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DESIGN FOR CORROSION CONTROL OF POTABLE
WATER DISTRIBUTION SYSTEMS

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An exhaustive review was made of the literature on corrosion problems and their control as they pertain to domestic water and water distribution systems. Information obtained is combined and presented in a manner suitable for convenient and and efficient use by designers responsible for new construction at the various United States Air Force bases; it covers the many corrosion-related variables encountered with respect to source of water supply, storage tanks, mains and the distribution lines for both hot and cold water essential to supplying domestic

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ABSTRACT (Cont'd)

water at these bases. Methods of reducing the corrosion of metals used in these systems are considered, first by identifying potential causes for corrosion in the soil and other external environments to be encountered and in the domestic water itself. Many different procedures to anticipate and control corrosion are presented, including the use of protective coatings, cathodic protection, and plastic composites as a substitute for metals. Problem areas such as galvanic corrosion, proper surface preparation and techniques for application of protective coatings are considered. Guidelines are given that combine economic considerations with practical corrosion control procedures that will give the most efficient service life compatible with a projected time-of-use requirement.

CONTENTS

Section		Page

ii

Section I

INTRODUCTION

1.1 PURPOSE

The purpose of this report is to provide the latest corrosion
control design procedures for potable water and water distribution sys-
tems for Air Force Base construction. The objective is to achieve maximum
protection against corrosion per construction dollar and thereby avoid
unnecessary corrosion breakdowns.

1.2   E

This report discusses corrosion control procedures for new construc-
tion for potable water and water distribution systems. It includes wells,
standpipes, storage tanks, mains, and hot and cold water domicile service
lines. This report primarily concentrates on design procedures for metals,
but also considers plastics as they completely eliminate most corrosion
problems and are being more widely used.

1.3 COST OF CORROSION

Corrosion costs for the United States have been estimated at 20
to 30 billion dollars per year. Costs due to corrosion include:

    a. Loss of plant equipment

    b. Loss of product

    c. Contamination of product

    d. Repair or replacement of equipment

    e. Pollution of environment and attendant clean-up costs and/or
       fines.

1

f. Medical expenses due to injuries or loss of life.

g. Service interruptions.

h. Deteriorated public relations.

In the past 5 to 10 years many technical developments have occurred in the field of corrosion. In order to properly assess these developments and their field applicability, a survey of the literature and of current industrial techniques for combating corrosion has been made. The findings of this survey were used as a basis for the preparation of this report.

Section II

SITE SELECTION

Site selection should be based on, among other things, environmental conditions which would lead to minimum corrosion. Such factors as the corrosivity of the soil, the atmosphere, and the water should be taken into consideration along with the ease of installation and maintenance.

2.1 DETERMINATION OF CORROSIVITY

2.1.1 Corrosion Surveys

A corrosion survey consists of the determination of soil and water composition, resistivity, pH, water table level, and for existing structures, corrosion potential measurements.

2.1.1.1 Soil Corrosivity. The characteristics of the soil at the site of a facility are important from a corrosion standpoint because of the necessity to bury many different metal components in the soil. Therefore, before specifying materials or protective measures for these materials it is necessary to conduct a complete soil survey to determine its corrosiveness. One of the most accepted and used methods for classifying a soil is by measuring its resistivity. If time permits, these resistivity measurements should be made during wet and dry seasons to determine the variations to be expected in resistivity. The resistivity is influenced by a number of variables which also influence the corrosivity of the soil: water content, salts such as nitrates, chlorides and sulfates, degree of aeration, soil conductivity, etc. The lower the resistivity the more corrosive is the soil.

Other variables which contribute to the corrosivity of the soil are the pH and the presence of anaerobic bacteria.

2.1.1.2 Water Corrosivity. There are two types of water to be considered in water corrosivity: one is ground water present at the site; and the other is the water necessary for human consumption, boiler feed water, cooling, etc., which may be obtained from wells, municipal water supplies, rivers or lakes.

The ground water is indigenous to the site, and its chief function is to act as an electrolyte to conduct an electric current through the soil and to contribute to the resistivity of the soil. Its efficiency as an electrolyte is determined by the chemical compounds it dissolves from the soil. Therefore, when the soil resistivity is determined, the corrosivity of the ground water is also indicated. Measurement of the pH also contributes to the determination of water corrosivity.

Knowledge of the chemistry of the water supply is essential in order to determine whether it is satisfactory for its many uses as obtained from its source or whether it is necessary to treat it before use. The most important elements and ions to consider are calcium, magnesium, sodium, potassium, chlorides, sulfates, nitrates, carbonates, and bicarbonates. In addition, dissolved gases, such as oxygen, carbon dioxide, and hydrogen sulfide, are important. Other factors of importance are pH, hardness as $CaCO_3$, and alkalinity.

2.1.1.3 Atmospheric Corrosivity. Atmospheres differ from area to area depending upon the type of activity in the area. The different areas can be divided into rural, urban, sea coast, industrial, coastal-industrial, etc. The corrosivity of the atmosphere in any selected area is determined by the pollutants present, plus the temperature variations, wind speed and direction, and humidity. Therefore, an atmosphere survey should be made at the selected site to determine its corrosivity. Such information will be necessary to the design engineer in determining what materials or what protective measures should be employed.

2.1.2 Results of Operating Similar Systems in The Area

If there are existing installations of a similar nature in the area, an evaluation of the operation of these installations should be made for equipment shutdowns, problems, or maintenance related to corrosion. Plant operating records should be reviewed, where available. Weaknesses in corrosion design should be particularly noted as indicated by unplanned shutdowns or maintenance expenses. Particular attention should be paid to shutdown periods and a determination of the causes of shutdown should be established. If the shutdowns are due to corrosion, then clearly, proper precautions and corrosion control procedures should be taken into consideration. The results from operating similar systems are perhaps the most valuable tool that a corrosion engineer has, and it should not be overlooked when consideration is being given in design work to the type and extent of corrosion protection necessary to establish adequate corrosion control.

2.2 ENGINEERING CONSIDERATIONS

There are certain basic engineering design considerations which should also be followed. These are:

a. Design for easy cleaning and drainage.

b. Design for easy component replacement where service failure is anticipated, e.g., modular construction design.

c. Avoid high localized stress concentrations.

d. Avoid dissimilar metal contacts.

e. Minimize or exclude air.

f. Avoid heat transfer hot spots.

g. Join by welding rather than riveting.

h. Use smooth wide radius bends in piping systems.

i. Avoid metallic contact with absorptive materials.

j. Avoid high velocities.

2.3 OPERATING CONSIDERATIONS

Operating conditions also play a role in corrosion design requirements. Factors such as ambient temperature, chemical composition of the water, and frequency of use should be considered. Continuous operations usually result in less corrosion and less maintenance requirements than intermittent operation where parts are left unattended or in a static condition for long periods of time. Water flow through structures aids in the removal of corrosion buildups from crevices, eliminates corrosion products or deposits, and will generally reduce corrosion. For this reason, flow or continuous use is desirable from a corrosion standpoint, rather than static conditions or intermittent use.

2.4 ECONOMIC CONSIDERATIONS

If the operating life required for a given installation is extremely short, then little to no corrosion protection may be required. On the other hand, if the base is to be a permanent installation, it may be economical to expend the necessary engineering design effort and construction costs in order to obtain long-term corrosion-free operation of base water systems.

In all construction work economic factors must be taken into consideration. These factors include initial costs of the materials, construction, and follow-on costs of maintenance. Follow-on costs

involved in additional corrosion protection may be high, and must be taken into consideration in the original design considerations. For example, adding anodes and rectifiers may cost two or three times as much as the cost of the original installation of the same equipment.

2.4.1 Initial Costs

The initial costs will include the costs of the structure and the cost of corrosion protection established for the structure. The choice of the material and the corrosion protection system will depend on economic factors as well as on the design life of the structure. These in turn will be controlled by available funds, the desired life of the structure, and the nature of the site where the construction is required.

2.4.2 Maintenance Cost During Estimated Service Life

In determining what type of structure and corrosion protection should be designed to minimize corrosion, the estimated service life must be considered. Also, anticipated maintenance costs for the various structures, systems, and corrosion protection devices, over the estimated service life should be such that the sum of original cost plus the maintenance costs are minimum per year of required service. For example, if a cathodic protection system is being designed, great care should be exercised in the initial design to be sure that the system will provide the current required not only initially but during later stages of operation without major redesign of the system. Current requirements usually increase during the life of a system as a result of coating degradation. Additions to a cathodic protection system during the life of the system become very expensive as compared to initial costs. The replacing of anode beds or the replacement of rectifiers with greater capacity is costly and may be difficult after other adjoining structures are in place. Therefore, it is usually wise to allow for such contingencies in the original design of the cathodic protection equipment. Often a figure of two to three times the initial current requirement is arbitrarily used for determining the size of the rectifiers and the anode beds required. The same comments also apply to coating systems. The least expensive coating system often will become the most expensive coating system in terms of cost per square foot per year. It is, therefore, important that the engineer designing a cathodic protection or a coating system consider not only initial cost but maintenance costs for the time period it is estimated that the structure will be in use.

2.4.3 Direct Loss (cost of piping, etc.)

Direct loss costs relate to replacement costs of the structure should the structure become inoperative or completely lost due to corrosion. However, it should be borne in mind that these replacement costs

can be minimized or eliminated by using the proper materials in tne original design. Once a structure is in place and other building or construction has taken place nearby, replacement may be many times the original cost.

2.4.4 Indirect Loss

As the title indicates, indirect loss does not relate to the direct loss of the structure and replacement of the equipment involved, but relates to other losses involved in a corrosion failure. Some of these losses are discussed below, along with considerations which should be borne in mind in designing for corrosion control.

2.4.4.1 Loss of Product. In establishing a design for a corrosion protection system, the cost of the product involved should be considered. If a perforation in a tank or line would involve the loss of product, then appropriate measures for protecting the structure should be employed. On the other hand, if the product is relatively inexpensive, for example water, less precaution would be called for in the design of corrosion protection systems when considering the loss of product only. Refer to subsection 2.6 for discussions of the dangers involved in a high-pressure water line washout or a water tank failure.

2.4.4.2 Loss of Operating Time. If a base or a production facility's down time is damaging to overall operation and must be minimized, this fact should be considered in designing and installing an adequate corrosion protection system. On the other hand, if the equipment is not critical in the operation of a base, or if there is auxiliary equipment available which may be used in the event of a breakdown, then failure of the equipment due to corrosion and loss of operating time becomes a less important factor.

2.5 MAINTENANCE CONSIDERATIONS

2.5.1 Ease of Maintenance

Whenever there is a design option, in the choice of pipeline routing, the routing shall be through open areas. The routing shall be such that washout damage would be minimized in the event of a rupture. Likewise, storage tanks for water shall be situated in open areas, away from other structures, so that a rupture would cause minimum secondary damage.

It is desirable to avoid placement of pipelines under or near other construction. Cathodic protection interference and maintenance problems can be greatly increased by adjacent pipelines or other

structures. Sufficient room shall be specified in original design layouts
to allow for easy access for corrosion control measurements and mainte-
nance requirements. Facilities should not be located so close to one
another as to preclude ease of maintenance.

2.5.2 Frequency of Visits

Cathodic protection, corrosion rate probes, etc., require regular
attention. Site lay-out, design for control panels, read-out equipment,
etc., shall be such that they will be readily available for frequent
visits. If the base is remote, and if visits are infrequent, then addi-
tional back-up equipment shall be specified to increase reliability,
or to advise personnel of unplanned equipment shutdown.

In corrosion design, it has been found that structures easily
maintained will be maintained to a much greater extent and more effec-
tively than structures which are difficult to maintain. Test leads for
corrosion rate instruments, for potential and current readout for cath-
odic protection, and ladders for inspection and maintenance should be
considered in corrosion design. Test leads are very important and should
be placed during initial installation at convenient locations for perti-
nent read-outs. Structures should not be crowded together; sufficient
working area should be allowed for easy access.

2.6 SAFETY CONSIDERATIONS

Any water storage tank or pressure line should be located so that
rupture or catastropic corrosion failure would not endanger personnel.

Although there is no fire hazard with water, high-pressure washouts
or dumping of large volumes of water can be dangerous and expensive.

For the above reasons, the design of water systems shall take
into account the possibility of corrosion, and sufficient allowance
should be made to prevent catastrophic failure during the anticipated
life of the facilities. The original design wi'l also take into account
ease of application of remedial measures which .aay be required during
the life of the structure to minimize corrosion.

2.6.1 Property and Personal Liability

When designing for corrosion protection systems the liabilities
involved, such as property and personal, should a failure occur must
also be taken into consideration. The personal liabilities would have

to do with any personnel injuries. Property liability would include equipment loss and could also include ecological damage, such as erosion of the soil or washout damage. The possibilities of such losses due to corrosion failure should be considered in designing for corrosion control.

2.6.2 Ecological Damage and Clean-Up Expenses

Much emphasis has been placed upon ecological considerations within recent years. For this reason, in any corrosion design, attention should be paid to the ecological factors involved in the event of a corrosion failure and a washout with attendant spillage of product, either from leaky pipelines, failed tanks, or other structures. With respect to tankage and other large volume reservoirs, the costs involved in repairing washouts should also be considered in corrosion design. Washouts become particularly dangerous when large volume tankage or high-pressure water lines are situated on high ground. The nearby down-slopes are susceptible to serious and costly erosion should corrosion failure occur.

Section III

CORROSION AND CORROSION CONTROL OF EXTERNAL SURFACES

This section is concerned with all external metallic surfaces which are subjected to the corrosive variables of the environment. This includes pipes, tanks, supporting structures, and any metals exposed to the atmosphere or buried in the soil. There are two ways of combating corrosion of these external surfaces: use materials which are insensitive to corrosion or use protective systems which will preserve the materials for the required service life.

3.1 CLASSIFICATION OF ENVIRONMENT

In order to design the facility at the selected site for the maximum maintenance-free performance the corrosion-inducing characteristics must be known. That is, what are the aggressive characteristics of the atmosphere and the soil at the site.

3.1.1 <u>Atmosphere</u>

The chemical composition of the components of the atmosphere should be determined.

Rural atmospheres are very seldom polluted and, as a general rule, are not considered corrosive. The amount of corrosion normally expected from rain, air, and sunshine is minimal. In coastal environments the atmosphere may be laden with sea salts, the degree depending upon the direction of the prevailing winds and the proximity to the ocean. In this case, the protective measurements employed should be resistant to sea salt air.

In industrial atmospheres the types and concentrations of the pollutants should be known to effectively combat their corrosive effects. Some of the more prevalent pollutants are sulfur dioxide (SO_2) gas, sulfide gases, chlorides, and nitrates. In coastal-industrial sites the sea salts in addition to any industrial pollutants contribute to the corrosivity of the atmosphere. In industrial sites the protective measures have to be tailored to combat the particular pollutants.

10

3.1.2 Soil

Soils vary widely in their physical and chemical characteristics which in turn affect their corrosivity towards metals. Soils consist essentially of four types of substances: mineral matter, organic matter, water, and air.

3.1.2.1 Effect of Moisture. The moisture content of a soil greatly affects its corrosivity. This is due to the decrease in the resistivity with the increase in the moisture content up to a point near saturation. It should be pointed out that it is the ion content of the electrolyte (water) that determines the resistance to the flow of an electric current, which plays a part in underground corrosion.

3.1.2.2 Effect of Aeration. In well-aerated soils, the iron compounds have been oxidized to the ferric state $Fe(OH)_3$. These soils have a red or yellow color. In poorly aerated soils, due to the low oxygen content, the soils are generally gray in color, indicating the presence of reduced forms of iron.

Size of soil particles has a definite relation to aeration and ability of soils to retain moisture. Differences in size of soil particles may cause the formation of concentration cells. Metals in well-aerated soils (larger soil particles) will be cathodic to metals in poorly aerated soils due to finer soil particles.

Aeration factors are those that affect the access of oxygen and moisture to the metal and, thereby, affect the corrosion. Oxygen can be from either atmospheric sources or available from the reduction of salts or compounds in the soil. This oxygen may tend to stimulate or retard the corrosion process, the quantity available being the controlling factor. Oxygen when present in large quantities will form insoluble compounds at the anode and thus retard corrosion. Oxygen when present in ordinary quantities will stimulate the corrosion process by combining with hydrogen released at the cathode. In ordinary quantities, oxygen may also combine with metal ions which have migrated away from the anode. This combination further increases the rate of corrosion. Oxygen when present in small quantities or absent will not affect the corrosion process, and corrosion will proceed at a minimum rate.

Some specific examples will illustrate the effects of well-aerated soils and poorly aerated soils.

On large diameter pipelines, the upper portion of the pipe usually is in soil that is well aerated, whereas the lower portion of the pipe is in soil that is poorly aerated. This causes the bottom of the pipe to corrode due to the formation of a differential oxygen cell with the anode on the bottom.

11

Where pipelines are installed in cross-country areas, a different type of aeration cell is formed. The soils in the open are more aerated than the portions in compacted areas such as highway and railroad beds. Pipelines exposed to such conditions will generally corrode more readily under the compacted areas because of the difference in aeration.

3.1.2.3 _Classification_. Soils are classified according to physical and chemical characteristics rather than from their geologic origin or geographic location. There are two general classifications in the United States, those in which lime accumulates in the subsoil and those in which it does not. The soils in which lime accumulates in the subsoil lie west of a line from northwestern Minnesota to a point on the Gulf of Mexico 100 miles north of the Mexican border. East of this line lime does not accumulate in the subsoil.

The simplest criterion for estimating the corrosivity of a given soil is its resistivity, which depends largely upon the nature and amount of dissolved salts in the soil, and is also affected by the temperature and moisture content, compactness of the soil, and presence of inert materials, such as stones and gravel. Obviously, the resistance of the electrolyte (in this case, ground water) is one of the factors that affect the flow of the current associated with corrosion. If other factors are constant, there is a relation between soil resistivit· and corrosion. Such a qualitative relationship is shown in the following tabular arrangement for steel products:

Resistivity Range (ohm-cm)	Corrosion Classification	Corrosivity Class
<700	Very corrosive	1
700-2000	Corrosive	2
2000-6000	Moderately corrosive	3
>6000	Mildly to noncorrosive	4

Since the resistivity of a soil changes with its water content and degree of aeration, it is recommended that resistivity measurements be made three or four times over a period of a year in order to obtain the variation with different seasons of the year and different moisture contents.

3.1.2.4 **Miscellaneous**. There are several other factors or phenomena that are difficult to classify because they are a combination of one or more of the previously mentioned causes of corrosion.

12

Bacterial action, another factor that influences underground corrosion, is associated with aeration and the formation and presence of soluble salts. Bacteria are not only the simplest but also the most numerous forms of soil life. Certain forms, aerobes, thrive in the presence of air but other forms, anaerobes, function best in the absence or near absence of air. Each type of bacteria produce different chemical products. For example, there is one type of bacterial action whereby sulfur-containing proteins and other organic combinations are transformed to hydrogen sulfide or elemental sulfur, and, if much air is available, these products are subsequently oxidized to the sulfite and sulfate conditions. However, the bacteria that has received the most attention in studies of underground corrosion is the anaerobic bacteria, spirovibrio desulfuricans, which extracts oxygen from the sulfate radical and thereby converts soluble sulfates to iron sulfide. It has been established that sulfate-reducing bacteria occur in practically all soils throughout the world when moisture, sulfates, and assimilable organic and mineral matter are present and oxygen is absent.

Anaerobic bacterial action has an effect on the corrosion of metals underground, principally because some of the products of bacterial action (H_2S and FeS) have been reported to accelerate the normal corrosion process.

3.2 MATERIALS SELECTION

Generally, it is more economical to use materials which do not require protection of any type if this is at all possible. For example, if in addition to being uncorroded in the required environment, the material also possesses the necessary mechanical properties, its use in preference to that of a material which requires protection can usually be justified if the required life is of sufficient length. Many times, the original cost of a corrodible material, plus the cost of protection and maintenance over the required life of the installation will exceed the original cost of a noncorrodible material.

3.2.1 Basis for Materials Selection

Materials selection should be based upon the corrosiveness of the environment in which it will be used. Information on the corrosiveness of the particular environment involved may be obtained in various ways.

3.2.1.1 Similar Systems in the Area. At many sites or locations there will be information available on the performance of materials being used in similar applications. Usually the people in charge of such installations will be glad to cooperate by furnishing performance

13

data on the materials they are using in addition to any methods of protection which have proven to be satisfactory. In cases such as these, performance data of materials and protective systems will be the most reliable which can be obtained and should be used.

3.2.1.2 Similar Systems in Similar Environments. Should there be no information available such as that described under paragraph 3.2.1.1, then the availability of information from similar systems in similar environments should be investigated.

In such situations the corrosive characteristics of the atmosphere, soil, and the ground water at the site in question should be determined. Then, with this information as a background, the location of similar environments where similar systems are in operation should be investigated. Such available information should be relatively reliable and should be used as a basis for designing the system in question.

3.2.1.3 Experimental Tests. If no reliable data and information are available as described in paragraphs 3.2.1.1 and 3.2.1.2, then the generation of experimental data may be necessary. If time permits, either field or laboratory tests should be conducted to obtain approximate information. If time is not available, then the services of a consultant with wide experience in the field in question should be engaged for guidance.

Of the two types of experimental data, that obtained by field testing is the more reliable because it is possible to more nearly simulate actual operating conditions. However, it is more time consuming and costly than laboratory testing.

If laboratory testing must be done from the standpoint of urgency, then the designer must be willing to accept the unreliability and disadvantages attendant with such tests. Laboratory tests are accelerated in some manner in order to obtain results within a shorter period of time. Some of the conditions which can be accelerated are: elevated temperature, increased humidity, increased velocity of flow, chemical solution to simulate special environments, increased chemical concentrations of solutions, etc., or combinations of two or more of the above. These factors usually increase the corrosion rates of materials and decrease the time required to obtain results. Also, in such laboratory tests, protective coatings, such as paints, can be caused to fail in shorter periods of time. Unfortunately, such tests very seldom duplicate the relative behavior obtained from the same materials or protective coatings in service. Because of the lack of correlation of laboratory tests with actual service performance, such tests are seldom recommended as a source of reliable information.

3.2.2 Galvanic Corrosion and Its Prevention

Galvanic corrosion is defined as "corrosion associated with the current resulting from the coupling of dissimilar metals together in an electrolyte" (in this case water). When two dissimilar metals are metallically connected in an electrolyte, current will flow (in the electrolyte) from one metal to the other. The metal from which the current is flowing (the anode) will corrode, and the metal to which the current is flowing (the cathode) will tend to be protected from corrosion. In this case the anode will corrode at a faster rate than its uncoupled rate in order to protect the more cathodic metal from corroding.

Dissimilar metals coupled in the atmosphere seldom create serious galvanic corrosion problems because they are active only when wet by an electrolyte. However, in water or soils such couples will corrode, the severity being dependent upon the conductivity of the electrolyte, the temperature, the metals comprising the couples, and the area relationships of the two metals.

Some metal combinations which commonly constitute galvanic couples are: cast iron-steel, cast iron-galvanized steel, steel-galvanized steel, galvanized steel-copper, galvanized steel-copper alloys (brasses and bronzes), steel-copper, cast iron-copper, steel-copper alloys and cast iron-copper alloys.

The best way to prevent galvanic corrosion is to design a system which requires the use of only one material or compatible materials.

However, in many systems this is impossible, so preventive measures must be employed. In practically all cases, galvanic corrosion can be prevented by inserting a dielectric separator between the two metals. For example, plastic bushings, connectors, or unions will electrically isolate one section of threaded pipe from another; dielectric gaskets, sleeves, and washers can be used to electrically isolate materials at a flanged connection.

In many applications, characteristics other than corrosion resistance to a particular environment are more important than corrosion resistance.

In any case, the mechanical and physical properties of the material must be adequate to fulfill the requirements of the application. If the material with adequate corrosion resistance does not possess the necessary mechanical and physical properties for the application, then it is necessary to compromise in such a way that all requirements are satisfactory or acceptable.

15

3.3 ALTERATION OF ENVIRONMENT

Usually no attempt is made to alter atmospheric conditions to
control corrosion except in enclosures such as buildings where the con-
taminants can be removed and the relative humidity can be controlled.
Such measures are rarely applicable for potable water systems. Protective
coatings might be considered as an alteration of the environment because
they present a barrier between the material surface and the atmosphere.
Protective coatings are discussed separately in Section 3.4.

In some special cases where cathodic protection is used (for
example, where the backfill is all rock) special uniform, high-conductive
backfill materials are used to encase the pipe prior to covering it with
the material removed to create the trench. Thus, the pipe is encased
with a material of one type which provides a uniform environment with
a constant electrical resistivity and degree of aeration. This method
of altering the environment is discussed more fully under "Cathodic
Protection," subsection 3.5.

3.4 PROTECTIVE COATINGS

A protective coating is a coating, either metallic or nonmetallic,
that forms a barrier between a material surface and the environment to
which it is exposed. For exterior surfaces of potable water systems
paint coatings will be the protective coatings of major concern.

3.4.1 Selection of Coatings

The coating selected for any installation will depend upon the
material to be protected and the environment to which it will be sub-
jected.

Different paint coatings have been formulated for different mate-
rials for use in different environments. For example, a paint coating
formulated for use on steel in a mild environment, such as a rural
atmosphere, would probably not provide satisfactory economical protection
to the same steel in a very corrosive atmosphere, such as a heavy indus-
trial or a chemical environment. The best paints have proved to be the
most economical for the longest periods of time.

There are specifications applicable to practically all general
and specific applications of materials. Since steel is used, because
of economy, for the greater majority of applications in the potable
water industry, specifications for painting it are of major concern.

The Steel Structures Painting Council has formulated specifications and recommendations for steel in practically any application. In addition, AFM 85-3 contains all government specifications for painting materials and should be used if possible.

Different types of coatings are required for different atmospheres, and still different types are best suited for application to materials underground.

In general, alkyds are very satisfactory for rural and mildly corrosive atmospheres. For more corrosive atmospheres vinyls, vinyl-alkyds, silicone-alkyds, urethane, epoxy, chlorinated rubber and zinc rich primer systems are used. Bituminous and coal tar epoxy systems are used for underground application.

Actual field experience on the performance of a coating is the most informative and reliable information that can be used for design and recommendation purposes. When it is possible to obtain information on an actual field application of a similar nature in a similar area and the specifics with regard to material, surface preparation, and method of coating application are available, performance information regarding such applications should be seriously considered for design purposes.

3.4.2 Design Factors

The performance of a protective coating can be enhanced or negated by consideration or lack of consideration of various design factors. Some of these more important factors are discussed below.

3.4.2.1 Accessibility. During the design stage every effort should be made to have every portion of the system which is to be protected as accessible as possible. A poorly applied protective coating will not provide satisfactory protection. If accessibility to portions of a system are not satisfactory for the proper application of the protective coating, satisfactory performance will not be obtained.

3.4.2.2 Sharp Corners. It is well known that protective coatings fail at sharp corners and edges before they fail anywhere else, because the thickness of cover is often much less at these areas than elsewhere. For this reason all corners and edges should be rounded in order to obtain a more uniform thickness of the protective coating. The rounding of corners and edges can be specified during design and can be more easily and economically accomplished during fabrication than afterwards.

3.4.2.3 Condensation. Most protective coatings and paints will not adhere to material surfaces, especially metals, if the conditions are such that moisture has condensed on the surfaces to be painted. Painting

17

should not be done when the relative humidity exceeds 60 percent or the temperature of the metal is lower than 50°F. Sometimes the relative humidity and temperature are such that the volatile solvents in the paint will cause moisture condensation when they evaporate; under such circumstances painting should be suspended until the weather conditions change.

3.4.3 Surface Preparation

Because of the more stringent air pollution regulations today and the limitations imposed upon field sandblasting, procedures of shop blasting and shop priming are becoming more widely used.

In designing for corrosion protection the proper choice of a painting system and the surface preparation required will be controlled by the environmental conditions and the life requirements of the installation. Methods of preparing the surfaces to be painted are discussed below.

3.4.3.1 Hand Cleaning. Hand cleaning will remove only loose or loosely adhering surface contaminants. Before cleaning, the surface must be free of oil, grease, dirt and chemicals. Hand cleaning is recommended only for spot cleaning in areas where corrosion is not a serious factor.

3.4.3.2 Power Tool Cleaning. Power tool cleaning methods provide faster and more adequate surface preparation than hand tool methods. Hand tools are satisfactory for removing small amounts of tightly adhering contaminants, but they are uneconomical and time consuming. Power tool cleaning should be preceded by solvent or chemical treatment.

3.4.3.3 Flame Cleaning. Flame cleaning is a method of passing high-velocity, oxy-acetylene flames over a metal surface. Oil and grease must be removed prior to flame cleaning.

3.4.3.4 Blast Cleaning. Blast cleaning abrades and cleans through the high velocity impact of sand, metal shot, metal or synthetic grit or other abrasive particles on the surface. It is most often used on metal structures in the field but may also be used, with caution, on masonry and stone. It is, by far, the most thorough of all mechanical treatments. There are four degrees of blast cleaning as established by the Steel Structures Painting Council (SSPC) and the National Association of Corrosion Engineers (NACE).

3.4.3.4.1 White Metal Blast (SSPC-SP5 or NACE-1). Blast cleaning to white metal is the ultimate in blast cleaning. It is used for coatings which must withstand exposure to very corrosive atmospheres

(chemical, heavy industrial or marine) where a high cost of surface preparation is considered to be warranted. This will contribute to maximum performance of the paint system.

3.4.3.4.2 Near-White Metal Blast (SSPC-SP10 or NACE-2). In this procedure the blasted surface will show shadows, streaks, and/or discolorations, but they will appear across the general surface area and not be concentrated in spots. It has proven to be sufficiently adequate for many of the special coatings developed for long-term protection in moderately severe environments.

3.4.3.4.3 Commercial Blast (SSPC-SP6 or NACE-3). With this blast all loose scale, rust, and other surface contaminants are removed. This method of surface preparation will result in a high degree of cleaning, and is generally considered adequate for the long life of the majority of paint systems under normal exposure conditions.

3.4.3.4.4 Brush-Off Blasting (SSPC-SP7 or NACE-4). This is a relatively low cost method of cleaning to remove old finishes in poor condition, loose rust, and loose mill scale. Brush-off blasting is not intended for use where severe corrosion is prevalent, but is, instead, intended to supplant hand tool and power tool cleaning where blast cleaning equipment is available. The brush-off method is also used for the removal of loose or degraded paint from masonry.

All blast-cleaned surfaces require that prime painting be completed on the same day to prevent new corrosion products from forming, since such blast-cleaned surfaces are subject to rapid corrosion if not coated.

3.4.3.5 Vacuum Blasting. Vacuum blasting is a relatively new method, which minimizes the dust hazard and in which the blast abrasive is reclaimed. This procedure, also known as dry honing, allows practically no dust to escape and contaminate the atmosphere. It is very efficient and economical for cleaning repetitive, small-scale surfaces in a shop.

3.4.3.6 Wet Blasting. This method reduces to a minimum the dust associated with blasting, but is not suitable for all types of work. Wet sand and other blast residues become trapped on upturned angles and horizontal girders creating difficult clean-up work. These residues must be removed by rinsing, brushing, or using compressed air, and the wet blasted surfaces will rust if not dried and primed immediately.

3.4.3.7 Centrifugal Blasting. This is a shop blasting method in which the abrasive grit is dropped into a spinning vaned wheel at a controlled rate. The grit is thus impinged against the material moving beneath it at a predetermined rate. This results in a controlled, uniformly cleaned surface. This type of surface preparation can be performed at a minimum cost, the abrasive can be reused, and dust is virtually eliminated.

3.4.3.8 Chemical Treatment. Chemical and solvent cleaning methods are seldom if ever used in the field. They are usually restricted to shop and tank immersion operations. They consist of solvent wiping, alkali cleaning, steam cleaning, and acid cleaning.

Chemical methods of surface cleaning are usually more suited to paint shop application while mechanical methods are generally more practical in field work. On the basis of overall effectiveness and efficiency, chemical cleaning is superior to mechanical methods, with the exception of blast cleaning. The paint or paint system selected for any given surface and environment is of primary importance. The coating and environment, then, determine the degree of surface cleaning required. The existing surface conditions, job location, equipment availability, and economic factors will serve as a guide to the cleaning method required.

3.4.4 Methods of Application

The most common methods of applying paint are by brush, roller, and spraying. Dip and flow coat methods are also used but the mechanics of operation limit their use to shop work. Of the three for field use, brushing is the slowest, rolling is much faster, and spraying is usually the fastest of all. The choice of method is based on many additional factors such as environment, type of substrate, type of coating to be applied, appearance of finish desired, and skill of personnel involved in the operation.

General surroundings may prohibit the use of spray application because of possible fire hazards or potential damage from overspray. Adjacent areas not to be coated must be masked when spraying is performed. This results in loss of time and, if extensive, may offset the advantage of the rapidity of spraying.

Roller coating is the most efficient on large flat surfaces. Corners, edges, and odd shapes, however, must be brushed. Spraying is also most suitable for large surfaces, except that it can also be used for round or irregular shapes. Brushing is ideal for small surfaces or for cutting in corners and edges.

Rapid-drying, lacquer-type products, e.g., vinyls, should be sprayed. Application of such products by brush or roller may be extremely difficult, especially in warm weather or outdoors on breezy days.

Coatings applied by brush may leave brush marks in the dried film; rolling leaves a stippled effect, while spraying yields the smoothest finish, if done properly.

To obtain optimum performance from a coating, there are certain basic application procedures which must be followed, regardless of the type of equipment selected for applying the paint. Cleaned, pretreated surfaces must be first coated within specific time limits established. It is essential that surface and ambient temperatures be between 50°F and 90°F for water-thinned coatings and 45°F to 95°F for other coatings, unless the manufacturer specifies otherwise. The paint material should be maintained at a temperature of 65°F to 85°F at all times. Paint should not be applied when the temperature is expected to drop to freezing before the paint has dried. Wind velocity should be below 15 miles per hour and relative humidity below 80 percent. Masonry surfaces that are damp (not wet) may be painted with latex or cementitious paints. Otherwise, the surface must be completely dry before painting. When successive coats of the same paint are used, each coat should be tinted differently to aid in determining proper application and to assure complete coverage.

3.4.4.1 Brush Application. Rapid-drying, lacquer-type products, e.g., vinyls, are very difficult to apply with brushes. Most other types of paints can be applied with brushes, but if not done properly brush marks can be left in the dried film. Brush application is the slowest method of application, but for trim, corners, doors and window frames, and difficult access areas no other method is satisfactory. Brush application is the only method for applying high-viscosity coatings.

3.4.4.2 Roller Application. Roller application of paint is rapid, and large surface areas can be covered in a short period of time. A paint roller consists of a cynlindrical sleeve or cover which slips on a rotatable cage to which a handle is attached. Rollers, like brushes, can be obtained in various sizes for different uses. There are recent advances in rollers by which paint is fed to the inside of a roller by pressure so that it is not necessary to keep reloading the roller periodically. By this method the speed of application is considerably increased.

3.4.4.3 Spray Application. Spray equipment is available in three general types.

3.4.4.3.1 Conventional Spray. The coating material is placed in a closed container. Pressurized air from a compressor forces the material through a hose to the spray gun. The gun is also connected to a separate air hose. At the gun, the material is atomized by the air supplied through the central openings in the air cap. This is the most inexpensive and most common spray technique, but it tends to create excessive overspray because of the high ratio of air to paint used.

3.4.4.3.2 Airless Spray. In this method, coatings are sprayed by the use of hydraulic pressure alone. The equipment is similar to conventional spray except that the compressor operates a hydraulic pump.

21

Atomization of the material is accomplished by forcing the material through a specially shaped orifice at a pressure of between 1,500 and 3,000 psi. Airless spraying usually permits the use of products with a higher viscosity. Considerable caution must be exercised because of the high pressures required.

3.4.4.3.3 Hot Spray. The hot spray technique can be adapted to either conventional or airless spray painting. The paint temperature is raised to 130°F to 180°F to lower the viscosity and reduce the quantity of solvent needed. The resultant coating has higher solids and will produce greater film thickness per coat.

3.4.4.4 Paint Mitt Application. The paint mitt is a mitten made of lambskin with the wool exposed and lined to prevent paint leaking through to the user's hand. It is excellent for painting small pipes, railings, and similar surfaces.

3.4.5 Wrappings and Other Types of Coatings

In many underground installations impregnated wrapping materials are used to increase the thickness of the coating in order to better resist mechanical damage from rocks, etc., in the soil. Some of the wrapping materials are discussed below.

3.4.5.1 Mill Coated Pipe. In recent years the use of mill coated pipe has been steadily increasing. Wrapping materials are applied over hot applied enamels under the most favorable conditions and, hence, the coatings are freer of defects.

3.4.5.2 Plastic Tapes (Pressure Sensitive). Pressure-sensitive plastic tapes for wrapping underground pipe or other structures, such as tanks, are essentially plastic protective wraps with an adhesive on one side to cause it to adhere to the pipe when applied to it under pressure. Polyvinyl chloride tapes are supplied in thicknesses of 10 and 20 mils. Polyethylene tapes are supplied in 12-, 14-, and 20-mil thicknesses.

3.4.5.3 Laminated Tapes With Primers. The major tape of this type available today consists of uncured butyl rubber laminated to polyvinyl chloride. Although it has no adhesive qualities it is applied to an adhesive primer while still wet.

3.4.5.4 Coal Tar Tapes. Coal tar tapes may be either hot-applied or cold-applied. They generally consist of a layer of specified thickness of coal tar pitch applied to a coal tar saturated fabric, plus a thinner coal tar coating on top, with a separator (paper or plastic film) on top of the outer layer.

3.4.5.5 _Extruded Plastic Coatings_. One of the most recent methods
of pipe protection underground is the extruded polyethylene coating.
This coating is applied at the mill to small diameter pipe.

3.4.5.6 _Asbestos Wrappers_. The asbestos felt wrapper is saturated
with either asphalt or coal tar enamel before application. This wrapper
is applied directly over the hot enamel as it is flooded or sprayed
on the pipe.

3.4.5.7 _Glass Outer Wrap_. Glass outer wrap is a thick film of
glass fibers held together with a binder. This wrap may or may not be
furnished saturated with tar or asphalt cutback before application. It
is also applied directly over the hot enamel as it is flooded or sprayed
on the pipe.

3.4.5.8 _Glass Inner Wrap_. Glass in the form of single filaments
laid down in random form and bonded together with a tough, flexible
binder is formed into a wrapper that is used with hot enamel applica-
tions.

3.4.6 _Coating Maintenance_

Paint systems deteriorate and will lose their protective ability
unless the film is maintained in an intact condition. All coated struc-
tures should be inspected at definite intervals. They should be inspected
at 6-month intervals in exterior or corrosive environments and at yearly
intervals in other environments. Their condition with reference to type
and stage of deterioration should be determined, and recommendations
should be made for the type of maintenance to be performed after each
inspection.

Recoating can be considered in two categories: spot painting or
complete repainting. Data from the Inspection Records will determine
which type should be done.

3.4.6.1 _Spot Paint or Touch-Up Painting_. Spot painting should
be performed when there are only local areas of failure, such as at
sharp edges, seams, pinholes, and holidays, with the greater portion
of the coating in satisfactory condition. Spot painting prolongs the
time required for complete repainting, because it stops the spread of
deterioration and decreases the cost of surface preparation.

3.4.6.2 _Total Recoating_. If a protective coating is permitted to
deteriorate excessively, then it becomes necessary to completely recoat
the structure. Complete recoating necessitates the complete removal of
the old coating, a completely new surface preparation, and the applica-
tion of a completely new coating system. Such extensive maintenance
procedures are expensive, and relatively more frequent maintenance pro-
cedures should be adopted to maintain structural integrity of the system.

23

3.5 CATHODIC PROTECTION

Cathodic protection is very simply the use of direct current electricity from an external source to oppose the discharge of corrosion current from anodic areas. When a cathodic protection system is installed for maximum effect, all portions of the protected structure collect current from the surrounding electrolyte and the entire exposed surface becomes a single cathodic area--hence the name. In all cases of underground corrosion, anodic areas and cathodic areas are present on a metallic structure, for example steel. At the anodic areas, where corrosion occurs, current flows from the anode into the surrounding electrolyte (soil or water). Likewise, where current flows from the electrolyte onto the structure, the surface of the structure is cathodic and does not corrode.

Hence, if every bit of exposed metal on the surface of a structure could be made to collect current, it would not corrode because the entire surface then would be cathodic. This is exactly what cathodic protection does. Direct current is forced to flow from a source external to the structure onto all surfaces of the structure. When the amount of this current flowing is adjusted properly, it will counteract corrosion current discharging from all anodic areas on the structure, and there will be a net current flow onto the structure surface at these points. The entire surface then will be cathodic and the protection complete.

During the design stage a preliminary survey must be made to determine the need for cathodic protection for all new water distribution systems containing underground metallic pipe or for water storage tanks. Considerations to be taken into account when justifying cathodic protection are covered in AFM 88-9, Chapter 4, Corrosion Control. If cathodic protection is required, it must be installed during construction of the facility. The cathodic protection system must be designed in accordance with criteria in AFM 88-9, Chapter 4.

Cathodic protection can be used to protect any metallic structure from corrosion whose surfaces are contacted by an electrolyte (a current conducting liquid) which may be either soil or water. However, the inside diameters of small diameter pipes cannot be protected.

3.5.1 General Requirements

There are two methods of applying cathodic protection, the sacrificial anode method and the impressed current method. Both types of systems have certain essential requirements: a power source, a continuous electrolyte to conduct the current from the anode to the structure being protected, and an external electrical connection between the structure and the power source to conduct the current back to the source.

3.5.1.1 <u>Sacrificial</u> <u>Anode Systems</u>. In the sacrificial anode method the structure to be placed under cathodic protection is metallically coupled to a metal less noble (more negative) than itself. A galvanic cell is thereby established in which the protected structure becomes the cathode and the less noble metal, the sacrificial anode. Current flows through the electrolyte from the anode to the cathode. The system is designed so that sufficient current will flow from the anode to suppress all local action currents on the surface of the protected structure.

3.5.1.2 <u>Impressed Current Systems</u>. In the impressed current method of cathodic protection, the anodes may consist of any conducting material found suitable for the purpose. Any available source of direct current may be used provided it is continuous. AC rectifiers are generally used for this purpose; however, motor-generator sets, gasoline engine generators, and wind-driven generators have been used. The direct current enters the electrolyte from the anodes, flows to the protected structure, and is drained back to the current source through a metallic circuit.

3.5.1.3 <u>Field Surveys</u>. Before a cathodic protection system is designed, it is necessary to conduct a field survey of the intended site to determine and obtain information on the characteristics of the environment.

It is necessary to know whether there are any existing cathodic protection systems in the area. If so, it must be determined whether there will be any interference between the two: whether the system in operation will interfere with the intended system, or whether the system to be installed will interfere with the system already in operation.

The characteristics of the soil or soils which will be in contact with the structure must be determined. The most important of these characteristics in the design of the system are resistivity, pH, and degree of aeration.

3.5.2 <u>Determination of Protective Requirements</u>

Cathodic protection is used almost universally in conjunction with a protective coating system. Such combinations reduce the current required to achieve complete protection. Protective coating systems never form a completely perfect or impervious barrier against intrusion of the environment to the metal surface. Also, such coatings tend to deteriorate with time. Cathodic protection furnishes protection at such defects; thus, such a combination affords complete protection against corrosion.

25

3.5.3 System Design

The information obtained from the field surveys and from what protective requirements are necessary should provide a basis for the design of the cathodic protection system.

One of the most important things to be realized in designing a cathodic protection system is that it should be over designed. The reason for this is that the protective coating will deteriorate with age, necessitating an increase in required current. Also, sometime during the life of the system additions might be made to the system, thus increasing the requirement for additional current. Usually, 1.5 times the initial current requirements is the design basis.

3.5.3.1 Impressed Current Versus Sacrificial Galvanic Anodes. If electrical power is available locally there is usually no economical advantage in using an impressed current system over a galvanic anode system or vice versa. If power will not be available or the system will be needed only temporarily, it is usually more economical to use sacrificial galvanic anodes such as zinc, magnesium, or aluminum. Galvanic anodes have the advantage of providing only a given known potential, without fluctuations that might occur with an impressed current system, especially when not properly monitored.

Impressed current anodes are made of graphite, high silicon cast iron (Duriron), steel, platinum, platinized titanium, scrap steel, old rails and pipe, and lead. Which type of anode to use is determined by availability, cost, life expectancy, and type of environment (soil or water). Where large amounts of current are required, impressed current systems are usually more economical.

Sacrificial galvanic anodes are made from special aluminum, magnesium, or zinc alloys. In soils, they are generally used in those cases where relatively small increments of current are required and where the soil resistivity is low enough to permit obtaining the desired current with a reasonable number of anodes.

3.5.3.2 Anode Placement. The placement of anodes, whether impressed or sacrificial, depends upon the system and the environmental characteristics such as type of electrolyte and resistivity. The configuration of the system also dictates the placement of the anodes because it is important that no portion of the structure be shielded from the currents traveling to it through the electrolyte.

3.5.3.3 Testing. When a cathodic protection system is installed, test points and alarm signals should be installed so that the condition and operation can be checked periodically. Testing of cathodic protection systems is very well described in AFM-88-9, Chapter 4, Section VIII, Corrosion Control, and in AFM-85-5, Maintenance and Operation of Cathodic Protection Systems.

Where soil resistivity fluctuates or where periodic inspection is impractical, the installation of automatic controls on an impressed cathodic protection system should be considered. Such automatically controlled cathodic protection systems are available from a number of cathodic protection companies.

In remote areas or even critical portions of local systems it might be advantageous to have alarm systems to alert personnel when a system or portion of one is damaged or rendered inoperative. Such systems are also available from many commercial companies.

For nonautomatic test systems, the following tests should be made periodically to monitor the operation of the cathodic protection system. Structure-to-soil potentials should be measured to determine the effectiveness of the cathodic protection being furnished. The measurement of current output should be made to determine the operating condition of anodes and/or rectifiers and to insure that sufficient current is being applied to the protected structure. The ability of soil or water to conduct electricity is closely related to the rate at which buried or immersed structures will corrode. The lower the resistance to current flow the higher the rate of corrosion. The practical measure of the ability of a material to resist the flow of electricity is known as resistivity. The greater the soil resistivity the lower its corrosivity. Therefore, resistivity measurements should be taken.

Section IV

CORROSION AND CORROSION CONTROL OF INTERNAL SURFACES

In order to properly design domestic water and water distribution
systems from the standpoint of corrosion control, it is first necessary
to define the corrosive environment. Then, corrosion control methods
can be selected to insure that the lifetime of the domestic water system
will be commensurate with the projected lifetime of the overall facility.

4.1 CLASSIFICATION OF ENVIRONMENT

Materials in domestic water distribution systems are exposed to
many different environmental conditions. Proper definition of these
conditions is essential in the design of effective corrosion control
methods for these systems.

4.1.1 Total Immersion

Many portions of domestic water supply systems are normally
completely filled with water at all times. This constitutes total immer-
sion. Short periods of atmospheric exposure due to equipment failure or
periodic maintenance will not significantly change the behavior of most
materials from their behavior during constant total immersion. The
behavior and protection of materials in conditions of total immersion
is dependent primarily upon water composition, temperature, and velocity.

4.1.1.1 Water Composition. Water composition is the single most
important factor in the deterioration and protection of interior sur-
faces of domestic water systems. The chemical analysis of the water
made during initial site selection, as outlined in paragraph 2.1.1.2
of this report, can be used as a basis for water system design if the
water to be used is in an untreated condition. If water treatment, such
as softening, is planned, then the composition of the treated water
should be used as a guide in water system design. A complete analysis
of the water, as outlined in paragraph 2.1.1.2 of this report, should
be made after any change in water source or water treatment. Such an

28

analysis should be made routinely at yearly intervals to detect any
change in water composition. When water treatment facilities are used,
then analysis should be made on the water both before and after treat-
ment because the composition of the water at each point in the water
system determines the corrosion which will occur or the corrosion control
method which will be used at that point in the system.

4.1.1.2 Temperature. Water temperature is also an important factor
in determining the corrosivity of the water and in planning for corro-
sion control. This is especially true in hot water supply systems. In
these systems water temperature should be monitored over an extended
period to determine actual maximum water temperature. For large heating
facilities continuous monitoring is recommended. For small domestic
heaters a portable system should be used to monitor the water tempera-
ture of selected sample units over an extended period (one week).

4.1.1.3 Velocity. Water velocity is also an important factor in
the corrosion and corrosion control of domestic water systems. Maximum
velocity, as determined by flow rates, should be calculated at each
point in the system. Velocities greater than 4 ft/sec are often undesir-
able.

4.1.2 Partial Immersion

Portions of the domestic water systems, such as tank walls and
water treatment equipment, may not be totally immersed. This condition
must be considered in the selection of corrosion contrc methods for
such applications.

4.1.3 Alternate Immersion

Portions of domestic water systems, such as storage tanks, may
be subjected to alternate immersion. Very short periods of atmospheric
exposure, such as those that occur due to equipment failure or periodic
maintenance, usually do not constitute alternate immersion. Conditions
of alternate immersion must be considered in the selection of corrosion
control methods for such applications.

4.2 MATERIALS SELECTION

The selection of materials which are compatible with the water
to which they will be exposed is one of the most effective methods
of corrosion control. This selection should be based upon the behavior
of similar systems in the area, the behavior of similar systems in

similar environments, results of experimental tests, and the application
of basic corrosion theory. The materials selected must also be compatible
with other system requirements such as strength, weight, etc.

4.2.1 Behavior of Similar Systems in the Area

If there are domestic water systems near the proposed site and if
the water supply in the system is similar to those at the proposed site,
then the materials which have shown acceptable corrosion resistance in
the existing system will normally behave in a similar manner in the new
system. This basis for materials selection is best determined when site
surveys for both the existing and proposed system are made and when
accurate determination of the long-term performance of the existing
system has been made and is readily available.

4.2.2 Behavior of Similar Systems in Similar Environments

When exposure conditions, such as water composition, temperature,
and velocity, have been determined, then materials selection can be
based upon the behavior of materials in other domestic water systems
which have similar environments. This materials selection procedure can
only be as accurate and reliable as the determination of the operating
environment. Also, as outlined in paragraphs 4.1.1.1, 4.1.1.2, and
4.1.1.3 of this section, changes in the environmental parameters must
be considered since seemingly small changes may drastically alter the
behavior of many materials.

4.2.3 Compatibility Charts

Tables I through IV should be used to determine the compatibility
of materials with waters in domestic water supply and distribution
systems. These charts are based upon experience in many water distribu-
tion systems and can be used for most potable water systems. The
presence of chloride ions in concentrations greater than 75 ppm, with
high sulfates, render a water more corrosive than indicated by these
charts; however, such high concentrations of these ions are found only
occasionally in potable waters. These charts may not be applicable when
anomalous concentrations of iron (Fe^{++}), chloride (Cl^-), nitrate (NO_3^-),
or hydrogen sulfide (H_2S) are present or when the pH of the water is
less than 6 or greater than 9. When these anomalous conditions are
encountered, water treatment facilities are generally needed to produce
water with desirable taste, odor, etc.

The charts are separated as to hardness. For a water of given
hardness the charts are entered at the left at the appropriate sulfate,
silica, and oxygen content, and, depending on carbon dioxide content,
temperature, and velocity, the compatibility of the materials with the
water are outlined on the right.

30

Table I. Soft Water

(Hardness as $CaCO_3$ = 15-90 ppm; Calcium (Ca) = 0-18 p.p.m.)

Sulfate (SO4) (ppm)	Silica (SiO2) (ppm)	Dissolved Oxygen (ppm)	Free Carbon Dioxide (CO2) (ppm)	Temperature (°F)	Velocity (ft/sec)	Materials for —									
						Mains						Building Distribution Systems			
						GRP	Asbestos Cement	Cement Lined Steel	Cast Iron	Carbon Steel	Cu-Ni 90-10	CPVC Plastic[a]	Copper	PVC Plastic[b]	Galvanized Steel
as found	0-15	1-10	<5	<140	<4	X	X	X			X	X	X	X	
					>4	X	X	X			X	X	X	X	
				>140	<4						X	X			
					>4						X	X			
			>5	<140	<4	X	X	X			X	X	X	X	
					>4	X	X	X			X	X	X	X	
				>140	<4						X	X			
					>4						X	X			
0-25	0-15	0-1	<5	<140	<4	X	X	X	X	X	X	X	X	X	
					>4	X	X	X	X	X	X	X	X	X	
				>140	<4						X	X			
					>4						X	X			
			>5	<140	<4	X	X	X	X	X	X	X	X	X	
					>4	X	X	X	X	X	X	X	X	X	
				>140	<4						X	X			
					>4						X	X			
0-60	>15	1-5	<5	<140	<4	X	X	X	X	X	X	X	X	X	X
					>4	X	X	X	X	X	X	X	X	X	X
				>140	<4						X	X			
					>4						X	X			
			>5	<140	<4	X	X	X	X	X	X	X	X	X	X
					>4	X	X	X	X	X	X	X	X	X	X
				>140	<4						X	X			
					>4						X	X			

a Not recommended for temperatures above 180°F.
b Not recommended for temperatures above 130°F.

GRP = glass fabric reinforced plastic
PVC = polyvinylchloride plastic
CPVC = chlorinated polyvinyl chloride plastic

31

Table II Average Water

(Hardness as $CaCO_3$ = 100-150 ppm; Calcium (Ca) = 18-35 ppm.)

Sulfate (SO_4)	Silica (SiO_2) (ppm)	Dissolved Oxygen (ppm)	Free Carbon Dioxide (CO_2) (ppm)	Temperature (°F)	Velocity (ft/sec)	\<Materials for— Mains\> GRP	Asbestos Cement	Cement Lined Steel	Cast Iron	Carbon Steel	Cu-Ni 90-10	CPVC Plastic[a]	\<Building Distribution Systems\> Copper	PVC Plastic[b]	Galvanized Steel
0-25 ppm	0-15	1-10	<5	<140	<4	X	X	X			X	X	X	X	
0-25 ppm	0-15	1-10	<5	<140	>4	X	X	X			X	X	X	X	
0-25 ppm	0-15	1-10	<5	>140	<4						X	X			
0-25 ppm	0-15	1-10	<5	>140	>4						X	X			
0-25 ppm	0-15	1-10	>5	<140	<4	X	X	X			X	X	X	X	
0-25 ppm	0-15	1-10	>5	<140	>4	X	X	X			X	X	X	X	
0-25 ppm	0-15	1-10	>5	>140	<4						X	X			
0-25 ppm	0-15	1-10	>5	>140	>4						X	X			
<Ca	>15	1-8	<5	<140	<4	X	X	X	X	X	X	X	X	X	X
<Ca	>15	1-8	<5	<140	>4	X	X	X	X	X	X	X	X	X	X
<Ca	>15	1-8	<5	>140	<4				X	X	X	X			
<Ca	>15	1-8	<5	>140	>4				X	X	X	X			
<Ca	>15	1-8	>5	<140	<4	X	X	X	X	X	X	X	X	X	X
<Ca	>15	1-8	>5	<140	>4	X	X	X	X	X	X	X	X	X	X
<Ca	>15	1-8	>5	>140	<4				X	X	X	X			
<Ca	>15	1-8	>5	>140	>4				X	X	X	X			
<Ca	as found	0-1	<5	<140	<4	X	X	X	X	X	X	X	X	X	X
<Ca	as found	0-1	<5	<140	>4	X	X	X	X	X	X	X	X	X	X
<Ca	as found	0-1	<5	>140	<4				X	X	X	X			
<Ca	as found	0-1	<5	>140	>4				X	X	X	X			
<Ca	as found	0-1	>5	<140	<4	X	X	X	X	X	X	X	X	X	X
<Ca	as found	0-1	>5	<140	>4	X	X	X	X	X	X	X	X	X	X
<Ca	as found	0-1	>5	>140	<4				X	X	X	X			
<Ca	as found	0-1	>5	>140	>4				X	X	X	X			

GRP = glass fabric reinforced plastic
PVC = polyvinylchloride plastic
CPVC = chlorinated polyvinyl chloride plastic

[a] Not recommended for temperatures above 180°F.
[b] Not recommended for temperatures above 130°F.

32

Table III. Hard Water

(Hardness as $CaCO_3$ > 150 ppm; Calcium (Ca) = 36-75 ppm.)

Sulfate (SO_4) (Ca)	Silica (SiO_2) (ppm)	Dissolved Oxygen (ppm)	Free Carbon Dioxide (CO_2) (ppm)	Temperature (°F)	Velocity (ft/sec)	Mains						Building Distribution Systems			
						GRP	Asbestos Cement	Cement Lined Steel	Cast Iron	Carbon Steel	Cu-Ni 90-10	CPVC Plastic[a]	Copper	PVC Plastic[b]	Galvanized Steel
>1.5	0-15	1-10	<5	<140	<4	X	X	X			X	X	X	X	
					>4	X	X	X			X	X	X	X	
				>140	<4		X	X	X	X	X	X	X		X
					>4		X	X	X	X	X	X			X
			>5	<140	<4	X					X	X	X	X	
					>4	X					X	X	X	X	
				>140	<4				X	X	X	X	X		X
					>4				X	X	X	X			X
<1.5	0->15	1-10	<5	<140	<4	X	X	X			X	X	X	X	
					>4	X	X	X			X	X	X	X	
				>140	<4		X	X	X	X	X	X	X		X
					>4		X	X	X	X	X	X			X
			>5	<140	<4	X					X	X	X	X	
					>4	X					X	X	X	X	
				>140	<4				X	X	X	X	X		X
					>4				X	X	X	X			X
<3	0->30	0-10	<5	<140	<4	X	X	X			X	X	X	X	
					>4	X	X	X			X	X	X	X	
				>140	<4		X	X	X	X	X	X	X		X
					>4		X	X	X	X	X	X			X
			>5	<140	<4	X					X	X	X	X	
					>4	X					X	X	X	X	
				>140	<4				X	X	X	X	X		X
					>4				X	X	X	X			X

[a] Not recommended for temperatures above 180°F.

[b] Not recommended for temperatures above 130°F.

GRP = glass fabric reinforced plastic
PVC = polyvinyl chloride plastic
CPVC = chlorinated polyvinyl chloride plastic

33

Table IV. Very Hard Water

(Hardness as CaCO$_3$ > 150 ppm; Calcium (Ca) > 75 ppm.)

Sulfate (SO$_4$) (Ca)	Silica (SiO$_2$) (ppm)	Dissolved Oxygen (ppm)	Free Carbon Dioxide (CO$_2$) (ppm)	Temperature (°F)	Velocity (ft/sec)	Materials for — Mains					Building Distribution Systems				
						GRP	Asbestos Cement	Cement Lined Steel	Cast Iron	Carbon Steel	Cu-Ni 90-10	CPVC Plastic [a]	Copper	PVC Plastic [b]	Galvanized Steel
<2	0-30	1-10	<5	<140	<4	x	x	x	x	x	x	x	x	x	x
					>4	x	x	x	x	x	x	x	x	x	x
				>140	<4						x	x	x		
					>4						x	x	x		
			>5	<140	<4	x	x	x	x	x	x	x	x	x	x
					>4	x	x	x	x	x	x	x	x	x	x
				>140	<4						x	x	x		
					>4						x	x	x		
>2	0-30	1-10	<5	<140	<4	x	x	x			x	x	x	x	x
					>4	x	x	x			x	x	x	x	x
				>140	<4						x	x	x	x	
					>4						x	x	x		
			>5	<140	<4	x	x	x			x	x	x	x	x
					>4	x	x	x			x	x	x	x	x
				>140	<4						x	x	x		
					>4						x	x	x		
<3	>30	1-10	<5	<140	<4	x	x	x	x	x	x	x	x	x	x
					>4	x	x	x	x	x	x	x	x	x	x
				>140	<4						x	x	x		
					>4						x	x	x		
			>5	<140	<4	x	x	x	x	x	x	x	x	x	x
					>4	x	x	x	x	x	x	x	x	x	x
				>140	<4						x	x	x		
					>4						x	x	x		

[a] Not recommended for temperatures above 180°F.
[b] Not recommended for temperatures above 130°F.

GRP = glass fabric reinforced plastic
PVC = polyvinylchloride plastic
CPVC = chlorinated polyvinyl chloride plastic

34

4.2.4 Results From Experimental Tests

When the information required to select materials on the basis outlined in paragraphs 4.2.1 and 4.2.2 above is not available, other selection criteria should be used. Experimental tests are often used as a basis for materials selection for water distribution systems. However, test results must be applied judiciously in the material selection process.

4.2.4.1 Field Testing. In field testing, sample materials are included in actual operating systems. With proper monitoring of operating environments and application of accepted material exposure techniques, the results of these tests will be useful in the design of systems using the same or similar waters. These tests are, however, expensive and time consuming. Such testing is only recommended when the information used for the selection criteria outlined in paragraphs 4.2.1 and 4.2.2 above is not available. Field testing is useful, however, in predicting actual system lifetimes and in establishing realistic inspection and maintenance schedules for existing water systems.

4.2.4.2 Laboratory Testing. Corrosion testing under laboratory conditions is useful in understanding the basic mechanisms of corrosion and determining the effect of environmental variables on material behavior. They are normally, however, of rather short duration and often do not simulate actual operating conditions. Laboratory corrosion testing is not, therefore, normally recommended as a basis for materials selection for water systems.

4.2.5 Galvanic Corrosion and Its Prevention

Galvanic corrosion of internal surfaces is attributable to the mechanism outlined in subsection 3.2.2 of this report. The basic methods of control of galvanic corrosion of internal surfaces are the same as outlined in that section. They are: use same material throughout the system, or use compatible materials throughout the system, or electrically isolate dissimilar materials. The compatibility of dissimilar metals with one another is usually based upon a galvanic series which is experimentally derived for a given water. Changes in this series with changes in water composition are usually minor. Further, many scale-forming waters will eliminate galvanic corrosion problems even though dissimilar metals/alloys are connected.

4.2.6 Compatibility With Other System Requirements

As outlined in subsection 3.2.2 of this report the selection of materials for use in domestic water systems must be based on many factors other than corrosion. Therefore compatibility of the material with

35

the water which it must contain or transport is only one factor in
materials selection. The selection criteria outlined in paragraphs
4.2.1 and 4.2.2 of this section are for materials which are commonly
used in water systems and therefore meet many of the other selection
criteria.

4.3 ALTERATION OF ENVIRONMENT

Corrosion control of internal surfaces by alteration of environ-
ment is normally limited to water treatment. When waters are treated
and their composition is altered, the altered composition must be used
to select materials and corrosion control procedures for use in the
portions of the water system which are exposed to the treated water.
Zeolite softening is one of the most commonly applied water treatments,
and water treated by this method is greatly altered in its corrosivity.
Whenever zeolite softening is contemplated, careful attention must be
paid to the materials selection and corrosion control for the softened
water distribution system.

4.4 PROTECTIVE COATINGS

Protective coatings, as defined in subsection 3.4 of this report,
are widely used to protect the interior surfaces of domestic water sys-
tems. Their use is often limited by inaccessibility to interior surfaces;
however, when protective coatings are properly selected and applied,
they can give low cost alternatives to the use of expensive construction
materials.

4.4.1 Limitations of Coatings for Protection of Interior Surfaces

The major limitation in the use of protective coatings on interior
surfaces is the inaccessibility to the surfaces. The interior surfaces
of large water tanks are readily accessible, the interior surfaces of
large diameter water distribution mains have limited accessibility, and
the interior surfaces of small diameter piping used in buildings are
virtually inaccessible. The relative accessibility of the surfaces
affects the initial application of the coating as well as the inspection
and maintenance of the coated surfaces.

4.4.1.1 Initial Application. The methods used for surface prep-
aration and coating of internal surfaces prior to the application of
protective coatings are the same as outlined in subsection 3.4.3 of
this report. Large tanks are normally coated on site after fabrication.

Small tanks and piping are normally shop coated during manufacture. Many of the surface preparation and coating application methods outlined in subsection 3.4.3 of this report have been adapted to the shop coating of internal surfaces of piping and small tanks. This equipment is normally automated. Sandblasting is the normally used surface preparation method. Coatings are either applied by spraying or by centrifugal coating. The centrifugal coating process is used extensively in the application of cement mortar and heavy coal-tar type coatings during the manufacture of larger diameter (1 foot) piping.

4.4.1.2 Inspection and Maintenance. When the internal surfaces are accessible, such as in large storage tanks, the inspection and maintenance of the internal coating are readily accomplished when the tank is empty. When the internal surfaces are inaccessible, such as in distribution mains, inspection and maintenance are normally impractical. The inspection and repair of coatings on piping prior to installation and the use of proper installation techniques are necessary to insure the maximum reliability of internally coated piping.

4.4.2 Selection of Coatings

Coatings for internal surfaces of domestic water systems, in addition to providing protection to the underlying material, must be compatible with the end use of the water which they contact. They must not contaminate the water with material which adversely affects its taste, odor, or toxicity. The selection of coatings for internal surfaces is based primarily upon accepted industrial standards, although in many applications successful field experience is used.

4.4.2.1 Based on Specifications for Specific Applications. The American Water Works Association (AWWA) Standards on internal coatings for various components of domestic water systems are an excellent guide to the selection of such coatings. Coating systems for specific applications are given in Section V of this chapter under the appropriate system subheading.

4.4.2.2 Based Upon Field Experience. If standard coating systems specified in the AWWA standards for internal surface coatings have been unsatisfactory in water supply systems in the area and nonstandard coatings have been used with satisfactory results, then such nonstandard coating systems can be used. However, the use of such nonstandard coatings is recommended only when it has been proven that the coating does not adversely affect the water quality or produce toxic effects.

4.4.3 Surface Preparation

As outlined in paragraph 4.4.1.1 of this section the applicability of many commonly used surface preparation methods to the preparation of internal surfaces for coating may be limited by accessibility. However,

most of the surface preparations are adaptable to the preparation of
all but the most inaccessible areas. Since air pollution can be con-
trolled under shop conditions, blast cleaning and pickling are widely
used in the preparation of internal surfaces for coating during manufac-
ture. The internal surfaces of large tanks can be cleaned using many of
the mechanical methods outlined in subsections 3.4.3.1 through 3.4.3.7
of this report. Since air pollution can be controlled in the cleaning
of the internal portions of such tanks, it is normally the preferred
method of on-site surface preparation.

4.4.4 Methods of Application

Automated coating application is widely used in shop coating of
the internal surfaces of many components of domestic water systems.
When the surfaces are readily accessible, such as in large tanks, any
method of application outlined in subsection 3.4.4 of this report can
be used. Spraying is normally the most cost effective method of applying
many coatings, although heavy coatings are often applied using dauber
techniques.

4.4.5 Coating Maintenance

Coating maintenance is normally not applicable to inaccessible
portions of water systems. When the surfaces are accessible, then the
maintenance of the coatings should be accomplished according to the
guidelines given in subsection 3.4.6 of this report.

4.5 CATHODIC PROTECTION

For a brief description of cathodic protection and what it does,
refer to Section 3.5.

4.5.1 General Requirements

The general requirements for cathodic protection systems for internal
surfaces are the same as those for external surfaces as described in sub-
section 3.5.1. Cathodic protection can be used to protect the internal
surfaces of storage tanks, standpipes, water treatment equipment, and
hot water storage tanks.

4.5.2 Determination of Protective Requirements

The protective requirements for a cathodic protection system are
dependent upon the water chemistry, coating, tank design, and the function

the tank serves. When complete details of these variables have been determined, then the requirements of the cathodic protection system can be established.

4.5.3 System Design

Because one is concerned here with the cathodic protection of internal surfaces, one is also, then, concerned with a relatively uniform electrolyte (water). Although there are a number of different structural shapes, they are all basically a combination of cylinders and curves. Both of these considerations are different from those conditions found on external underground surfaces where there is considerable irregularity in electrolyte uniformity and structural configuration.

4.5.3.1 Impressed Current Versus Sacrificial Galvanic Anodes. Cathodic protection systems for internal surfaces are almost always of the rectifier type. Great flexibility can be built into a rectifier system to meet a wide variety of current requirements without adding greatly to the cost. Sacrificial galvanic anodes are seldom used because they usually cost more than rectifier systems and are not as flexible. There is one exception to this: glass-lined domestic hot water tanks are almost universally protected with magnesium sacrificial anodes.

4.5.3.2 Selecting Anodes. As noted in 4.5.3.1 sacrificial magnesium galvanic anodes are used almost exclusively for protecting the insides of glass-lined domestic hot water tanks. Since impressed current systems are used almost exclusively for protecting internal systems, this section will be devoted to those anodes that are used for this type of system. These different anode materials are themselves consumed at various rates in performing their functions.

Some of these anodes must be replaced annually; they are aluminum, steel, or stainless steel. However, the one used almost exclusively is 2017-T4 aluminum alloy. Other anode materials are relatively permanent under most conditions; they are platinum, graphite, and Duriron. Because of high cost, platinum, platinum-clad metals, platinized titanium, and platinized columbium anodes are used only in special applications. Graphite has performance limitations in freshwaters although it performs well in seawater. Therefore, the permanent type of anode almost universally used is Duriron (cast iron containing 14% silicon).

Aluminum anodes (2017-T4) are almost always limited to use where icing conditions occur during the winter months.

Duriron anodes are used where winter icing conditions do not exist, because it increases markedly in brittleness at lower temperatures.

4.5.3.3 Anode Placement. With information on the total surface area to be protected, the configuration of this surface, and the total current required to achieve complete protection, the spacing and arrangement of the necessary anodes can be determined.

The spacing and arrangement of the anodes must be calculated so that each square foot of surface to be protected will receive the same current, i.e., equal protection.

4.5.3.4 Testing. When a cathodic protection system is installed, test points and alarm signals should be installed so that the condition and operation can be checked periodically. Testing of cathodic protection systems is very well described in AFM-88-9, Chapter 4, Section VII, Corrosion Control, and in AFM-85-5, Maintenance and Operation of Cathodic Protection Systems.

Periodic inspections of cathodically protected internal surfaces, such as those in water storage tanks, often are not performed at stated intervals because of the inconveniences and difficulties involved.

Therefore, to insure more uniform application of current and, hence, more reliable protection, automatically controlled systems are recommended; these have proven to be more economical and to supply more uniform protection than is the case when such controls are not used.

Automatically controlled cathodic protection systems are available from a number of cathodic protection companies. An automatically control. cathodic protection system for water storage tanks such as that described in Naval Civil Engineering Laboratory, Technical Report R-765, "Surveillance and Automatically Controlled Systems for Cathodic Protection of Water Tank Interiors," April 1972, has performed very well over a period of 3 years.

Alarm systems should be installed at surveillance locations to alert responsible personnel of any malfunction of the system.

For nonautomatic test systems measurements such as those described under paragraph 3.5.3.3 of this report are also used for internal systems.

Section V

SPECIFIC APPLICATIONS

5.1 PRODUCING WELLS

5.1.1 Design Factors

Water wells consist of a casing, a drop line or piping, and, in
many cases, screens. The casing is normally cemented at the surface
only, except in the case of a deep well. In this instance it may be
cemented at deeper zones where the well passes through more than one
water-producing zone. Concrete is alkaline in nature and offers an
excellent barrier against external corrosion wherever ferrous metallic
well casing is cemented. Another method protecting the exterior of steel
casing is by cathodic protection. However, design and installation
of an effective cathodic protection system is costly. If the casing
runs through some shallow salt water zones, consideration should be
given to cementing to prevent concentration cell corrosion along the
pipe length in the well due to exposure to water of varying compositions.
Cementing the pipe in place through any saline zones is desirable from
a corrosion standpoint and is also recommended from ecological standpoints
so that the salt water will not dump into the freshwater aquifers below.

5.1.2 Materials Selection

5.1.2.1 Casing. Materials selection for well casings should be
made on the basis of performance of casings in the vicinity or by the
criteria outlined in Tables I through IV. The most commonly used well
casing materials are carbon steel, alloy steel (which exhibits generally
the same corrosion characteristics as carbon steel), and cast iron.
Cement, porcelain, vitreous enamel, bitumastic enamel, and rubber coat-
ings are often used to improve the corrosion resistance of the casings
and are beneficial if care is taken during handling to insure that
the coatings remain intact.

Reinforced plastics and asbestos-cement can also be considered
for casing application for wells. Plastics completely eliminate the
corrosion problem but require skill for proper design and in-service

41

application. Asbestos-cement pipe can be used for short inserted settings and, as outlined in Tables I through IV, shows good resistance to waters which are aggressive toward other casing materials. Installation techniques for these materials are different from those used with metallic pipe, and accepted installation procedures must be followed to insure a successful well system.

5.1.2.2 Piping. As in the selection of materials for well casings, well piping materials should be selected on the basis of performance of piping in the vicinity or by the criteria outlined in Tables I through IV. Carbon or alloy steel are the most commonly used piping materials. These materials are, as in casings, often coated for corrosion resistance. Reinforced plastic pipe should also be considered for use as piping. However, as for casings, nonmetallic piping requires special skill in proper design and installation, and their use is recommended only when steel or coated steel piping is unsatisfactory.

5.1.2.3 Screens. Screens are often necessary for wells producing from unconsolidated formations. Again the best basis for selection of screen material is performance of well screens in the vicinity or the compatibility criteria outlined in Tables I through IV. The most commonly used screen materials are silicon bronze, iron, steel, monel metal, and stainless steel. Silicon bronze is recommended when there is no information regarding the performance of screens in the vicinity, and the water composition is unknown. Monel metal, Type 304 stainless steel, or Type 316 stainless steel screens are recommended for use where iron, steel, and silicon bronze screens have proven unsuccessful or are not compatible with the well water based upon the criteria outlined in Tables I through IV. Although 90-10 cupro-nickel is not normally utilized as a screen material, it should be considered for problem wells.

5.1.2.4 Pumps. Impellers and housings should be made of bronze or phosphor bronze. The pump bowl is to be of cast iron and lined with baked porcelain. The porcelain lining gives corrosion protection and also reduces surface friction losses in the pump. The impeller shaft should be of K-monel. American Water Works Association (AWWA) standard AWWA-E101-71 for pump materials should be used in all design work.

5.2 TREATMENT PLANTS

Due to problems with appearance, taste, odor, corrosivity, and infections or poisonous material, water obtained from many sources is unfit for domestic use. By mechanical, physical, or chemical treatment such undesirable water can be rendered suitable for domestic use. Because water treatment facilities must often handle aggressive water and corrosive chemicals, corrosion can be a major problem. However, corrosion problems can be minimized by proper design.

5.2.1 Filtration

The filtration of large amounts of water for domestic use is
normally accomplished by passing the water through sand and gravel beds
contained in concrete pools. Concrete is not subject to deterioration
in most potable waters. However, if protection of the concrete is neces-
sary, it can be coated with a chlorinated rubber paint (Specification
TT-P-95). Proper preparation of the concrete by sandblasting and/or
chemical treatment as per AFM-85-3 is necessary to insure good coating
performance. Materials for auxiliary filtration equipment, such as
pipes, valves, etc., should be selected based upon experience with
waters of similar composition in the vicinity or the compatibility
criteria outlined in Tables I through IV.

5.2.2 Chemical Treatment

Chemicals to improve water quality for domestic use are often
extremely corrosive. Materials for storing, distributing, mixing, and
metering these chemicals must be carefully selected. The manufacturers
and suppliers of water treatment equipment and chemicals are an excellent
source of information on the selection of materials for such applications.

5.2.3 Degasification

In order to remove undesirable quantities of dissolved gases from
water for domestic use, degasification is often required. The two most
common methods of degasification are aeration and deaeration. Since
degasification equipment must handle water with undesirable concentrations
of dissolved gases, sometimes at high temperatures and pressures, corro-
sion of this equipment can be a major problem. Commercial degasification
equipment is normally designed to satisfactorily handle such undesirable
water. However, materials selection can be based upon the compatibility
of the materials with the water to be treated as outlined in Tables I
through IV.

5.3 WATER STORAGE FACILITIES

Elevated or ground level storage tanks are often included in
domestic water supply systems to allow for high peak demands, to serve
as an emergency supply, or to equalize distribution system pressure.

Materials for construction of water storage tanks must be compatible
with the water to be stored, or they must be protected from corrosion.
Steel is the normal material of construction for elevated tanks. Ground

level tanks are constructed from steel, fiber-reinforced plastics, or
concrete. Storage ponds are often lined with mortar; however, plastic
membrane-lined storage ponds are now under development. Since water
storage tanks are usually large in size, material costs are an important
part of the material selection process.

5.3.1 Steel Storage Tanks

Due to its high strength, toughness, and relatively low cost,
steel is often the material of choice for large ground level water
storage tanks and for elevated storage tanks.

5.3.1.1 Corrosion Resistance. Steel does not resist corrosion
by potable water and for that reason, bare steel tanks must not be
used except in cases of emergency.

5.3.1.2 **Exterior Protection**. Those most commonly accepted methods
for protection of steel water tanks are coatings and cathodic protection.

Protection for undersides of flat bottom tanks is seldom critical.
If the tanks are placed on a well-drained sand pad, they will be prac-
tically corrosion free. However, if because of other special considera-
tions additional corrosion protection is desired, then the bottom can
be painted or oiled. The paint usually used is an asphalt varnish applied
in one coat in accordance with Federal Specification TT-V-51A. Addition-
ally, weld seams are usually protected by 6-inch-wide, 1/8-inch-thick
asbestos strips which have been saturated with a high-melting point,
corrosion-inhibitive wax. Proper surface preparation and coating proce-
dures as outlined in subsection 3.4 of this report should be followed
to insure desired coating performance.

For exposed surfaces of steel water storage tanks, alkyds are
the most widely used paint systems. Alkyds may be applied over a commer-
cially blasted steel surface with good results. Two or three coat systems
of six to eight mils total dry film thickness are recommended. The first
coat should be a primer and must be a minimum of two mils thick. If a
high-build, two-coat system is being used, the primer may be three mils
thick (dry film thickness). Topcoats are available in widely varying
colors but are usually chosen to match the surrounding environmental
coloration. Greens, browns, tans, and white are used most frequently.
When applying the exterior paint system the weather should be warm and
dry. The minimum temperature usually acceptable for painting is 50°F
and the maximum relative humidity is 60%. During painting there must
be no tendency for condensation to occur on the steel surface from sol-
vent evaporation. For exterior systems exposed in areas along the coast
or under marine atmospheric conditions, which are generally aggressive,
or for storage tanks which are exposed in highly corrosive industrial

areas, additional corrosion protection is recommended. This may be obtained by going to other paint systems. Some of the other paint systems which have been used are vinyl alkyds, vinyl acrylics, vinyls, PVA latex or an acrylic latex, silicone alkyds, and zinc-rich primer systems. A zinc-rich primed coating system has a number of distinct advantages. Zinc produces a white corrosion product rather than the usual red or reddish brown steel corrosion product. For this reason rust stains are not produced on zinc-rich primed tanks. The zinc has excellent resistance against abra⁻.on from rocks, etc., and generally protects the steel from abr⁺⁻ʲe damage of this type. Further, if there is a rupture in the zinc-rich primer, it affords a degree of cathodic protection in the area adjacent to the break. Both organic and inorganic zinc-rich primers are used with success for exterior priming of water tanks. If appearance is not a factor, the zinc rich primer may be used by itself as a coating system. It has excellent resistance against atmospheric corrosion. However, it is subject to attack in industrial environments if they are either highly acidic or alkaline in nature. Under such corrosive industrial conditions the primer must be top-coated with a suitably resistant topcoat system; vinyls or vinyl acrylics are frequently used for this purpose. If appearance is a factor, some of the better weathering topcoats include the acrylics, silicone alkyds, and vinyl acrylics.

5.3.1.3 **Interior Protection.** The interiors of steel water tanks should be protected by both coating and cathodic protection. All interior coatings must conform to American Water Works Association (AWWA) Specification D-102-64 or Chapter 10, AFM 85-3. The particular coating selected should be chosen on the basis of the criteria outlined in subsection 3.4 of this report. When the information necessary to select a coating on the basis of water composition, temperature range, etc. is not available, a coal-tar enamel coating should be used. A cold-applied, tasteless and odorless coal-tar enamel (AWWA D-102-64 Inside paint system No. 10, Cold T&O tar) can be used in most applications. However a hot-applied coal-tar enamel (AWWA D-102-64 Inside paint system No. 8, Hot-applied T&O tar) should be used where abrasion resistance is required. Cathodic protection should be used to further protect areas of the tank interior which are immersed. Only those portions below the water line can be protected. As the water rises and falls, the area in the zones temporarily covered will be protected only while the water contacts these areas. These areas will not be protected when the water is lowered.

Cathodic protection should be applied to the interior of the tank using either the impressed current or sacrificial anode system as outlined in subsections 3.5 and 4.5 of this report. The recommended system for the interior of coated steel water tanks is the controlled potential type utilizing inert anodes. However, where seasonal freezing occurs a sacrificial anode system may be preferred. Either system should be designed with suitable test stations, and periodic checks should be made to determine system potentials.

45

5.3.2 Fiber Reinforced Plastic Tanks

Fiber Reinforced Plastic (FRP) tanks have excellent corrosion resistance and are essentially inert to all waters (corrosive and non-corrosive). They are used for ground level water storage and, because of cost, are not recommended for tanks in excess of 20,000-gallon capacity unless on-site construction is possible. Damage during shipment and erection is a major problem with FRP tanks. Tanks larger than 20,000 gallons can be produced by on-site construction. This procedure has the advantage of avoiding in-transit damage. There are, however, several precautions which should be borne in mind if this design procedure is used. These relate primarily to quality control of the resins and reinforcement and process control. As the fabrication is made out-of-doors, process control is a major problem. Also, large FRP tanks require a stable foundation. If there is any question of foundation integrity, steel should be used rather than FRP due to its higher strength and toughness.

5.3.3 Mortar-Lined Storage Ponds

Where large quantities of water are desired to be stored with minimal costs, ponds should be considered. The structure of the soil must be such as to support the mortar lining or plastic lining (See paragraph 5.3.4). Two to five inches of mortar or mortar aggregate or lightweight mortar aggregate are blown into place after a suitably sized reservoir has been bulldozed or excavated in place. The mortar lining is usually not subject to attack by the water unless the water is extremely soft or contains considerable dissolved hydrogen sulfide or carbon dioxide. In some instances wire mesh is laid above the ground as reinforcement. This is not necessary if the ground has good integrity and is free from shifts. If mesh is laid in place, it can and will perhaps suffer corrosion after 3 to 4 years of exposure if the ground water contains appreciable quantities of chloride ion. Some reservoir ponds are roofed while others are not. The roofing can be galvanized sheet metal simply laid in place to keep out the dust and debris, or aluminum sheet, or corrugated metal. The reservoirs are usually not tight, and the roof is approximately 2 to 5 feet above the surface of the water. Condensation will occur on the bottom side of the roof, and, for this reason, galvanized steel or aluminum sheeting are recommended. If plain steel is used, it must be protected on both sides with a suitable coating system as outlined in subsection 3.4 of this report.

5.3.4 Plastic-Lined Storage Ponds

These ponds are created in the same manner as described in paragraph 5.3.3 except that they are lined with plastic or some other type of sheet material such as rubber. Again, large volumes of water can be stored at

relatively low costs. The reservoirs are quickly and easily constructed for forward bases and find good usage if long life expectancy is not required. The plastic sheet materials must be carefully joined together by adhesives or by heat welding to make them effective in preventing leakage from the ponds. Plastic-lined concrete ponds have also been used. They are effective where the concrete has developed cracks and begins to show appreciable leakage. In order to avoid washouts and undesirable soil water flows, the storage ponds are often located in relatively low spots so that leakage does not become the serious problem it might if the ponds were located on an elevated site.

5.3.5 Other Tanks

Other types of water storage tanks, such as wooden tanks or cloth-reinforced rubber bladders, are usually considered to be temporary in nature, and corrosion is usually not a factor in their utilization. However, where applicable, the basic principles of corrosion control by materials selection and protective measures should be utilized to insure maximum reliability of such facilities.

5.4 DISTRIBUTION FACILITIES

Water must be conveyed from its source to the consumer. This is accomplished by a distribution system. This piping system may either be buried or above ground. Corrosion control for such systems is important because of their high replacement cost, the potential for property damage, and the dependence of the consumer on an uninterrupted water supply. This corrosion control is accomplished by proper materials selection, proper system design, coatings, and cathodic protection.

5.4.1 Materials Selection

Materials selection for distribution systems should be based upon the criteria outlined in subsections 3.2 and 4.2 of this report. Distribution system components are exposed to the water on the inside and either soil or atmosphere on the outside. The materials selected must be resistant to both environments or must be protected. An outline of the applications of several commonly used distribution system materials is given below.

5.4.1.1 Steel. Steel piping has excellent strength and ductility, is easily fabricated, and has a low overall cost. As outlined in Tables I through IV steel is resistant to internal corrosion in many waters; however, most steel distribution lines are coated internally.

47

The internal coating may be a lining of cement mortar, a coal
tar or an epoxy type of coating. The larger diameter piping, usually
of steel, is often internally coated by hot-applied coal tar. Some pipe
lines in use have been carrying potable water for about 50 years with
this type of lining. The mortar-lined pipe and the PVC type piping
are of a more recent vintage.

All piping and internal coatings as well as design and installations
should be according to AWWA Specification Series C-200 and C-600. Exter-
nal protection of steel piping above ground is achieved by coating.
Coating systems should be selected on the basis of criteria outlined
in subsection 3.4 of this report. Zinc rich coatings are normally recom-
mended for this application and may be topcoated for cosmetic purposes.
Other coating systems, such as normal alkyd, bitumastic, and tar, are
also commonly applied to above ground piping. External protection of
steel piping underground is achieved by coating, and, if required, by
coating and cathodic protection. If the soil is aggressive or if a long
system lifetime is desired, cathodic protection is recommended in addi-
tion to coating. The selection and design of such cathodic protection
systems is outlined in subsection 3.5 of this report.

5.4.1.2 Cast Iron. Cast iron pipe is also commonly used in water
distribution systems. Compared with steel it has lower strength and
ductility. It is, therefore, fabricated in heavier sections. Whereas
steel pipe is often joined by welding, cast iron pipe must have mechan-
ical joints. Although the cost of cast iron pipe is lower than that of
steel, the greater weight and increased installation costs of cast iron
pipe must be considered in the materials selection. Cast iron pipe, as
outlined in Tables I through IV, is resistant to corrosion in many
waters; however, in most installations the pipe is coated internally.
Internal coatings for cast iron pipe are of the same types recommended
for steel as outlined in subsection 5.4.1.1 and in AWWA Specification
Series C-100. Installation of cast iron water mains should be made
according to AWWA Specification Series C-600. As in the case of steel,
external protection of cast iron water distribution systems is obtained
by coating and cathodic protection, and these should be accomplished
as outlined in subsection 5.4.1.1 of this report.

5.4.1.3 Asbestos Cement. Asbestos cement is often used for piping
in domestic water distribution systems. It is resistant to deterioration
by many domestic waters as outlined in Tables I through IV. Asbestos
cement piping is attacked by high purity water, however, and should not
be used to carry water with a specific resistivity greater than 500,000
ohms. Asbestos cement is also resistant to attack by most common soils.
It is not resistant to acidic soils with low pH (<4). Lack of ductility
of asbestos cement is a major problem in its utilization. Careful atten-
tion to installation specifications as outlined in AWWA Specification
C-603-65 is necessary to insure successful installation. Also, due to

48

its low ductility, asbestos cement pipe must be well supported when used above ground and must not be buried in unstable soils. Asbestos cement is less expensive than either steel or cast iron, especially in the larger sizes; however, high installation costs can reduce its cost advantage over these materials.

5.4.1.4 Aluminum. Where light weight and portability are required, aluminum alloy piping may be considered. It has fairly good corrosion resistance for potable water application, and it is frequently used in irrigation systems where portability in piping is important. No external corrosion protection is usually required. Internal corrosion protection may be effected by a lining of coal tar, coal-tar epoxy, or epoxy. In some types of water bare aluminum will prove to be perfectly satisfactory, and a coating will not be necessary.

Aluminum shall not be used in water which contains heavy metals such as copper, mercury, or iron. These metals tend to spot deposit on aluminum, and where the deposit exists rapid corrosion will be initiated. The copper effectively becomes a strong cathode, and corrosion is initiated immediately adjacent to the copper or other heavy metal deposition. Aluminum corrodes in soils of pH greater than 8.5 as well as in soils having resistivities less than 1500 ohm-cm.

5.4.1.5 Plastic. Plastic materials, such as PVC or reinforced plastic, can be used for water distribution systems where lightweight and extreme corrosion resistance are required. Proper quality control, design, and installation practices are well developed for application of these materials in water distribution systems. Plastic pipe can be used for any application up to 4 inches in diameter except where greater crushing strength is required or where heavy machinery loads are encountered such as under roads and runway pavements. Satisfactory performance will be obtained by following the manufacturers' recommendations.

5.4.1.6 Copper. Copper is resistant to corrosion by many domestic waters as outlined in Tables I through IV. It is also resistant to corrosion by most common soils. Copper piping is relatively expensive, however, and its use is generally limited to pipe sizes smaller than those used in water distribution systems.

5.4.2 Design

In order to insure the maximum reliability of domestic water distribution systems good design practices must be followed. Installation specifications as outlined in AWWA Specification Series C-600 must be followed. To insure maximum corrosion resistance other design factors are also important.

5.4.2.1 Couplings and Fittings. In order to minimize galvanic corrosion as outlined in subsections 3.2.2 and 4.2.5 of this report, galvanically compatible materials should be used for couplings and fittings on metallic water distribution systems. If the piping materials are not suitable for the fabrication of couplings or fittings, then materials more noble than the pipe should be used. This will prevent rapid corrosion of the couplings and fittings due to an unfavorable anode-to-cathode area relationship. If more noble couplings and fittings cannot be used, electrical isolation from the pipe must be achieved. Insulating couplings and bushings are available for such isolation. Also, smooth-faced couplings are suggested. If the couplings do not present a smooth face toward the internal flow, then severe turbulence can be generated and protecting corrosion products can be removed by this turbulence. If the protective corrosion products are removed, extensive corrosion can result, usually just down stream from the rough-faced couplings. This corrosion is a combination of cavitation corrosion and erosion corrosion.

5.4.2.2 Velocity of Flow. As outlined in subsection 4.1.1.3 and Tables I through IV of this report, the velocity of flow is an important factor in the corrosion of many materials. It is desirable to limit flow velocities to 4 ft/sec in distribution systems to avoid deleterious velocity effects. A maximum design velocity of 7 ft/sec should never be exceeded.

5.4.2.3 Working Pressure. Normal working pressures of water distribution systems have little or no effect on the corrosion occurring unless large amounts of dissolved gas are held in solution by the pressure. However, deterioration of the system must be taken into account in the determination of safe working pressures. If significant deterioration is expected or discovered, working pressures should be reduced accordingly to avoid catastrophic failures.

5.4.2.4 Stray Currents. Metallic water distribution systems are susceptible to corrosion by stray currents. Stray currents are electrical currents which flow through paths other than the intended circuit. Direct currents are of primary importance. Alternating currents have little effect on commonly used water distribution system materials. Stray current sources are commonly grounded DC power supplies, electric welding equipment, cathodic protection systems, and electroplating plants, although any grounded direct current source can cause stray current corrosion. Stray current corrosion occurs where the current leaves the structure, and it can cause rapid failure. Stray current corrosion can be minimized by connecting the current source directly to the distribution system at the point where current would leave the structure. Stray current corrosion can also be minimized by the application of cathodic protection or the placement of an intentional anode of scrap iron which is connected to the distribution system at the point where

current leaves the distribution system. In many cases the installation of insulating couplings in the system can make it a less favorable path for stray currents; however, if large potential gradients are present this practice may cause accelerated attack at the insulating joint. Stray current corrosion can usually be detected by measuring the pipe-to-soil potential over a long period of time (24 hours). Since the direct current source usually fluctuates in power level while other sources (galvanic or cathodic protection currents) remain steady, fluctuations in pipe-to-soil potential will reveal the presence of stray currents; by locating a potential direct current source with a similar power fluctuation pattern the stray current source can often be determined.

5.4.2.5 Long Line Currents. Long line currents are similar to stray currents in effect but are caused by variations in soil type along a pipeline. Long line currents are therefore a type of galvanic current. Passage of distribution systems through soils with dissimilar characteristics (salinity, resistivity, pH, etc.) should be avoided. When this routing is not possible, insulating couplings should be installed in the system near the discontinuity between different soil conditions. Coated piping is less susceptible to long line current attack than is uncoated piping. Also, since these currents are usually low, cathodic protection can usually eliminate attack due to long line currents and should be utilized whenever long line currents are a potential problem.

5.5 WATER SERVICE IN BUILDINGS

5.5.1 Piping

The selection of piping materials for buildings should be made on the basis of the compatibility of the material with the water which it must carry. The compatibility of the commonly used building piping materials with domestic waters is outlined in Tables I through IV of this report. The actual selection of materials should be based upon the overall system cost (materials and installation and maintenance) over the expected system lifetime. Only the internal corrosion of piping systems in buildings is considered for normal installations. If external corrosion problems are anticipated external corrosion control as outlined in subsections 3.4, 3.5, and 5.4 of this report should be utilized where applicable.

5.5.1.1 Steel, Galvanized. Galvanized (zinc coated) steel is compatible with some domestic waters at temperatures less than $140^{\circ}F$. These waters generally have high hardness or have a high silica content; they therefore have a tendency to form scale at higher temperatures.

51

Galvanized steel is low in initial cost, and it is not difficult to find personnel competent in its installation. However, due to the possibility of changes in water quality (especially due to water softening) and the possibility of temperatures in excess of $140^\circ F$, galvanized steel is not normally recommended for long-term domestic water service systems in buildings.

5.5.1.2 Copper. Copper piping is resistant to many domestic waters in hot water and cold water supply systems. It is somewhat more expensive than galvanized steel, but this is offset by lower installation and maintenance costs. However, corrosion failure of copper piping is often catastrophic in nature and can occur very rapidly with small changes in water composition. For instance, copper piping is not resistant to waters with high carbon dioxide contents. In many domestic water supply systems original water sources must be supplemented. Deep wells are completed which have high carbon dioxide contents, and this water is blended with water from the original source. This raises the carbon dioxide content of the water and causes rapid failures of the copper piping in buildings. Since such small, seemingly insignificant changes in water composition can cause rapid failure of copper piping systems, careful continuous attention must be paid to water quality in systems utilizing copper piping.

Design velocities not in excess of 7 ft/sec in cold water and 4 ft/sec in hot water are desirable in most waters. Careful installation of copper piping is also necessary for satisfactory performance. Proper design and installation procedures for copper piping are outlined in the Copper Tube Handbook, published by the Copper Development Association, Inc., 405 Lexington Ave., New York, N.Y. 10017. Copper piping is recommended for most domestic water service systems in buildings.

5.5.1.3 Copper-Nickel (90-10). Piping fabricated from 90% copper and 10% nickel is more resistant to corrosion by domestic waters than copper piping. This is especially true at high temperatures and velocities. The higher cost of copper-nickel versus copper piping is often justified when the resistance of copper is questionable in hot water distribution systems. Copper-nickel piping is recommended for all hot water systems where the use of copper is questionable. Of course, proper installation of the copper-nickel piping is necessary and should be accomplished according to the manufacturer's instructions.

5.5.1.4 Plastic. Both PVC (polyvinyl chloride) and CPVC (chlorinated polyvinyl chloride) piping are resistant to corrosion by all domestic waters. PVC is useful at temperatures up to $130^\circ F$, and CPVC is useful at temperatures up to $180^\circ F$. The major problems encountered with plastic water distribution systems in buildings are due to poor design and installation procedures. Also, due to inexperience, the cost of installation of plastic piping is often excessive. Proper design and installation

52

procedures for PVC and CPVC piping are available in publications by
the Plastic Pipe Institute, 250 Park Avenue, New York, N.Y. 10017. As
more experience is gained in the use of plastic pipe in domestic water
distribution systems, plastic piping may become more attractive for
many applications. Its use should be considered as an alternative to
metallic piping where corrosion is a problem.

5.5.2 Fittings

Fittings for all piping should be fabricated from the same material
as the pipe wherever possible. The use of dissimilar materials will
result in galvanic corrosion. This attack, as outlined in subsection
4.2.5 of this report is minimized by high water resistivity, small dif-
ferences in galvanic potential, favorable anode-to-cathode area relation-
ships, large distances between anodes and cathodes, and high resistivity
in the metallic current paths. Should the use of dissimilar metals be
necessary, galvanic corrosion should be minimized by application of
these measures. Complete electrical isolation between dissimilar compo-
nents is often accomplished by utilization of insulating couplings.
These couplings should be included in the design of any building water
distribution system where galvanic corrosion is a potential problem.
Fittings should be designed to present a smooth surface to the internal
flow to reduce friction losses in the system and to reduce turbulence
which can cause cavitation corrosion, erosion corrosion, or impingement
attack.

5.5.3 Hot Water Heating Tanks

Hot water heating tanks under 100-gallon capacity, either gas-
fired or electrically heated, are considered for domestic hot water
heating in this section.

5.5.3.1 Materials and Linings. Unless documented experience with
domestic hot water tanks in the area utilizing similar waters indicates
that they are unsatisfactory, glass-lined steel hot water heating tanks
are recommended. Other tank materials such as galvanized steel, monel,
silicon bronze, or copper shall be used only when documented experience
in the area with similar waters indicates that they are more cost effec-
tive.

5.5.3.2 Cathodic Protection. Most glass-lined steel domestic hot
water heating tanks that are commercially available are equipped with
internal magnesium anodes for cathodic protection of the steel at holi-
days in the glass lining. These anodes are necessary for protection of
the tanks in most domestic waters and are recommended for all domestic
tanks. The anodes are normally attached to the cold water inlet pipes

53

and are normally removable for inspection and, if necessary, replacement. It is recommended that the anodes be inspected 2 years after initial installation of the tank. If they are consumed, or nearly consumed, they should be replaced. An inspection and replacement log should be kept for sample heating tanks, and a maintenance program for all heating tanks should be developed from these records. Optimum inspection intervals will vary considerably with various waters and in some water, as determined by anode consumption in sample tanks, may not be necessary. With some aggressive waters anode replacement at yearly intervals may be necessary.

5.5.3.3 Temperature Controls. Temperature controls on domestic hot water heating tanks shall be adjusted so as not to exceed 140°F. Temperature controls which cannot be adjusted above 140°F are recommended for use where unauthorized personnel have access to the controls. Temperatures in excess of 140°F are unnecessary and often dangerous for domestic use. They can lead to accelerated corrosion and scaling damage.

GLOSSARY OF TERMS

Abrasive -- The agent used for abrasive blast cleaning; for example,
sand, grit, steel shot, etc.

ABS plastic -- Acrilonitrile-butadiene-styrene plastic.

Absorption -- Process of soaking up, or assimilation of one substance
by another.

Active -- Referring to the negative direction of electrode potential,
Antonym; noble.

Adhesion -- Bonding strength, the attraction of a coating to the surface
to which it is applied.

Adhesive -- A substance capable of holding materials together by surface
attachment.

Air drying -- Drying by oxidation or evaporation by simple exposure to
air.

Airless spraying -- Spraying using hydraulic pressure to atomize the
paint.

Air volume -- Quantity of air in cubic feet (usually per minute) at
atmospheric pressure.

Alcohol -- A flammable solvent; alcohols commonly used in painting are
ethyl alcohol (ethanol) and methyl alcohol (Methanol, wood
alcohol).

Alkali -- Caustic, such as sodium hydroxide, lye, etc.

Alkyd plastics -- Plastics based on resins composed principally of
polymeric esters, in which the recurring ester groups are an
integral part of the main polymer chain, and in which ester
groups occur in most cross-links that may be present between
chains.

55

Alligatoring -- Surface imperfections of paint having the appearance of alligator hide.

Amide -- Curing agent combined with epoxy resins.

Amine -- Curing agent combined with epoxy resins.

Anaerobic -- Free of air or uncombined oxygen.

Anode -- An electrode of an electrolytic cell at which a net oxidation reaction occurs. In corrosion processes, the anode is the electrode that has the greater tendency to go into solution. Antonym: Cathode. Synonym: See inert anodes, sacrificial anodes, and auxiliary electrodes.

Anodic protection -- A technique to reduce corrosion of a metal surface under some conditions by passing sufficient anodic current to it to cause its electrode potential to enter and remain in the passive region.

Asphalt -- Residue from petroleum refining; also a natural complex hydrocarbon.

Auxiliary electrode -- An electrode commonly used in polarization studies to pass current to or from a test electrode. It is usually made out of a noncorroding material.

Barrier coating -- Shielding or blocking coating or film.

Bell end -- An enlarged portion of a pipe that resembles the socket portion of a fitting and that is intended to be used to make a joint by inserting a piece of pipe into it. Joining may be accomplished by solvent cements, adhesives, or mechanical techniques.

Binder -- In a reinforced plastic, the continuous phase which holds together the reinforcement.

Bituminous coating -- Coal tar or asphalt based coating.

Blast cleaning -- Cleaning with propelled abrasives.

Blisters -- Bubbles in dry or partially dry paint film.

Bright blast -- White blast.

Brush-off blast -- Lowest blast cleaning standard, a light blast.

Caking -- Hard settling of pigment from paint.

Catalyst -- Accelerator; curing agent; promoter.

Cathode -- The electrode of an electrolytic cell at which net reduction occurs. In corrosion processes, usually the area which is not attacked. Typical cathodic processes are cations taking up electrons and being discharged, (e.g., $2H^+ \rightarrow H_2$) oxygen being reduced, and the reduction from a higher to a lower valence state.

Cathodic protection -- A technique to reduce corrosion of a metal surface by passing sufficient cathodic current to it to cause its anodic dissolution rate to become negligible.

Caustic embrittlement -- That form of stress corrosion cracking occurring in steel exposed to alkaline solutions. (See stress corrosion cracking.)

Cavitation -- Damage of a material associated with collapse of cavities in the liquid at a solid-liquid interface.

Cell -- A system consisting of an anode and a cathode immersed in an electrolyte. The anode and a cathode may be separate metals or dissimilar areas on the same metal. When the electrodes are in electrical contact with each other, their difference in potential causes current to flow and produces corrosion at the anode.

Chalking -- The development of loose removable powder at or just beneath an organic-coating surface.

Checking -- The development of slight breaks in an organic coating which do not penetrate to the underlying surface. Checking may be described as visible (as seen by the naked eye) or as microscopic (as seen under magnification of 10 diameters).

Chemical conversion coating -- A thin integral protective or decorative film produced in situ by chemical reaction of a metal with a chosen environment.

Chlorinated rubber -- A particular film former used as a binder, made by chlorinating natural rubber.

Coal tar-epoxy paint -- Paint in which binder or vehicle is a combination of coal tar with epoxy resin.

Coatings -- Surface coverings; paints; barriers.

Coat of paint -- Layer of dry paint resulting from a single wet application.

Cohesion -- Property of holding self together as in a paint film.

Composition -- Analysis; make-up.

Cooling water -- Any water that removes heat from a point or area of higher temperature and delivers it to a point or area of lower temperature.

Corrosion -- Oxidation; deterioration due to interaction with environment.

Corrosion fatigue limit -- The maximum stress endured by a metal without failure in a stated number of stress applications under defined conditions of corrosion and stressing.

Corrosion potential (E_{corr}) -- The potential of a corroding surface in an electrolyte, relative to a reference electrode. Synonym: rest potential, open circuit potential, freely corroding potential.

Couple -- See galvanic corrosion.

Cracking -- Splitting, disintegration of paint by breaks through a film to substrate.

Crazing -- A network of checks or cracks appearing on a paint or plastic surface.

Cross-spray -- Spraying first in one direction and then at right angles.

Cure -- To change the properties of a polymeric system into a final, more stable, usable condition by heat, radiation, or reaction with chemical additives.

Curing agent -- A catalytic or reactive material which is required for curing.

Decomposition potential (or voltage) -- The potential of a metal surface necessary to decompose the electrolyte of a cell or a substance thereof.

Degreaser -- Chemical solution (compound) for grease removal.

Depolarization -- The removal of factors resisting the flow of current in a cell.

58

Deposit -- A foreign substance, which comes from the environment,
adhering to a surface of a material.

Descaling -- Removing scale.

Detergent -- Cleaning agent.

Dew point -- Temperature at which moisture condenses.

Dezincification -- A corrosion phenomenon resulting in the parting of
zinc from copper-zinc alloys (see parting).

Diffusion -- The movement of material, such as a gas or liquid, in
material. If the gas or liquid is absorbed on one side of a
piece of material and given off on the other side, the phe-
nomenon is called permeability. Diffusion and permeability
are not due to holes or pores but are caused and controlled
by chemical mechanisms.

Dilutents -- See thinners.

Dispersion -- Suspension of one substance in another.

Dry spray -- Overspray or bounce back; sand finish due to spray particles
being partially dried before reaching the surface.

Drying time -- Time interval between application and a specified
condition of dryness.

Dry to touch -- Time interval between application and ability to be
touched lightly (tack-free time).

Electrochemical cell -- See cell.

Electrochemical equivalent -- The weight of an element or group of
elements oxidized or reduced at 100% efficiency by the passage
of a unit quantity of electricity.

Electrolysis -- The chemical change in an electrolyte resulting from
the passage of electricity.

Electrolyte -- A chemical substance or mixture, usually liquid, containing
ions which migrate in an electric field.

Embrittlement -- Severe loss of ductility of metal or alloy.

Emulsion paint -- Water-thinned paint with an emulsified oil and/or
resin or latex vehicle.

59

Enamel -- A paint which is characterized by an ability to form an especially smooth film, often an alkyd.

Environment -- The surroundings or conditions (physical, chemical, mechanical) in which a material exists.

Epoxy plastics -- Thermoplastic or thermosetting plastics containing ether or hydroxy alkyl repeating units, or both, resulting from the ring-opening reactions of lower molecular weight polyfunctional oxirane resins, or compounds, with catalysts or with various polyfunctional acidic or basic coreactants.

Erosion corrosion -- A corrosion reaction accelerated by abrasion by solid particles carried by a liquid or gas.

Extrusion -- A process whereby heated or unheated plastic forced through a shaping orifice become one continuously formed piece.

Ferrous -- Iron containing.

Filiform corrosion -- Corrosion which occurs under films in the form of randomly distributed hairlines.

Filler -- A relatively inert material added to a plastic to modify its strength, permanence, working properties, or other qualities, or to lower costs. (See also reinforced plastic.)

Fluorocarbon plastics -- Plastics based on resins made by the polymerization of monomers composed of fluorine and carbon only.

Film thickness -- Depth of applied coating, expressed in mils (1/1000 in.).

Fretting corrosion -- Deterioration at the interface between two contacting surfaces accelerated by relative motion between them.

Galvanic corrosion -- Corrosion associated with the current resulting from the coupling of dissimilar electrodes in an electrolyte. Also known as couple action.

Galvanic series -- A list of metals and alloys arranged according to their relative corrosion potentials in a given environment.

Galvanized steel -- Steel coated with a thin layer of metallic zinc applied by a hot dip or electrolytic process.

Gel -- A jelly-like substance.

Gelling (gelation) -- Conversion of a liquid to a gel state.

General corrosion -- A form of deterioration that is distributed more or less uniformly over a surface.

Gloss -- Shininess; lustre; ability to reflect in mirror direction.

Graphitic corrosion -- Deterioration of gray cast iron in which the metallic constituents are selectively leached or converted to corrosion products leaving the graphite intact. (See parting.)

High build -- Producing thick dry films per coat.

Holiday -- Pinhole, skip, discontinuity, vo _ in a paint film.

Holiday detector -- Device for detection of pinholes or holidays of a nonconductive film over a conductive substrate.

Humidity -- Measure of moisture content; relative humidity is the ratio of the quantity of water vapor in the air compared to the greatest amount possible at the given temperature. Saturated air is said to have a relative humidity of 100%.

Hydrogen embrittlement -- Embrittlement caused by entrance of hydrogen into the metal. (As for example, through pickling or cathodic polarization.)

Hydrogen overvoltage -- Overvoltage associated with the liberation of hydrogen gas. (See overvoltage.)

Hydrostatic design stress -- The estimated maximum tensile stress in the wall of the pipe in the circumferential orientation due to internal hydrostatic pressure that can be applied continuously with a high degree of certainty that failure of the pipe will not occur.

Immunity -- A state of resistance to corrosion or anodic dissolution caused by the fact that the electrode potential of the surface in question is below the equilibrium potential for anodic dissolution.

Incompatibility -- Inability to mix with or adhere to another material.

Inert anode or electrode -- An electrode which does not corrode or react under an impressed anodic potential.

Inert pigment -- A nonreactive pigment.

Inhibitive pigment -- One which retards the corrosion process.

Inhibitor -- A chemical substance or combination of substances, which when present in the proper concentration in the environment, prevents or reduces corrosion by a physical, physico-chemical or chemical action.

Intercrystalline corrosion -- See intergranular corrosion.

Intergranular corrosion -- Preferential corrosion at grain boundaries of a metal or alloy. Also called intercrystalline corrosion.

Ion -- An electrically charged atom or group of atoms.

Iron rot -- Deterioration of wood in contact with iron.

Langlier index -- A calculated saturation index for calcium carbonate that is useful in predicting scaling behavior of natural water.

Latex -- Rubber like; a common binder for emulsion (water) paints; there are natural and synthetic latexes.

Leveling -- Flowing out to films of uniform thickness; tendency of brush marks to disappear.

Lifting -- Softening and raising of an undercoat by application of a top coat.

Long-line current -- Current flowing through the earth from an anodic to a cathodic area which returns along an underground metallic structure (generally applied only where the areas are separated by considerable distance and where current results from concentration cell action).

Mastic -- A heavy bodied high build coating.

(MEK) methyl ethyl ketone -- A strong flammable organic solvent.

(MIBK) methyl isobutyl ketone -- A strong flammable organic solvent.

Micron μ -- 1×10^{-6} meters.

Mil -- One one-thousandth of an inch.

Mil scale -- The heavy oxide layer formed during hot fabrication or heat treatment of metals and alloys.

Mixed potential -- A potential resulting from two or more electrochemical
reactions occurring simultaneously on one metal surface.

MVT (moisture vapor transmission) -- Moisture vapor transmission rate
through a known membrane.

Noble -- Referring to positive direction of electrode potential, thus
resembling noble metals such as gold and platinum. Antonym:
active.

Noble potential -- A potential more cathodic (positive) than the standard
hydrogen potential.

Nonferrous -- Containing no iron.

Nylon plastics -- Plastics based on resins composed principally of a
long-chain synthetic polymeric amide which has recurring
amide groups as an integral part of the main polymer chain.

Olefin plastics -- Plastics based on resins made by the polymerization
of olefins or copolymerization of olefins with other unsatu-
rated compounds, the olefins being in greatest amount by
weight. Polyethylene, polypropylene and polybutylene are the
most common olefin plastics encountered in pipe.

Open circuit potential -- See corrosion potential.

Orange peel -- Dimpled appearance of dry film; resembling an orange peel.

Overcoat -- Second coat; top coat

Overspray -- Sprayed paint which did not hit target; waste.

Overvoltage -- The change of an electrode potential from its reversible
equilibrium value due to polarization. (See hydrogen overvoltage
and polarization.)

Oxidation -- Loss of electrons by a constituent of a chemical reaction.

Oxygen concentration cell -- A galvanic cell resulting from difference
in oxygen concentration between two locations.

Paint system -- The complete number and type of coats comprising a paint
job. In a broader sense, surface preparation, pre-treatments,
dry film thickness, and manner of application are included in
the definition of a paint system.

Parting -- The selective attack of one or more components of a solid
solution alloy.

Pass (spray) -- Motion of the spray gun in one direction only.

Passivation -- A reduction of the anodic reaction rate of an electrode involved in electrochemical action such as corrosion.

Passive-active cell -- A cell, the emf of which is due to the potential difference between a metal in an active state and the same metal in a passive state.

Patina -- The green coating which forms on the surface of copper and copper alloys exposed to the atmosphere.

Permeability -- See diffusion.

pH value -- Measure of acidity or alkalinity; pH 7 is neutral; the pH values of acids are less than 7, and of alkalis (bases) greater than 7.

Phenolic plastics -- Plastics based on resins made by the condensation of phenols, such as phenol and cresol, with aldehydes.

Pin-holding -- Formation of small holes through the coating.

Pits -- Corrosion of a metal surface, confined to a point or small area which takes the form of cavities.

Pitting Factor -- The ratio of the depth of the deepest pit resulting from corrosion divided by the average penetration as calculated from weight loss.

Plasticizer -- A paint ingredient which imparts flexibility.

-- A material incorporated in a plastic to increase its workability and its flexibility or distensibility.

Polarization -- The deviation from the open circuit potential of an electrode resulting from the passage of current, as for example achieving a protected potential of -0.9V with respect to $Cu/CuSO_4$ electrode for a steel structure.

Polyester plastics -- Synonymous with alkyd plastics.

Polyethylene plastics -- Plastics based on polymers made with ethylene as essentially the sole monomer.

Polymerization -- A chemical reaction in which the molecules of a monomer are linked together to form large molecules whose molecular weight is a multiple of that of the original substance. When two or more monomers are involved, the process is called copolymerization or heteropolymerization.

Polypropylene plastics -- Plastics based on polymers made with propylene as essentially the sole monomer.

Poly(vinyl chloride) -- A resin prepared by the polymerization of vinyl chloride alone.

Porosity -- Degree of integrity or continuity of a paint film.

Pot-life -- Time interval after mixing of reactive components of a paint during which liquid material can be properly applied.

Pre-treatment -- Treatment given a surface prior to applying a primer or first coat of paint. For example an acidified wash.

Profile -- Surface contour of a blast-cleaned surface as viewed from the edge; cross section of the surface.

Protective life -- Interval of time during which a paint system protects substrate from deterioration.

Reinforced plastic -- A plastic with some strength properties greatly superior to those of the base resin, resulting from the presence of high strength fillers imbedded in the composition (see also filler).

Resin -- A material, natural or synthetic, contained in varnishes, lacquers and paints; the film former.

-- A solid, semisolid, or pseudosolid organic material which has an indefinite and often high molecular weight, exhibits a tendency to flow when subjected to stress, usually has a softening or melting range, and usually fractures conchoidally.

Rest potential -- See corrosion potential.

Rigid plastic -- For purposes of general classification, a plastic that has a modulus of elasticity either in flexure or in tension greater than 7000 kgf/cm^2 (100,000 psi) at 23°C and 50% relative humidity when tested in accordance with ASTM Methods D747, Test for Stiffness of Plastics by Means of a Cantilever Beam, ASTM Method D790, Test for Flexural Properties of Plastics, ASTM Method D638, Test for Tensile Properties of Plastics, or ASTM Methods D882, Test for Tensile Properties of Thin Plastic Sheeting.

Runs -- Curtains or sags in a paint film.

Rust -- Corroded iron; red iron-oxide deposited on metal; also other metal oxides formed by corrosion of iron or steel.

Sacrificial anode -- An anode which corrodes and sacrifices itself,
           providing protection to an adjoining metallic component.

Sacrificial protection -- Reduction or prevention of corrosion of a
           metal in an electrolyte by galvanically coupling it to a
           more anodic metal.

Sandblast -- Blast cleaning using sand as an abrasive.

Saran plastics -- Plastics based on resins made by the polymerization of
           vinylidene chloride or copolymerization of vinylidene chloride
           with other unsaturated compounds, the vinylidene chloride being
           in greatest amount by weight.

Scale -- Rust or other deposits adhering or occurring in thin layers.

Scaling -- Process of removing scale. (See descaling.)

Season cracking -- A term usually applied to stress corrosion cracking
           of brass.

Semirigid plastic -- For purposes of general classification, a plastic
           that has a modulus of elasticity either in flexure or in ten-
           sion of between 700 and 7000 kgf/cm^2 (10,000 and 100,000 psi)
           at 23°C and 50% relative humidity when tested in accordance
           with ASTM Method D747, Test for Stiffness of Plastics by Means
           of a Cantilever Beam, ASTM Method D790, Test for Flexural
           Properties of Plastics, ASTM Method D638, Test for Tensile
           Properties of Plastics, or ASTM Methods D882, Test for Ten-
           sile Properties of Thin Plastic Sheeting.

Shelf-life -- Maximum interval in which a material may be stored and
           still be in usable condition.

Shot blasting -- Blast cleaning using steel shot as the abrasive.

Silicone plastics -- Plastics based on resins in which the main polymer
           chain consists of alternating silicone and oxygen atoms, with
           carbon-containing side groups.

Solids -- Non-volatile portion of paint.

Solvent -- A liquid in which another substance may be dissolved.

Spalling -- The chipping, fragmentation, or separation of a surface or
           surface coating.

Spark tester -- A high voltage holiday detector which sparks at holidays.
           (See holiday detector.)

66

Standard electrode potential -- The reversible potential for an electrode
        process when all products and reactions are at unit activity
        on a scale in which the potential for the standard hydrogen
        half cell is zero.

Standard thermoplastic pipe materials designation code -- A means for
        easily identifying a thermoplastic pipe material by means of
        three elements. The first element is the abbreviation for the
        chemical type of the plastic in accordance with ASTM D1600.
        The second is the type and grade (based on properties in accor-
        dance with the ASTM materials specification); in the case of
        ASTM specifications which have no types and grades or those in
        the cell structure system, two digit numbers are assigned by
        the PPI that are used in place of the larger numbers. The
        third is the recommended hydrostatic design stress (RHDS) for
        water at 23°C (73°F) in pounds per square inch divided by 100
        and with decimals dropped; e.g., PVC 1120 indicates that the
        plastic is poly-(vinyl chloride), Type I Grade 1 according to
        ASTM D1764 with a RHDS of 2000 psi for water at 73°F. PE 3306
        indicates that the plastic is polyethylene, Type III Grade 3
        according to ASTM D1248 with a RHDS of 630 psi for water at
        73°F. PP 1208 is polypropylene, Class I-19509 in accordance
        with ASTM D2146 with a RHDS of 800 psi for water at 73°F; the
        designation of PP12 for polypropylene Class I-19509 will be
        covered in the ASTM and Product Standards for polypropylene
        pipe when they are issued.

Stray current corrosion -- Corrosion resulting from direct current flow
        through paths other than the intended circuit. For example,
        by any extraneous current in the earth.

Stress accelerated corrosion -- The increased corrosion caused by applied
        tensile stresses.

Stress corrosion cracking -- Premature cracking of metals produced by
        the combined action of corrosion and surface tensile stress
        (residual or applied).

Styrene-rubber plastics -- Compositions based on rubbers and styrene
        plastics, the styrene plastics being in greatest amount by weight.

Surface preparation -- All operations necessary to prepare a surface
        to receive a coating of paint.

Tarnish -- Surface discoloration of a metal resulting from the formation
        of a thin film of corrosion product.

Thermogalvanic corrosion -- Corrosion resulting from a galvanic cell
        caused by a thermal gradient.

67

Thermoplastic -- Capable of being repeatedly softened by heating and hardened by cooling through a temperature range characteristic of the plastic, and that in the softened state can be shaped by flow into articles by molding or extrusion.

Thermoset -- A plastic which, when cured by application of heat or chemical means, changes into a substantially infusible and insoluble product.

Thinners -- Volatile organic liquids for reducing viscosity; solvents.

Tie coat -- Intermediate coat used to bond different types of paint coats.

Tooth -- Profile; mechanical anchorage; surface roughness.

Toxic -- Poisonous.

Toxicity -- Degree of poisonousness or harmfulness.

Throwing power -- The relationship between the current density at a point on the specimen and its distance from the counter electrode. The greater the ratio of the surface resistivity shown by the electrode reaction to the volume of resistivity of the electrolyte the better is the throwing power of the process.

Tuberculation -- The formation of localized corrosion products scattered over the surface in the form of knoblike mounds.

Urethane plastics -- Plastics based on resins made by the condensation of organic isocyanates with compounds or resins that contain hydroxol groups.

Vinyl plastics -- Plastics based on resins made from monomers containing the vinyl group $CH_2 = CH -$.

Vinylidene chloride plastics -- See saran plastics.

Viscosity -- A measure of fluidity.

Viscosity cup -- A devic for measuring viscosity.

Voids -- A term generally applied to paints to describe holidays, holes, and skips in the film.

Volatiles -- fluids which evaporate rapidly from a paint film.

Wash primer -- A thin inhibiting paint usually chromate pigmented with a polyvinyl butyral binder.

Weld decay -- Localized corrosion of weld metal.

White blast -- Blast cleaning to white metal.

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