A two percent zinc chloride-three percent phosphoric acid solution may be a better wash than the zinc sulfate solution. If the surfaces are sufficiently aged and weathered by time, this treatment will not be necessary. Concrete should be two years old before it can be coated safely with oil paints.

The zinc sulfate wash will neutralize the alkali on the surface of new concrete, but more will come out.

If concrete walls have been aged sufficiently and have been painted previously with water base paints or wainscoated with bituminous paints and it is desired to apply more permanent coatings such as the modern rubber base paints or enamels, it is necessary to clean the surface thoroughly by sand blasting to the original surface. This procedure at the same time "tooths" it. The further stipulation is that the first or prime coat should be brushed on. Succeeding coats may be brushed, rolled, or air applied as desired.

#### 6.32 Concrete Floors

**6.321 Free From Oil and Grease:**—Where it is desired to renew the paint on old painted concrete floors, one of three methods may be chosen:

1. The floor can be cleaned of old coatings by the use of a sanding machine. This method is very effective but extremely dusty. Such a procedure, however, has the advantage of leaving the surface well roughed so that if the prime coats are thinned properly, adherence will be excellent.

2. The old paint can be removed by

paint removers. This procedure is effective and free from the dust problem. It, however, involves the tedious job of removing the resultant solvent-film mess and the washing of the floor with turpentine or mineral spirits.

3. A third procedure could be the dry method of scraping and wire brushing. This method does not involve the dust or the muss of the other methods but it is also not quite as effective. This method, while tedious, might be the better to adopt for small areas.

In general, the method adopted must be determined by the area, room content, thickness of old films, manpower, and equipment available.

Before painting concrete floors, they should be etched with an acid solution made by diluting one part of full strength muriatic acid with three parts of water. The operator should use all safety precautions while working with acid. The solution should be prepared in a plastic or wooden bucket. Apply the solution with a stiff fiber brush. Scrub well while applying. A gallon should treat 75 to 100 sq ft (7 to 9 sq m) of surface area. When the bubbling has stopped (it takes about 20 min) flush the floor clean and let it dry thoroughly. Almost every floor paint requires a dry floor before the paint can be applied.

**6.322 Greasy Floors:**—When it is desired to paint a previously unpainted concrete floor that is impregnated with grease and oil, one of three methods may be selected, namely, a wet scrubbing method, a dry solvent method, and a caustic lye method.

**6.3221 The Wet Scrubbing Method:**—The wet method consists of a thorough scrubbing of the surface with stiff bristle brushes and a warm water solution containing 0.5 lb (0.2 kg) of trisodium phosphate, or its equal per 1 gal (3.8 l) of water. To this also should be added a sufficient quantity of a wetting agent. The scrubbing should be vigorous and the operator

should protect the hands with rubber gloves. This procedure should be followed with a thorough rinsing with clean water to remove all alkali. Then the cleaned surface should be etched with muriatic acid using a 5- to 10-percent solution by volume in water. This step mildly roughs the surface and removes the glaze resulting from too smooth troweling. Sufficient etching is indicated if a slight sprinkle of water tends to sink into the surface. The acid treatment must be rinsed completely away with clean water and the floor allowed to dry thoroughly before applying paint.

**6.3222 The Solvent Method:**—The solvent method for removing grease and oil from concrete floors consists of covering the surface with about 3 in. (7.6 cm) of saw dust. The saw dust then is soaked with a high solvent, low volatile thinner such as hydrogenated petroleum naptha. The whole surface then should be covered with a rubberized cloth or similar covering to help retain the solvent and allowed to stand for 16 to 24 hr. The solvent should be renewed as necessary. At the end of the soaking period, the saw dust layer is removed and the floor thoroughly scrubbed with stiff bristle brushes and clean solvent to remove completely all oil and grease from cracks and crevices. This process should be followed with the etching procedure described above, washed clear of acid, and allowed to dry. *The solvent method is not desirable where open flames or sparking electric equipment is present, and is in fact so dangerous as to preclude its use except by experts with special equipment. Even a spark from a shoe might set it off as an explosion.*

**6.3223 The Caustic Lye Method:**—A wet method that involves no danger from flame or spark consists of covering the floor with a thin layer of saw dust and saturating the layer with a solution of caustic lye at the rate of 1 lb/gal (0.2 kg/3.8 l) of water. This

mixture is allowed contact with the floor over night and then scraped off. The floor then is washed with hot

water and the etching treatment applied as described in 6.3221. Repeat the treatment if necessary.

## 6.4 PREPARING GALVANIZED IRON SURFACES

Galvanized iron is used in numerous structures in and around wastewater treatment plants. Often it is desirable that such structures be protected further by painting. Ninety-two plants answered a Federation questionnaire that asked if galvanized iron surfaces were painted, whether painting was satisfactory, and what pretreatment, if any, was used. An analysis of these replies showed that 63 plants painted galvanized iron, 26 plants did not paint, and 4 plants gave no reply. Furthermore, 9 plants used a pretreatment of acetic acid (vinegar), 8 plants used muriatic acid, 16 plants allowed time for weathering, 3 plants used a copper sulfate wash, and 8 plants reported no preparation. Nine plants reported that the painting of galvanized iron has proven unsatisfactory.

### 6.41 Types of Galvanized Surfaces

Types of galvanized surfaces are as follows:

1. Iron is coated with zinc commercially by an electroplating process, hence the term "galvanized." Electroplated zinc is laid on in fine plate crystals, leaving the surface smooth and bright.

2. Iron also is coated by a dipping process whereby the acid cleaned iron is "fluxed" with a solution of ammonium chloride and dipped one or more times into a bath of molten zinc. Dipped galvanizing produces a continuous non-crystalline film that is more smooth and shiny than the plated method.

3. A third and more recently developed process applies zinc as a molten spray using air pressure. This is called metallizing. The process pro-

duces a rough surface that tends to be porous. In a short time rust spots seep through.

Of the above three, dipped galvanized metal offers the better protective properties since its film is continuous and can be reinforced by multiple dippings. Its surface, however, is not adapted to receiving paint by reason of the absence of an etched surface to which the paint may bond.

### 6.42 Method of Surface Preparation

There are two common methods used.

1. The most common of all is to allow the galvanized surface to "weather," since the purpose of the galvanizing itself was to protect the base metal. Weathering produces a roughened surface by allowing time for a film of zinc oxide to form. This process changes the surface from a shiny finish to a dull gray to which paint will bond.

2. Many galvanized surfaces are damaged or need painting at the time of their installation. It is not desirable or practical to wait for weathering, so one of several primers may be used.

- (a) Vinyl wash coat which is a phosphoric acid solution can be used and a zinc dust paint is recommended as the primer.

- (b) Acetic acid also is used commonly.

- (c) Where an acid wash is not practical the telephone company has used a zinc dust—zinc oxide primer for pretreatment. This primer is a modification of Federal Specification TT-P-641.

## 6.5 PREPARING WOOD SURFACES

While wood surfaces are not as prevalent in and around wastewater treatment plants as other surfaces, the preparation of a wood surface for painting is an important item in its preservation. Moisture is the principal enemy of a good paint job on wood. Other important factors include the method of paint application and the drying time allowed between coats.

### 6.51 New Wood

New wood should present a clean, smooth, dry surface. Knots should be blow-torched to partially draw out the resin, which should be scraped off and the surface then coated with shellac. Depressions should be filled with sufficient putty to allow for contraction and later surfaced with sand paper.

### 6.52 Painted Wood

Painted wood, if the existing coatings are adherent and free from paint

defects, may be brushed clean, sanded where necessary, and repainted. Previously painted wood, however, may have such an accumulation of paint and be otherwise so defective that it will be necessary to remove it. This may be done either by thorough scraping, sanding, and smoothing the edges around sound paint areas, or else the old paint will have to be removed completely. The tedious and time-consuming job of completely removing such coatings is best done with a blow torch and scrapers. This work requires a day when there is little wind to avoid the cooling of the surface and slowing of the work, since there must be sufficient heat to soften and blister the paint film. Paint removers are likely to be too expensive for large areas. The use of caustic soda is ill advised since it tends to penetrate the surface and thus deteriorates the new coatings.

## 6.6 PREPARATION OF MASONRY SURFACES

Masonry surfaces which are to receive paint should be dry and clean of all dirt, grime, and foreign particles before painting.

### 6.61 New Masonry

New masonry should be aged prior to painting with oil-base paints for a period of 30 to 60 days. This permits the removal of moisture and in the case of lime plaster to decrease the alkalinity of the surface film.

If the water-based paints are to be

used, the drying period can be shortened to two weeks.

### 6.62 Old Masonry

Old masonry that is dirty and greasy will have to be cleaned with a hydrocarbon solvent to remove the oil and grease. Once this is removed then the surface can be cleaned with a trisodium phosphate solution using sponges. Circular motions are less fatiguing and only small areas should be washed between rinsings.

## 6.7 PREPARATION OF BRICK WALLS

Old brick walls should be dry and swept clean before they are painted. If they have been painted the scaled areas should be scraped or brushed until there is no loose material. Blasting of the surface may be necessary if all of the material is to be removed.

Brick surfaces that have effloresced will have a calcium sulfate deposit. This deposit should be scrubbed with muriatic acid solution (10 percent by volume) and then washed down.

If the walls have been marred by



soot and smoke, they should be washed with a strong soap, detergent, or solution of trisodium phosphate. After cleaning the walls, they should be

rinsed thoroughly with clear water. There may be occasions when steam cleaning will be necessary to remove stubborn stains.

## 6.8 PREPARATION OF MISCELLANEOUS SURFACES

Surfaces previously painted with bituminous paints or surfaces that have been coated with cork-asphalt compounds for insulating purposes, such as "No-Drip," should be sealed before they are painted. If this is not done, the asphalt will bleed through the paint.

Beaver board and cellulose material must be sealed properly before a paint can be used.

Surfaces that have been coated with an enamel or gloss paint or that are varnished should be prepared for re-coating by either roughing the surface with steel wool or medium sand paper. There are some solvents or chemical solutions available for application to the surface which will soften or permit the new paint to bond to the old surface.

## 6.9 CONCLUSION

The workmen who prepare the surface should be given proper instructions in the use of the tools that are to be used. They also should be shown what is expected as the minimum acceptable surface preparation. Inspection on the part of the supervisory staff is as important as any phase of the total job.

Irrespective of the type of paint used or method of application, the more thoroughly any type of surface has been prepared to receive the paint, the greater will be the dividends returned in its "life" and its protective value.

## 7. PAINTS AND COATINGS

### 7.1 METAL SURFACES

#### 7.11 Primers

The most important paint in a drying-oil painting system is the first or prime coat. Other paints in the system are, of course, important, but the efficiency of the entire paint job is determined to a considerable extent by the effectiveness of the prime coat. Its composition, thickness, adhesion to the metal, and suitability for the purpose are, therefore, all important considerations.

To be of universal service on metal in or around a wastewater treatment facility, an ideal priming paint of the drying-oil type must serve two very distinct purposes.

It must be thoroughly gas and waterproof at the surface, i.e., it not only must be impervious to moisture and acids, but it also must be gas tight against hydrogen sulfide. The hydrogen sulfide gas has a very small molecule and will penetrate most paint films. If the gas penetrates it will attack the steel and form iron sulfide. This formation, of course, destroys the paint bond to the steel and when the bond is lost the loose paint is damaged more easily by abrasion. The prime paint also must not soften appreciably when covered by accumulations of oils, greases, and soaps, nor be damaged easily by the abrasion of floating matter which usually accompanies these oils, greases, and soaps.

The paint not only must be impervious to its surroundings, but it also must furnish good bond of itself to the steel and itself provide good bond for the top coats. These several physical qualities are afforded largely by the vehicle, although the pigment does add considerably to the quality of the paint and its durability.

The pigment adds to the protective value of the paint film by increasing the paint density. The pigmentation, however, must not be so great as to decrease the imperviousness.

The size and shape and, to an extent, the composition of the pigment also affect the performance of the paint film. For instance, mica (and especially graphitic mica) when used in moderate amount adds considerably to the life and usefulness of a metal priming paint. Possibly this results because the mica in effect increases the film thickness, which is one of the factors governing the paint durability. It also is possible that the graphite in the graphitic mica spreads itself as a film on the surface of the mica flakes and being a poor wetter by water, its effect is to waterproof the whole paint film and thus prolong the paint life.

A second, even more important function of the prime coat is to "inhibit" corrosion of the metal whenever the corroding liquids eventually get through the paint film to the steel as they inevitably do.

A number of pigments function well in this respect. The best known and most used inhibitors are zinc chromate and basic lead chromate. Red lead also has been classed among the inhibitors; its most useful contribution to the paint formulation is that it furnishes a tough, impervious, and strongly adherent lead soap.

Note that a priming paint which serves well under one set of conditions may not do well at all under another set.

Steel is in many locations in and around a wastewater treatment facility where the paint remains damp practi-

cally all of the time and where hydrogen sulfide gas is abundant.

The presence of these more severe conditions in a treatment plant necessitates a somewhat different approach to the painting problem than where the conditions are more mild. The vehicle in particular must be more highly resistant to these conditions than is necessary for paints used on a bridge and on the steel of most buildings.

**7.111 Red-Lead Primers:**—When a priming paint is mentioned one naturally thinks of a red lead and oil paint and for most situations a red lead and oil paint does make a very satisfactory metal primer. Such paints have been used with success for years. Recently, however, there have been a number of other paints developed for the most severe conditions of service which have gained considerable popularity.

**7.112 Zinc Dust-Zinc Oxide Primers:**—Zinc dust-zinc oxide paints are very useful for painting new galvanized sheet metal and for touching up the threads and damaged spots of new galvanized pipe. It also has been found that zinc dust-zinc oxide paints serve very well as a touchup prime coat in a repaint job to be finished with one coat of aluminum. It also has been used as an all over prime coat under the one coat of aluminum. These paints are rather expensive as compared with other primers, however.

**7.113 Iron Oxide-Zinc Chromate:**—In plant construction it is always convenient to standardize on one priming paint for use everywhere irrespective of where the steel is to be used. Top coats applied after erection can be varied according to the location to combat the peculiarities of the exposure, but the engineer cannot very well tell the fabricator to vary his shop coat on different parts of the work according to where the steel is to be placed. Such instructions, if given, would result in endless confusion and countless errors. Even in maintenance repainting work it is less bothersome to stock one type of prim-

ing paint so that the painters can use it everywhere. This practice reduces the amount of stock necessary for the storekeeper to have on hand. Such a paint, however, must be designed for the worst conditions encountered in the plant if it is to be applied generally.

Some waste treatment plants have standardized on iron oxide-zinc chromate as a single metal primer for general use. This has given very good service, except that it does not seem to be suited to use in very damp atmospheres such as are encountered in screen houses and grit chambers and also on the underside of the roof of water tanks.

Neither is the red metal primer suited to painting new galvanized surfaces where zinc dust-zinc oxide paints have proven better. Otherwise, the red metal primer has been found to outlast most other paints, even in submerged locations, if it is applied correctly to properly prepared surfaces and properly covered by suitable top coats.

The primer has a marked advantage over red lead as a shop coater in that material painted today can be shipped out tomorrow without a great deal of damage being done to the paint by the handling. It also appears to endure exposure to sunlight and weather without being protected by top coats better than does red lead. A red metal primer paint formulation is as follows:

	Percent by Weight (volatile free basis)
Zinc chromate (P44)	22.80
Red lead (ASTM D83-41)	1.63
Red iron oxide (P42)	19.54
Graphitic mica (P43)	17.91
Crystalline silica (P33)	3.25
Grinding varnish (V37.25), nonvolatile	34.87
Total Nonvolatile	100.00
Pigment to nonvolatile vehicle ratio $\frac{1}{2}$ to $\frac{2}{1}$ .	

Note: This ratio is varied according to the fineness of the grind. Drier (V75) is

**7.114 Vinyl Primers:**—This is a two-part formulation. The primer base is mixed with the primer liquid before using. Because of chemical changes which take place when allowed to stand for long periods of time that affect the adhesive qualities of the paint, only the amount to be used for one day's operation should be mixed at a time. When used properly, vinyl paints have a tenacious adhesion and toughness superior to most conventional varnish-type primers. Vinyl paints can be immersed immediately in water since they cure in water as well as in air. The primer will tolerate slight moisture condensation on the metal without harm to its adhesion qualities.

Coatings made from these resins exhibit great flexibility and are resistant to most caustic and acid solutions. They are almost totally unaffected by oils, greases, and aliphatic petroleum solvents. Their resistance to salt solutions has enabled them to be used for painting ship bottoms.

## 7.12 Top Coats

Under this heading those paints are discussed which are suited more particularly to use on steel over the previously described drying-oil primers, although some of these paints may be used directly on metal without interposition of a primer. This broad subject will not be covered fully; however, some of the more important factors which govern their proper selection will be pointed out.

Top coats serve (a) to protect the prime coat, as for instance from the full effect of continued immersion in water and from the softening effect of the oils, greases, and soaps, and

added to make the paint dry to touch in not less than 4 hr and dry hard in not more than 20 hr. Thinner also is added but is not to exceed 50 percent by weight of the total vehicle. 1- $\frac{5}{8}$  lb (0.74 kg) of lecithin is added as a wetting agent to each 100 gal (380 l) of the paint as made.

the abrasion of floating matter; (b) to decorate the surface, as in an office or laboratory; and (c) they may serve both to protect the prime coat and to decorate the surface, as for instance outside in the sunlight where the decorative coats shield the varnish of the prime coat from the effects of actinic light; also in a screen chamber where the decorative coats protect the prime coat from the full effect of the atmospheric moisture and hydrogen sulfide.

**7.121 Bituminous Coatings:**—Bituminous coatings of various kinds have been used for many years on both iron and steel but usually without interposition of a prime coat. (Here in mentioning a prime coat we do not include the application of a clear coat of bitumen which is sometimes done to make a heavier coat bond better to the surface. The prime coat referred to is that used to inhibit corrosion and also to waterproof the surface.)

Bituminous materials are supplied in four different forms:

- (a) as a hot coat material,
- (b) as a cutback paint,
- (c) as an asphaltic varnish, and
- (d) as a water emulsion.

**7.122 Hot Coats:**—Most engineers are familiar with the hot tar dip which often is prescribed for use directly on the metal of cast iron pipe. Engineers know from experience that this coal tar dip in most situations provides excellent protection to the metal, especially in underground work.

In fact, it may be said generally that if a heavy hot coat of either coal tar or asphalt could be applied uniformly without pinholes or flaws and if that coating material could be designed so that it would remain intact without alligatoring, cracking, or flowing in the sunlight and weather, it would provide about the best protection for underground and under wastewater treatment plants because these

hot coat materials are quite waterproof and, while they may be somewhat softened, are not affected seriously by the oils, greases, and soaps present in wastewater and resist damage by floating debris very well. Unfortunately these high ideals usually are not attainable. Coal tar tends to alligator and flow in hot weather and crack in cold weather when exposed for one reason or another, and asphalts by nature are not entirely water and gas tight, although very thick coatings approach tightness.

When the article to be coated can be dipped into bitumen, as is cast iron pipe, or where the hot material can be spun on the interior, as often is done inside large pipes, applying it to considerable thickness, the coating can, with care, be made almost perfect, uniform, even, and free of pinholes, skips, and other flaws. However, when a hot coat is applied to steel construction already erected, the hot material must be daubed onto the surface. Experience has shown that it is very difficult to daub on a hot coat in this way without leaving pinholes and flaws which can be detected by an electric brush drawn over the surface and which, of course, detract from the protective value of the coating.

Hot bituminous coatings, or in fact any other type of bituminous coating, protect the steel only by being water and gas tight. If they are not water and gas tight they furnish no inhibition of corrosion such as do prime coats containing zinc or lead chromate.

It is important, therefore, that bituminous coatings be quite thick and that they be applied as a solid, continuous film over the surface.

**7.123 Cutbacks:**—From the standpoint of the protection afforded, cutbacks are by far the poorest of the four types of bituminous coatings. While they often display a bright and pleasing appearance when first applied they are almost never water and gas tight.

Cutbacks have two faults. First, the solvent used, particularly in the coal-tar cutbacks, is very likely to lift the prime coat and thereby greatly diminish its usefulness. Second, cutbacks harden by evaporation of the solvents and thinners. As the volatile leaves the coating the bitumen which is left behind begins to stiffen. The volatile then forms concentration centers to which the remaining volatile drains to escape. These points of thinner concentration are the last places in the film to dry. As the bitumen is freed of the volatile it shrinks because of a reduction of volume and as it shrinks it draws away from the centers of thinner evaporation so that in the end when the film is wholly dry these vortices remain as little wells which do not close because the bitumen by that time is too stiff to flow back into the holes. The film, as a consequence, remains pervious to water and gas.

**7.1231 Asphaltic Varnishes:**—Asphaltic varnishes are made by cooking gilsonite, wurtzilite, or elaterite (which are ancient solidified forms of asphalt) with tung oil or linseed oil or combinations of the two and then thinning to working consistency. They are true varnishes; the asphalt reacts as a kind of resin to combine with the drying oil.

The varnish films, when dry, are quite waterproof, but are quite sensitive to oils, greases, and soaps. They then are not suited to submerged wastewater application but do fairly well applied in several coats on surfaces submerged in clean water. They make fairly good black paints for use inside, even in rather damp locations. They are not so satisfactory for outside painting because of the action of sunlight.

**7.1232 Bituminous Emulsions:**—Bituminous emulsions are usually dull and uninteresting in appearance. They are, however, quite water and gas tight when dried in thick coat-

ings and they do not alligator. They harden by precipitation of the bitumen when the emulsion "breaks." In hardening they solidify from the bottom up so that there is no tendency to form pinholes as is the case with cutbacks. They, therefore, present a solid, uniform, and continuous film when dry. Neither do water emulsions lift the prime coat as do some of the cutbacks since the water is not a solvent for the primer. The emulsion must dry for at least two weeks and preferably for a month before it is submerged or it will re-emulsify.

**7.1233 Chemical Emulsions:**—Soap emulsions have not proven to be as good as the clay emulsions in submerged locations. So-called chemical emulsions where the emulsifying agent is made very small in percentage also are said to be suitable for submerged conditions.

In making the clay emulsion it should be specified that the clear emulsion, in addition to the bitumen and clay (required for its emulsification) shall contain 10 percent by weight of zinc oxide (powdered variety). Zinc oxide is used not only to keep the emulsion alkaline so that it does not so easily re-emulsify, but also that zinc may be present to arrest any hydrogen sulfide which may try to penetrate the film to the steel.

To the clear emulsion add asbestos fiber in amount equal to 13 percent of the total weight to make the asphalt cling together better when the emulsion is being applied in a heavy coat and also make it remain better in place when it is softened by the oils, greases, and soaps of wastewater. Two grades of fiber are used, 1/3 being what is commercially known as 7-M grade, and 2/3 being what is called asbestos pulp or float.

**7.124 Grease Coatings:**—These consist of bituminous waxy compounds made rust preventive by the addition of chemical rust inhibitors. Beside being applied easily and quickly, they

seem to be the answer to some of the most annoying rust problems. The surface to be protected need not be thoroughly clean and dry. Any heavy rust or loose paint should be chipped off. The grease coatings are non-drying or semi-drying. They gradually soak through the rust and coat the underlying metal. Further corrosion is stopped. The film remains soft and plastic and can be described as normally self-healing. Any damage beyond self-healing is repaired easily without any surface preparation. Grease coatings obviously cannot be used in places where a workman would come in contact with them because of their non-drying nature. A grease coating would rub off on clothing.

### 7.13 Pigments for Decorative Paints

Before taking up decorative paints in detail, it will be well to consider first the suitability of various pigments for use in such paints in and around a wastewater treatment facility. The number of pigments which can be used in top coat paints exposed to wastewater is rather limited because sewage gas and especially hydrogen sulfide reacts chemically with many of the pigments to change their color. Carbon dioxide, another constituent of sewage gas, also reacts with some of the pigments to change their color. Sulfur dioxide from industrial gases may cause a similar darkening of certain pigments.

It is desirable, therefore, to know something about the behavior of the various pigments when they are contacted by sewage or industrial gas.

While it may not be complete, the following list of pigments is believed to include all of the common color pigments which have been found satisfactory for use in decorative paints at wastewater treatment facilities.

Whites: Zinc oxide, zinc sulfide, titanium dioxide.

**Blacks:** So far as known none of the blacks are affected by sewage gas.

**Oranges and Yellows:** Cadmium and selenium sulfides. Hansa yellow is stable but quite expensive. International orange (dinitroaniline) also is quite stable.

**Greens:** Chrome oxide green is an excellent color not affected by sewage gas.

**Blues:** There are no very good blues.

**Reds:** Practically all iron oxide reds are stable.

**Browns and Grays:** Any derived color which can be made of any combination of the above color pigments almost certainly will be stable. Of course, dark shades of gray and brown show less darkening by hydrogen sulfide, even though some of the pigments may be affected.

#### *Metallic Powders and Pastes*

**Aluminum:** Turns slate color due to formation of aluminum hydroxide which is white and presence of impurities like copper which darken it.

**Zinc:** Whitens due to formation of zinc oxide and zinc sulfate.

**Bronze:** Blackens due to formation of brown-black copper sulfide.

**Chrome:** Unaffected by sewage gas.

### **7.14 Machine Enamels**

The engineer often wants larger and more showy pieces of equipment like pumps, motors, blowers, and the like to have a high gloss. This requires the use of an enamel. The principal difference between an ordinary paint and an enamel is that a paint is designed for durability and protection, while an enamel is designed more particularly for appearance. Usually the pigment volume is made somewhat less in the enamel than it is in a paint, but the same effect may be accomplished by choosing pigments which have low oil absorptions.

Machine enamels must be very flexible since the machine temperature is often subject to wide variation as between the cold end of a blower or pump in the winter and the hot end of the blower in the summer. They also must be resistant to the lubricating oils and greases and particularly to the oil which a mechanic uses to wipe off the dust and dirt from the machine. On a steam turbine the enamel must withstand steam leakage and perhaps a temperature up to 350°F (176°C) on uninsulated trim. It also must withstand blows from wrenches and other tools and abrasion from other equipment coming in contact.

The pigment nonvolatile vehicle volume ratio in many enamels is usually made 1 to 3, but in black enamel, because of the flattening effect of carbon black, the ratio is 1 to 4.

A good metal primer first should be applied evenly on the surface to be painted. When this is dry it should be sanded lightly to remove the gloss. A suitable machine filler then should be applied all over either with a brush (if the surface is already quite smooth) or with a knife (if it requires considerable filling to bring the surface level). This filler should be smoothed out to an even, uniform surface.

When the filler is fully dried and hard, it should be sanded thoroughly to make the surface perfectly smooth, after which a thin coat of clear phenolic varnish should be applied all over to seal the filler against entrance of moisture and oil. This seal coat should be lightly sanded, after which the enamel coats of paint may be applied, sanding between coats. Usually two coats of enamel will be sufficient. If, however, the enamel coatings as applied still do not produce the gloss which the operator desires, a clear coat of varnish may be added over the enamel.

**7.141 Vinyl Coating System:**—The best known vinyl coatings are those

based on vinyl chloride-vinyl acetate co-polymer. These coatings at normal temperature are inert and unaffected by strong or weak acids and alkalies. They are not affected by water or animal and vegetable greases and therefore are well suited for use in wastewater treatment plants. They are applied usually as a system consisting of primer, intermediate, and finish coats. Vinyl paints require more coats than other types of paint because the film per coat is thin. Extensive and careful surface preparation is imperative and application by skilled painters is essential. As many as six to nine coats are required. They are used on the underside of the roof of a steel water tank and also on the metal equipment and steel construction in a screen house or a grit chamber and on the metal parts of a vacuum filter drum.

The system is made up of three different paints, each serving a different purpose and applied in a specified order: primer, intermediate coat, and top coat.

**7.142 SDC No. 232 Wash Primer:**—The primer is shipped as two separate solutions which must be mixed together just before the paint is applied and the application must be to an absolutely clean steel surface which means that in most cases the steel must be sandblasted or pickled. The dry thickness of the wash primer should be between 0.3 and 0.5 mils.

The intermediate coat material must be interlaced between the primer and the top coat because the latter will not bond to the former but will bond to the intermediate coat and the intermediate coat will bond satisfactorily to the primer. The dry thickness of the intermediate coat should be between 3 and 4 mils.

The co-polymer of vinyl chloride and vinyl acetate which affords the high resistance of the system to untoward conditions is the top coat. It usually is applied in several coats and may be of various colors.

The total dry thickness of the top coat should be between 3 and 5 mils except in the submerged locations where the thickness should be doubled.

**7.143 Vinylidene Chloride Paints:**—Another group of paints closely related to the vinyl type of paints is the vinylidene chloride type. The two types are about equally satisfactory for use in damp places if each is applied properly to clean surfaces.

The paints are highly resistant to most chemicals and quite impervious to moisture. The paints are made both as alcoholic-ketonic solutions of the resins and as water emulsions. Both types within certain limits can be pigmented as desired. The prime coat contains the zinc chromate for inhibiting the corrosion while the top coats afford the waterproofing. They, therefore, afford very good protection to the steel.

The water emulsion types are of particular interest because they not only afford good protection to the steel, but they also can, to better advantage than most other types of paints, be used in confined quarters such as on the inside surfaces of a water tank or on the interiors of vacuum filter drums.

These paints and the vinyls have another advantage which is of interest to a plant operator where sludge is being filtered and dried. When the metal parts of the drums of the vacuum filters are painted with ordinary paints, the sludge adheres to the paint so that a considerable cake builds up on the surface. The filter drums then come to have an unkempt, neglected appearance. When painted with either the vinyl or the vinylidene chloride types of paints, the painted surface sheds the sludge and the filters look cleaner and better cared for.

The vinylidene chloride paints should be applied to an absolutely clean metal surface; the metal must be free not only of all organic matter, oil, grease, and soap, but also of all old paint and mill scale. When



cleaned the surface then should be treated with phosphoric acid to afford the best bond before applying the paint.

**7.144 Oleoresinous Enamels:**—Outside paints require a vehicle which will retain its elasticity over long periods of time. Of the many oleoresinous enamels on the market, the type based on a phenolic tung oil-linseed oil varnish of medium oil length has been used satisfactorily in wastewater treatment plants. Its

chemical resistance is very good and its outside life satisfactory.

**7.145 Alkyd Type Vehicles:**—Alkyds are synthetic resins based on a combination of certain alcohols such as glycerol with certain acids such as phthalic. Alkyd types of vehicles are quite satisfactory for use in outside paints where the conditions are not too damp. They will keep cleaner in industrial atmospheres than will the linseed oil paints.

## 7.2 NON-METALLIC SURFACES

### 7.21 General

Non-metallic surfaces in a wastewater treatment plant when painted are, as a rule, painted only to improve their appearance. In a few cases the painting may be to brighten up some dark corner for operational reasons, but protection of the underlying surface is rarely an important consideration. In this respect the painting of non-metallic surfaces differs radically from the painting of metallic surfaces where the preservation of the metal is the prime reason for the painting. Non-metallic surfaces often painted are those of concrete; plaster; brick, stone, and cement-block masonry; heat insulation; and wood.

In view of the fact that the preservation of the underlying surface is not the primary purpose of the painting of most of these non-metallic surfaces, the basis of the paint selection is reduced to a consideration of the one question: How will the paint react to its surroundings? Most decorators are familiar with these problems in the ordinary situation, but they may not be so familiar with the special conditions which prevail around a wastewater treatment plant.

One of the first things to note about plant exposures is the presence and the effect of sewage gas on the color of paints.

### 7.22 Walls and Ceilings

The walls and ceilings of offices, laboratories, pumping stations, and other buildings where wastewater is not in direct contact with the atmosphere of the rooms to saturate it are not particularly difficult to paint. Very often the effect of the sewage gas on the color is the only special matter to command attention. The surface to be painted, however, may itself require special consideration and treatment.

Very little trouble has been experienced in painting the walls and ceilings in these relatively dry rooms when the concrete, plaster, and brick are first primed with one coat of aluminum paint consisting of  $\frac{3}{4}$  lb (0.34 kg) of aluminum paste to 35-gal (138-l) phenolic varnish. Over this seal coat one can apply a flat paint of the color desired. This top coat paint also is made usually with a phenolic varnish vehicle, because often these surfaces do become damp and the phenolic varnish is reasonably resistant.

When the surface to be painted is very porous or very damp, or where the underlying material contains an alkali, some special provisions may need to be made. These surface conditions often require some kind of seal coat.

1. Where the surface is very absorbent the porosity will cause what is called "suction" whereby the top coats are robbed of their vehicle. Since this suction usually varies over the surface, the texture and color will become mottled. This mottling of the texture and color is objectionable in that it spoils the artistic value of the paints.

2. Where the concrete, plaster, or masonry is still green and damp at the time or where the wall or ceiling remains damp due to seepage, the top coats must either themselves not be subject to damage by the moisture, or they must be protected by an undercoat which will waterproof the surface.

3. Where the cement, the plaster, the aggregate, or the tempering water contains an alkali and the walls or ceiling either remain damp continually or are occasionally wet, the top coat must either itself be of a nature that is not subject to saponification or it must be protected by an undercoat which will not be affected by the alkali.

Sometimes none of the above three conditions require a sealing of the surface and sometimes only one or two of them cause trouble. Where any of them are present the paints next to the concrete, plaster, or brick must be suitable.

Sometimes the decorative paint itself will seal pores of the surface sufficiently and resist the moisture and saponification, but very often a sealer underneath the color coat is required. One of the best of these sealer coat materials (which also may serve as the decorative coat if desired) is a polystyrene paint made from resins.

If the conditions are very bad, especially in basements, tunnels, and storage rooms and also on brick, concrete, and block walls, serious consideration should be given to the use of a portland cement paint which will not only seal the surface, but also will serve to decorate.

A workable formulation is as follows:

	Percent by Weight (measured dry)
Portland Cement	40.0
Sand (Well graded but all passing No. 16 mesh and not more than 5 percent finer than the No. 200 mesh.)	59.7
Either Ammonium or Calcium stearate	0.3
Total dry materials	100.0
Water added to make a creamy mixture.	

Where the wall surfaces are rough like those of cinder block, a stiff fiber brush like a fender brush produces the best coatings. Where the surfaces are smoother like a brick wall, a softer fiber brush like a roofing brush gives the best coatings. The coatings must be well rubbed into the pores of the wall or ceiling to make them bond well to the surface.

The above discussion relates to the painting of walls and ceilings in relatively dry rooms where the walls and ceilings themselves may need some treatment before the paints can be applied properly. There are rooms, however (such as those in a screen house, an operating gallery, or a grit chamber), where the atmosphere of the room is always in contact with wastewater and, therefore, always near saturation. Sometimes the outside walls and ceilings of these rooms are very thin and uninsulated so that moisture from the atmosphere will be condensed on their inside faces especially in the winter when they are cold. The surface then may remain wet for weeks or even months at a time. Unless the paints used on these surfaces are very water resistant they will be damaged greatly by this continued saturation. Moreover, if the moisture freezes on the surface, some of the paints which might be used will

be pried off by the frost action (as for instance a cement wash paint).

The polystyrene paints are probably the most satisfactory ones to use under these circumstances and a phenolic varnish type probably the next best coating material.

The best solution to the problem, however, if it can be done, is to cover the cold surfaces with standard sheet insulation to prevent the walls from becoming so cold. If that solution seems impracticable a somewhat less effective measure would be to spray on a heavy coat of insulmastic cork paint or no drip as suggested for use on "sweating pipes." The insulating value of these materials depends greatly on their dry thickness so they should never be made less than  $\frac{1}{2}$ -in. (1.3-cm) dry thickness for this purpose. Since these are bituminous materials it will be necessary to paint their exposed surface with at least one coat of aluminum paint when they are thoroughly dry before applying any color coats to prevent the bitumen from bleeding through into the top coats. The number of coats of aluminum required will depend on how dry the bituminous coat is at the time of painting.

In connection with the painting of walls and ceilings for decoration a word should be added concerning the architectural value of different kinds

of paints. Gloss paints generally are not considered to be so good architecturally as are flat paints when used over large flat areas because the lights and shadows of the reflection from the gloss paint brings out all of the unevenness and imperfections of the surface which is painted. Since it shows up all of these imperfections in the workmanship, the gloss seems to cheapen the appearance of the whole construction.

On the other hand, flat paints seem to level out these imperfections so that they do not appear. The quality of workmanship of the entire job, therefore, seems to be enhanced. The flat paints then for this reason are considered architecturally better than are the gloss paints.

Gloss paints, however, are usually, but not always easier to keep clean because the dirt does not adhere to the surface easily. However, if the vehicle of the flat paint is fashioned of a hard varnish it, too, will shed the dirt fairly well. Most engineers choose the flat paints for their walls and ceilings where they want the rooms to look well.

The new silicon water repellants are very satisfactory for use on masonry, and paints can be applied over them if desired. The silicon water repellants should be applied when the masonry is new, before effluorescence begins.

## 7.3 CONCRETE FLOORS

Concrete floors to be painted must be clean and free of all material which will detract from the life of the paint. When properly made and thoroughly cured and dried, ready for painting, the pores of the surface should be open, clean, and unfilled and the whole surface free of dust and moisture. Occasionally concrete floors need to be pretreated with the zinc chloride and phosphoric acids as discussed above for walls and ceilings.

Rubber-base paints are probably superior to water-cement paints for concrete in general as they are easily cleaned and washed and are more resistant to corrosive gases and fumes. Most of these coatings are based on chlorinated rubber or butadiene-styrene co-polymer. They possess remarkable resistance to humidity, acids, alkalis, and other destructive agents. They are unaffected chemically by the lime found in all masonry. This

should be kept in mind when painting concrete. Rubber-base coatings are marketed in attractive colors. Color selections should be made from the

wide range of colors which do not contain lead pigments. Colors based on lead pigments are unsuitable for wastewater treatment plants.

## 7.4 WOOD WORK

Wooden floors should be made of dry, well-seasoned lumber, and their surface should be machine sanded to bring to an even, smooth finish. Traverse the floors sufficiently to remove all warpage and unevenness. Corners and inaccessible areas along walls where the machine cannot enter should be hand-scraped and sanded to an equivalent even surface.

After this primary leveling the whole surface should be gone over with fine sandpaper or steel wool to polish it.

The floor then may be either waxed or varnished using a phenolic varnish.

Wooden baseboard, window and door casings, and other wooden construction around a wastewater treatment plant are subject to rot due to the prevalence of moisture. For best service all wooden construction should be treated with penta-chlorophenol or equal fungicide and then all hidden surfaces preferably backprimed with aluminum paint. The joints, after fitting but before fastening together, also should be coated with this same aluminum paint if possible to keep out the moisture.

The face surfaces may be either varnished, waxed, or painted. Wooden floors are better when they are painted on the back face (bottom) surface.

Laboratories are sometimes furnished with wooden-topped chemical tables. The wood for this purpose should be hard and close grained, free of knots and other imperfections. The surface should be sanded to a smooth, even surface before finishing.

“Carbonized black acid-proof finish” has proved to be very satisfactory applied in two solutions composed as follows:

### Solution No. 1

Chlorate of potash	300 g
Chloride of copper	360 g
Water	4 l

### Solution No. 2

Anilin hydrochloride	600 g
Water	4 l

A full treatment consists of four applications. Each application consists of one coat of solution No. 1 applied and dried, after which two coats of solution No. 2 are applied and dried.

Sufficient time is allowed between coats for the wood to dry thoroughly. After each complete application of three coats and when the last coat has become thoroughly dry, the surface is washed with clean water and again allowed to dry before proceeding with the next application of three coats.

After the final coat of the final application has dried completely and the surface has been washed and dried, the surface is given a full coat of raw linseed oil thinner with about 15 percent by volume turpentine to which mixture sufficient cobalt drier shall be added to make the oil dry within 8 hr.

If necessary, to fill the pores of the wood, additional coats of linseed oil as above specified shall be added and dried, after which the surface shall be rubbed to an even color, dull black finish.

## 8. APPLYING THE PAINT

### 8.1 GENERAL

Proper application of paint is very important, sometimes more important than surface preparation, depending on the amount of labor involved. It is estimated that the cost of this phase of the work is about 65 to 75 percent for labor, and 25 to 35 percent for materials, regardless of the method used. Painting is not as simple as slipping a brush up and down or passing a spray gun in the vicinity of the surface. On the contrary, there are many fine points to painting, which spell the difference between a lasting job and one that must be repainted prematurely.

Many different methods of applying protective and colorful finishes are used today. However, since the con-

cern here is in the application of paint in a wastewater treatment plant, only brush and spray methods will be considered.

Painting of plant structures should not be for show purposes only, even though painting for appearance sake is often desirable; such programs ought to be the exception rather than the rule. Too frequent painting should be avoided because it wastes labor and material, adds to fire hazard, and may cause paint failure by cracking from the added film thickness. It may be found that soiled surfaces which are subjected to a treatment with a scrub brush, rather than a paint brush, may be the wisest move.

### 8.2 BRUSH APPLICATION

The brushes selected should be of the proper style and quality to permit the paint to be applied efficiently and with minimum effort. By improper use high quality brushes can be ruined making them unfit for the next job. It is better to use a fully oversized brush than an undersized model. Pure bristle brushes are the best but their cost may prohibit their use on all types of work. Excellent results are obtained if the bristles are animal bristles, deformed nylon, or other comparable material that is capable of holding maximum amounts of paint on the brush. Brushes made of pure bristles exterior and horeshair interior are less expensive and satisfactory for large flat areas. Synthetic brushes are finding favor in all applications as they are less expensive and tougher than natural brushes and provide longer wearing life with rough service.

New brushes must be broken in similarly to a new pair of shoes. In the absence of the brush manufacturer's breaking-in instructions, a new brush may be soaked in raw linseed oil from 48 to 72 hr to prevent the porous bristles from absorbing pigment particles. This will make the brush more flexible, easier to clean, and better to use. The brush should be wrapped before suspending it in linseed oil by folding it in heavy paper to cover the bristles from the ferrule to the tip. This will allow the brush to hold its shape when it is rested on its end. The soaking should be followed by washing in mineral spirits or turpentine until all excess oil is removed. The brush now is ready for use.

To keep the brush in good condition, clean the coating material from it immediately after every use, even for an overnight interruption.

If a brush has been used in:

1. Paint, enamel, or varnish
2. Shellac or alcohol stain
3. Lacquer
4. Water or casein paints
5. Epoxies

To clean the brush:

Use turpentine or equivalent synthetic solvent.  
Use alcohol as a solvent.  
Use lacquer thinner, preferably by the same manufacturer who made the lacquer.  
Wash out immediately in plain cold water.  
Use lacquer thinner or preferably use the thinner or cleaner as recommended by the manufacturer.

Be sure to work the solvent well into the heel. When all paint has been removed, the brush should be washed in warm sudsy water, rinsed in clear warm water, dried, and wrapped in paper to protect the bristles. Do not allow the brush to stand on its unsupported bristles as this will force it out of shape.

It is important that paint cans be opened in the proper way, keeping the cover flat and unbent so that it can be used again. If a skin has formed on the surface of the paint, remove it carefully and discard it. The paint must be thoroughly mixed and thinned in accordance with the directions of the manufacturer before using. If there are particles or skins dissolved at this point, remove them by straining the paint through a wire screen or cheesecloth.

At the completion of the present work the remaining paint should be stored properly. Pour the unused paint into smaller containers, seal, then place in a cool, dry place. If the original label has been lost, it is well to label each can in front showing formula number and date of manufacture. By placing the oldest cans in front, they will be used first when the next job is started. Turn the cans bottom up at least every six months.

In applying paint to the surface it

is important to get the correct grip on the brush. The brush is held well up into the hand with the first three fingers resting on the metal band in position so that it is at a 45-deg angle to the surface of the work. The brush is dipped into the paint a distance half the length of the bristles which is far enough to load the brush, without dripping. Pat the brush gently on the inside of the can, not the edge, to remove excess paint. At all times paint should be kept from getting into the heel of the brush. Its accumulation there can cause a great deal of trouble.

Brushing should be done in a manner that will provide a smooth coat of uniform thickness. Brushes should be kept full of paint, and excessive brushing should be avoided. Apply the paint with short brush strokes depositing uniform amounts with each stroke; brush paint thoroughly into all surface irregularities; finally, smooth or level the paint film with longer strokes at about right angles to the direction of the first strokes allowing only the tip of the bristles to drag so that a film without deep brush marks will result. Always brush paint toward rather than away from the freshly painted or wet edges. Work paint well into crevices and corners. Brush out all sags and runs in the film.

### 8.3 SPRAY-GUN APPLICATION

The easiest method of painting large or irregular surfaces is by means of a spray gun. With this method a painter with sufficient know-how in

handling this equipment can apply a coat of paint in either a thick or thin film far more evenly than he can with a brush.

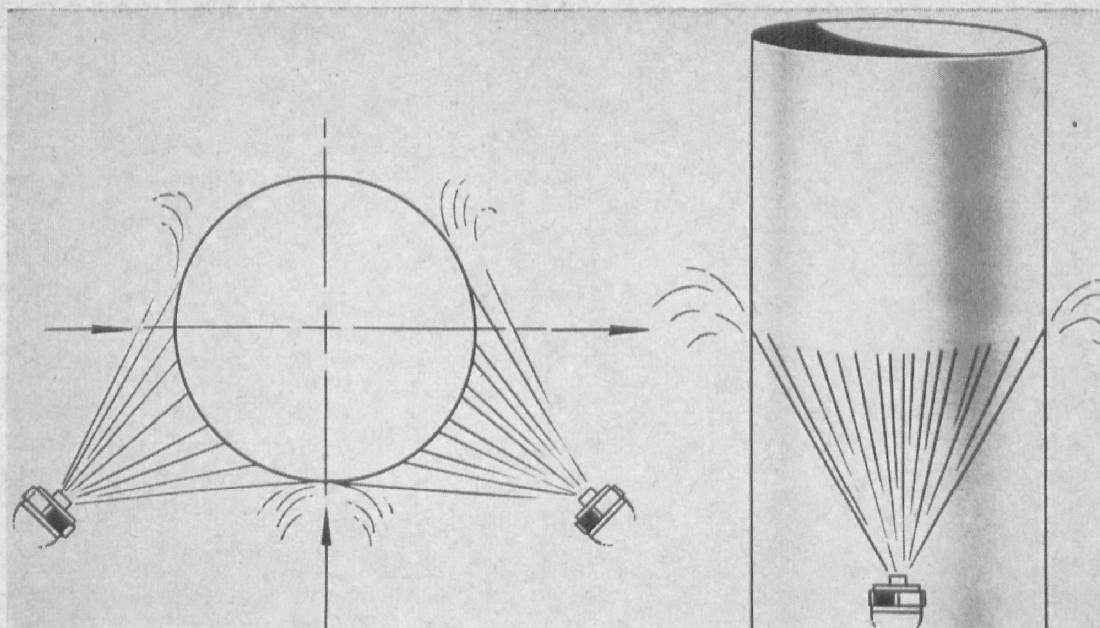


FIGURE 8.—Spray painting is fast but must be done thoroughly and properly to assure complete coverage. (Courtesy Amercoat Corporation.)

Spray equipment must be capable of properly atomizing the paint and be suitably controlled with pressure regulators and gauges. Separators should be in the lines to provide a means to drain the oil and condensed water periodically from the compressed air. Spray guns, air caps, nozzles, needles, and pressures should be used as recommended by the paint manufacturer as best suited to handle his product. Directions governing the use and limits of airless spray apparatus and paint atomizing devices, as given by the equipment manufacturer, should be followed strictly.

Pressure on material in the pot and of air at the gun should be adjusted for optimum spraying effectiveness and to suit changes in elevation of the spray gun over the pot, air pressure at the gun should be high enough to atomize the paint properly, but not so high as to cause excessive fogging of paint, excessive evaporation of solvent, or loss of material by overspraying. Manufacturers of spray painting equipment have done a splendid job in providing illustrations of the opera-

tion, care, and maintenance of this apparatus, so only a brief comment for comparison with brush painting will be made.

In application, the spray gun is held at a distance from 6 to 10 in. (15.2 to 25.4 cm) away from the work. The stroke is made with a free arm motion. Keep the gun perpendicular to the surface at all points of the stroke since a sweeping or arc stroke will cause uneven application. Release trigger at the end of each stroke while the gun is still moving and start gun moving at beginning of next stroke so gun is in motion when trigger is pulled. Direction of spray strokes should be toward rather than away from edges. The pattern of paint deposited at each stroke should overlap the edge of the pattern last deposited. When film thickness requirements make multiple layers necessary within a single coat, subsequent layers should be applied at right angles to the direction of the one previously applied. All runs and sags in the film should be brushed out immediately or the paint should be removed and the surface repainted.

## 8.4 THINNERS

Never thin any paint more than is absolutely necessary. The necessity for thinning usually is present only under certain circumstances as (a) in cold weather to get a paint to flow easily, (b) for spray painting if the paint is not specifically formulated for spraying and if the proper adjustments of the spray equipment and air pressures do not permit a satisfactory paint application, and (c) on porous surfaces where absorption is

rapid the thinner serves to carry a protective coating of paint into all pores, cracks, and crevices.

For a list of thinners suggested for various types of paint, and the maximum amount to be used, always check the manufacturer's directions on the paint container as to how much and when to use. Basically the amount of thinner to be used should never exceed  $\frac{1}{8}$  gal/gal.

## 8.5 ATMOSPHERIC CONDITIONS AND TEMPERATURES

Painting may be done at any time during the year if certain rules are born in mind, chief of which is that the weather should be clear, dry, and warm. Paint should not be applied to exposed surfaces in rain, snow, fog, mist, frost, dew, or other forms of moisture. Relative humidity of the surrounding air should not exceed 85 percent.

The air temperature should not be below 40°F (4.4°C) and the work should never be done after a sudden sharp drop in temperature, or if the

temperature is expected to drop to 32°F (0°C) before the paint has dried. The best results can be secured for paints if they are applied at temperatures above 70°F (21°C) which is considered normal.

In applying heat resistant paints, they should be put on at temperatures between 60° and 100°F (16° and 38°C) in a thin, even coat, and allowances for setting of at least 3 hr must be made before the temperature is returned to the highest point.

## 8.6 DRYING TIME

The basis of the theory for drying is varied according to vehicle constituent. For instance, linseed oil products dry by oxidation, tung oil base paints by polymerization, lacquers and spirit finishes by evaporation, and thermal setting resins utilize heat for drying.

Many factors influence the speed with which paint dries: (a) slow drying often is caused by oil, wax, or grease under the paint film; (b) the type of surface often varies the drying time as metals or other hard surfaces absorb none of the paint and tend to cause slower drying; (c) cold weather retards drying; (d) hot, dry weather

speeds up drying; (e) extremely humid atmosphere will retard drying; (f) no circulation of air slows the drying process; and (g) a thin coat dries fastest.

Dryers, in addition to those already in the paint, are not recommended because excess dryers tend to produce a brittle, short-lived paint film. It is suggested that, when in doubt, dryers should be omitted.

Many paints dry hard enough for normal use in a few hours or at most, a day; but no paint film reaches its maximum hardness for several days.



## 8.7 NUMBER OF COATS

Generally five mils are considered the minimum total dry film thickness for a paint system applied over steel surfaces. It is necessary to know the spreading and flow properties, mixing and thinning limitations, drying characteristics, and safety requirements for handling many types of paint relatively unknown a decade ago. There are a bewildering number of generic types and sub-types of paint formulations available, all of which have their individual characteristics and behavior patterns. They range from the alkyds, through bitumens, chlorinated rubbers, epoxies, furanes, hydrocarbons, metallics, neoprenes, oil-based materials, phenolics, styrene polymers, urethanes, and vinyls to the zinc-rich formulations often mistakenly used alone as priming coats in paint systems.

Surfaces which are to be coated for the first time, or which are found to be relatively porous, will soak up large amounts of paint. In such instances the first step should be an application of a size or sealer which has the faculty to bridge the pores or fill them at the surface, thus reducing suction or absorption of the paint. As a consequence, these compositions are very helpful in saving paint and providing uniform appearance.

Before painting any wood surface, all knots and resin deposits should be covered first with a thin coat of shellac before the prime coat is applied. This would be followed by the undercoat on which is applied the finished coat in one or additional layers.

Concrete surfaces which are in good condition usually must be coated with some type of approved filler and sealing compound. The chief danger and cause of paint failure is due to the fact that the concrete may contain moisture which will force the film from the surface. A practical test for moisture is made by fastening a rubber

mat on the surface to be painted and allowing it to remain for two or three days. If moisture collects on its underside, it is necessary to wait until the concrete is thoroughly dried out. All cracks first should be filled with suitable compound before any surface treatment begins.

In repainting surfaces which have been coated previously, it is well to observe the following. Nearly all asphalt paints will bleed through the surface of any ordinary paint put over them. This may be retarded by a heavy coat of aluminum paint which will help to seal the asphalt and give a good base for any painting coat. Do not try to paint over any calcimine work as this must be washed thoroughly from the surface before another paint is applied. Oil paints and enamels should not be applied over casein paints on wood surfaces without priming. Paint derived from coal tar products contains volatile substances which constantly evaporate and will tend to stain any paint put over them. There are no definite suggestions to be made for painting over tarred surfaces. The best solution where surfaces are coated with cold water paint is to remove all of the old paint before applying the new. Aluminum paint usually will resist the powerful bleeding action of creosote although it should never be applied before the creosote has been weathered for at least 10 weeks, in order to allow the volatile oils to escape. Lacquer cannot be used successfully over other paints because certain of its ingredients are very strong solvents, often being used in paint removers, which cause the paint layers on which it is applied to lift.

The first coat always should be brushed carefully over all parts of the surface so that all cracks, openings, and holes will receive enough paint to

wet the surface. Openings and cracks should be filled properly as soon as the primary coat is dry. After about a week, if the atmosphere has been clear and dry, this should be dry enough to receive the second coat. Sometimes breaks appear in the surface of a paint coating which rather resemble the appearance of an alligator hide. This is sometimes caused by the application of hard finishing coats over a soft primer or especially before the primer has thoroughly dried. A priming coat should be allowed to dry thoroughly and it always should be as hard or harder than the outer coats.

Subsequent coats should be applied carefully, the number dependent on the service or life expected. For ordinary work both interior and exterior, a good prime coat followed by a single finish coat is satisfactory. Often times, after a good scrubbing a previously painted surface can be brought back as good as new with one coat. Locations in damp areas or where subjected to corrosive liquids or gases will require special paints and an increased number of coats. Heat resistant paints are placed in a thin, even

coat, with one coat being sufficient on interior surfaces. For underwater painting, two prime coats are recommended followed by the last coat before the water is reintroduced. It has been reported that it takes a minimum thickness of four coats to prevent salt water penetration, which is good advice to the wastewater treatment plant operator for many areas. Since fewer coats may result in a paint job with weak spots, it is well in multi-coat work to vary the color of each successive coat slightly so as to avoid any skips or misses.

It is a wise operator who heeds the sign for changing the paint guard from time to time. When the gloss has gone from the paint or the colors begin to look washed out, it is a warning that it is time to change the guard. The usual life of a good exterior paint coating is from four to five years. There are on every structure, however, some danger spots such as edges, corners, crevices, rivets, bolts, and welds which, when they reveal the need for painting, usually indicate that an entirely new job is needed for the structure.

## 8.8 SAFETY PRECAUTIONS

Some painting must be done in confined areas. Unless provisions are made to change the supply of air the paint fumes will cause dizziness and finally fainting. It is well to watch for the danger signs. Headaches or dizziness are warnings to get out in the fresh air. Most paint materials are highly inflammable and must be handled with care, avoiding contact with flame or heat. Saturated oily rags in confined places can catch fire through spontane-

ous combustion. Removal of paint from the skin with solvents may cause irritation so it is a good precaution to keep the body covered as much as possible. Ropes, ladders, and safety belts always should be inspected before a job is started. The paint bucket should be secured thoroughly when working from heights, and other tools should be anchored to prevent their falling on persons passing underneath.

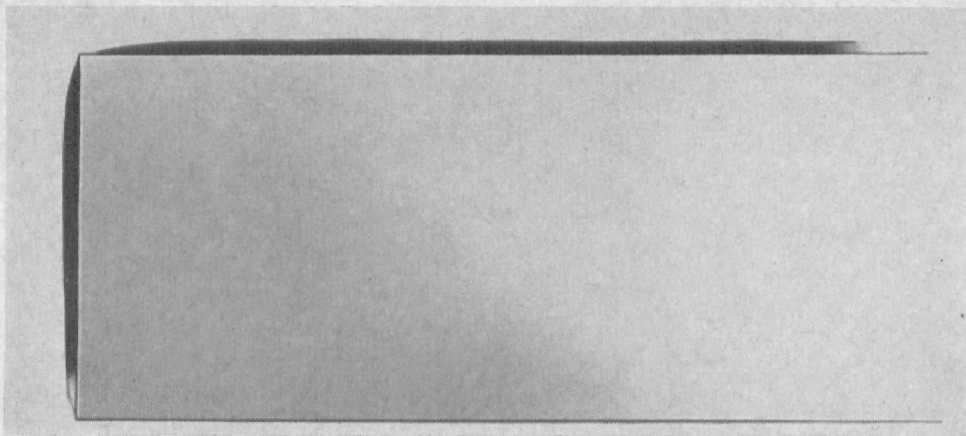


FIGURE 9.—Paints and protective coatings pull back from sharp edges; care must be exercised in application. (*Courtesy Amercoat Corporation.*)

## 8.9 SUMMARY

Adherence to a few general rules will help to insure a satisfactory paint job.

1. Surface dryness and preparation to prevent moisture from breaking out beneath the paint film.

2. Sufficient number of coats, not to be too thick as they are applied.

3. Removal of part or all of the old coating that has become too heavy.

4. Thorough drying of each coat before another one is applied.

5. Proper use and care of tools and the correct type of paint for each particular job.

6. Consideration of the importance of weather and temperature on the outcome of the work.

## 9. MISCELLANEOUS FACTORS IN GOOD PAINTING PRACTICE

The main factors used in good painting practice have been discussed in previous chapters of this manual.

Some of these factors will be reviewed again.

### 9.1 SURFACE PREPARATION

Surface preparation of metals and concrete for painting are difficult jobs at times due to the moisture and gas conditions found in nearly all waste treatment plants.

The most common method of cleaning metal surfaces involves wire brushing, scraping, then washing the surface with a phosphoric acid solution. The surface also may be washed with mineral spirits, turpentine, or alcohol. The prime coat should be applied immediately.

To paint wet or damp pipe surfaces, wash with hot water along with a

good cleaning compound, such as trisodium phosphate, dry pipe by wiping with turpentine or alcohol, and paint immediately.

A handy tool for cleaning rust and scale can be made from worn rasps or mill files. They make fine surface scrapers when fitted with a handle.

Woodwork usually is cleaned by wire brushing, blow torch, sandpaper, or some chemical remover of paint. In the priming of woodwork, the paint should be thinned with turpentine to permit the first coat to soak into the pores of the wood.

### 9.2 PAINTING PROBLEMS

Bleeding, peeling, and blistering of the paint coating has caused trouble on many jobs. Bleeding often happens when applying paint over tar or creosote. Peeling can result from a poor foundation being provided by the primer, a poor grade of paint, or too thick an application. Blistering is caused by moisture being trapped beneath the paint film or high temperatures before the oil has set.

Driers should be used very sparingly as they tend to shorten the life of the paint film. The thinner recommended by the paint manufacturer always should be used.

The primer is the real life of the paint job and should be selected and applied carefully. The ideal primer should have a hard tenacious film, good waterproof qualities, and rust-inhibiting pigments. The prime coat should

be harder than the finish coat. A soft undercoat may cause the finish coat to crack.

No painting should be done except in dry weather. Paint should not be applied in foggy, frosty, misty, or snowy weather, or when temperatures are below 40°F (4.4°C). The best results will be obtained when temperatures are around 60°F (16°C) or higher.

Whether the paint is applied by spraying or brushing does not matter too much. Good results can be obtained by either method if the paint is applied properly under favorable conditions. Spraying is considered the best for cold-weather conditions. Again some say that brush application of prime coats promotes good adhesion, while spraying is satisfactory for top coats. Brush application is used on

most small jobs. Some of the advantages claimed for spray painting are: three or four times faster, smoother and more even distribution of paint; better penetration on porous surfaces; and more economical. Adjacent equipment such as motors, switch gear, speed reducers, and similar equipment within reach of spray painting should be protected by adequate covering. This procedure will add to the painting cost.

The painting of wire fences is a task that confronts many wastewater treatment plant personnel. The problem is how to do this rapidly and effectively, without wasting paint or getting it all over other areas beside the fence. There are two methods which have proven satisfactory. One involves spraying the paint on the fence, using a movable backboard fitted with a drain trough across the bottom to catch the excess paint for reuse. The other method involves application of

the paint by means of a large diameter roller with extra long nap on the sheepskin covering.

How often to repaint is a question often asked at wastewater treatment plants. It is much more economical to keep a paint job in good repair than to wait until a greater part of the coating has been destroyed and then paint. No two plants have the same conditions to deal with on the paint problem. The paint problem seems to be much more serious in northern latitudes than it is in warmer climates. Where metal is exposed to moisture and gases it may need touching up once in six months or possibly once a year, depending on the exposure. Most outside exposures are painted on the average of every two or three years. Mild exposures may be all right for four to five years. Records should be kept of the painting or repainting of all structures and equipment, including the date, method of cleaning, kind of paint, number of coats, etc.

### 9.3 USE OF PAINT FOR IDENTIFICATION AND SAFETY

To many wastewater treatment plant operators, paint is just a cover and protection applied to conceal the earmarks of use and time and to protect against the effects of wear, weather, and corrosion; but paint is useful in other ways such as for identification. When this characteristic is utilized, series of pipelines can be identified readily as to function. The identification code as recommended in the Great Lakes-Upper Mississippi River Board of State Sanitary Engineers, Recommended Standards for Sewage Works (Ten-State Standards), is as follows:

**Painting:** The use of paints containing lead should be avoided. In order to facilitate identification of piping, particularly in the large plants, it is suggested that the different lines have contrasting colors. The following color scheme is recommended for purposes of standardization:

Sludge line—brown.

Gas line—red.

Potable water line—blue.

Chlorine line—yellow.

Sewage line—gray.

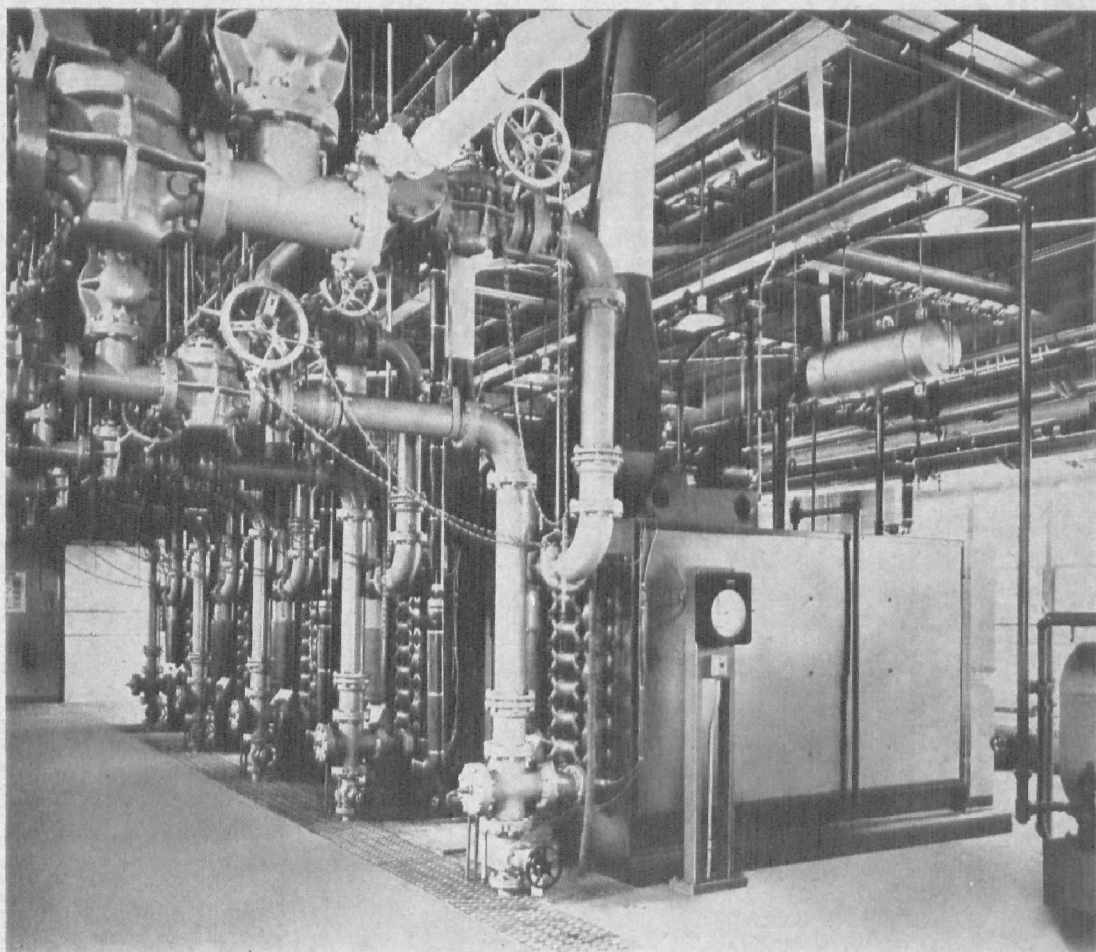
Compressed air line—green.

Water lines for heating digesters or buildings—blue, with a 6-in. red band spaced 30 in. apart.

Protruding ledges, low over-head pipes, beams, unexpected steps, or curbings will draw attention when spotlighted by some contrasting color. Paint also is useful for beautification even though this is a secondary purpose. The tasteful use of colorful paints can contribute much to the attractiveness of any plant. Paint, teamed with light, can provide a daily tonic of considerable value.

Color can flash danger warnings, locate vital equipment, identify machine parts, and brighten the rooms of the





**FIGURE 10.**—Paint can be both functional and attractive as illustrated at the Mill Creek Water Pollution Control Plant, Cincinnati, Ohio. (Courtesy Inertol Company of Koppers Company, Inc.)

plant. Applied to machines, the first job of color dynamics is to separate the critical from the non-critical parts of the machine. The critical or operating parts of the machine should be given a color that comes quickly to the eye, a color that stands out in strong contrast to the stationary or non-critical parts of the machine. This is known as a focal color because it focuses the worker's attention exactly where it should be—on the working parts of the machine.

There are certain receding colors which are used to cause the non-criti-

cal parts of the machine to drop back. "Machine gray" has been used to a certain extent for this purpose. Green is considered one of the best receding colors as it has a relaxing effect on the human eye. The wide spread of green by nature in the forests and field is the proof of this color.

Color applied to the walls and ceiling of a room will produce a feeling of cheerfulness and restfulness along with good visibility. Color not only has a physiological effect on the worker's eye and body, it also has a physiological effect on his mind.

**PAINTS AND PROTECTIVE COATINGS FOR  
WASTEWATER TREATMENT FACILITIES  
—MOP 17**

Technical Practice Committee, Subcommittee on Paints and  
Protective Coatings

1969

New Manual of Practice No. 17, title as above, is intended to provide designers, operators, and maintenance personnel of wastewater collection and treatment facilities with the fundamental theory and practical aspects of the need for, choosing, application, and maintenance of paints and protective coatings.

**Keywords:** coatings, corrosion, corrosion control, corrosion effects, corrosion environments, corrosion prevention, maintenance, (Manual of Practice), painting, paints, plants, protective coatings, sewage treatment, (Water Pollution Control Federation).

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