TPC Publication 7

Prevention & Control of Water-Caused Problems in Building Potable Water Systems

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CONTENTS

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Foreword

The National Association of Corrosion Engineers has had a technical committee on corrosion by domestic waters for many years. For almost a half century, commercial water treatment companies have provided services for the control of corrosion in urban buildings in many areas. However, despite the information available through the National Association of Corrosion Engineers and despite the services of commercial water treating companies, there continue to be numerous water related operating problems and equipment failures, even in recently built structures. Many of these problems and failures have been caused by faulty design of the plumbing systems. It appears that available information on the proper design of plumbing systems to avoid corrosion problems has not been brought effectively to the attention of engineers designing these systems.

The publication of this manual by the National Association of Corrosion Engineers is an attempt to rectify this situation. By bringing this information together in convenient form, the Association hopes to provide plumbing design engineers with information that will assist in overcoming the water-caused problems which reduce the efficiency and shorten the life of domestic water systems in buildings. Although the principles and many of the details given in this manual apply to buildings of any size, the information has been assembled primarily for designers of potable water systems for larger buildings, such as high-rise office and apartment buildings, hospitals, schools and hotels.

This manual was prepared by Task Group T-7G-2 of NACE Unit Committee T-7G on Corrosion and its Control in Water-Using Systems of Buildings. Unit Committee T-7G is one component of Group Committee T-7 on Corrosion by Waters.

Introduction

Although modern commercial buildings, such as high-rise structures, may have a dozen or more different water systems for heating, cooling, and other services, this manual deals only with potable water systems: (a) Cold Water Systems, (b) Hot Water Systems, and (c) Recirculating Chilled Drinking Water Systems.

Potable water is defined as "water suitable for drinking."

This manual deals primarily with the problems of scale and corrosion in domestic hot water systems, since such problems are much more serious and prevalent in hot water systems than in cold water systems. High temperatures generally cause increased scaling and corrosion and these problems are generally less common in cold water systems. When these problems are encountered in cold water systems, the solutions recommended for hot water systems are generally equally applicable.

The most common corrosion accelerating faults observed in the design and operation of domestic hot water systems are:

1. Operation of the domestic hot water system at too high a temperature [above 57 C (135 F)] (See Chapter 3).
2. Complete softening of water, with the corresponding increase in the corrosiveness of the supply.
3. Choice of the wrong piping material for the particular water supply, and failure to recognize the need for water treatment additives.
4. Faulty system design, such as the installation of copper tubing of too small diameter resulting in too high velocity, with subsequent erosion-corrosion.

Examples of water-caused problems are:

1. *Reduction in the potability of the water. (A possible health hazard.)*
   The average user may note off-tastes, off-colors, odors, sediment in the water and stains on fixtures, laundry, silverware, etc. Chemical laboratory examination may be required for the detection of foreign materials, trace metals or other contaminants at a concentration too low to affect taste, color, odor, etc. or bacteriological examination may be required for detection of bacteria, pollutants, etc.

2. *Reduction in operating efficiency and the life of the system, caused by scale or corrosion. (Capacity decrease, maintenance increase, or required replacement of system components.)*
   The average user or an operator may note (a) development of leaks in the water system, (b) a decrease in the water flow rate at faucets, (c) a reduction of pressure in the system, (d) a reduction of capacity

for heating hot water, as evidenced by low water temperatures, (e) a malfunction of temperature controls, ice-making machines, mixing valves, valves and seats, shower heads, safety valves, etc., and (f) the staining of fixtures.

3. *Miscellaneous.*
Occasionally, problems occur that are independent of both design and operation of the building systems. These problems may occur as a result of water main repairs in the area or the use of water to combat fires, which may cause a temporary development of an undesirable taste and odor in the water. Should these conditions persist, the origin of the problem must be determined and corrected.

There are solutions to practically all of these water-caused problems. However, the solutions may be simple or complex and often require the assistance of a qualified corrosion or water treatment expert. Recommendations for solutions are included in the following chapters of this manual.

The composition of the water supply may have a considerable bearing on water system problems encountered. Most buildings receive water from a public water supply system. The Environmental Protection Agency (EPA) has stated that the vendor of the water is considered to have the responsibility for supplying to a building water that (a) is safe for drinking and sanitary purposes, (b) is reasonably attractive in appearance, has no objectionable odor or taste, minimal color, and is essentially free of suspended solids, and (c) does not contain even low levels of contamination/pollutants such as trace metals. In the legal sense, each State has well defined Standards for drinking water to serve as a guideline for water vendors. In general, these State Standards correspond to "the new National Interim Primary Drinking Recommendations" as specified by the EPA, effective in June, 1977. (See Chapter 9.)

While the tentative Secondary Drinking Water Regulations include additional maximum contaminant levels for color, odor, chloride, sulfate, copper, zinc, iron, manganese, hydrogen sulfide, total dissolved solids (TDS) and foaming agents, as well as pH and corrosivity, these standards are currently not enforceable. Building owners, then, must generally accept responsibility for the quality of water in the building; however, there have been cases in which the water purveyor has accepted responsibility for corrosive conditions in a building system. When acceptable standards in respect to corrosivity of a water supply are set and the secondary standards are enforceable, the water purveyor will definitely have to accept the responsibility for the corrosivity of the building water system.

A building owner can be held responsible for the installation of unsatisfactory materials or for installing an unsatisfactorily designed plumbing system or for allowing entrance of contaminants, (back-siphonage, contaminated roof tanks, etc.) into a potable water system. Therefore, building owners should obtain assistance from building system designers, public health specialists, and corrosion or water treatment specialists to correct and avoid undesirable conditions.

CHAPTER 1
WATER-CAUSED PROBLEMS

The problems in potable water systems will be reviewed from two viewpoints. This chapter will first examine the symptoms that signify trouble to the user or building operator and will then identify the causes of the symptoms. This dual approach is needed because some of the same symptoms are produced by different processes, each of which may require completely different preventive or corrective measures. As an example, a common cause of gradual reduction in the flow of water from a pipe may be partial clogging due to the buildup of a deposit. This deposit may be a scale formed by precipitation of hardness from the water, in which case partial softening of the water will both improve the flow and prevent further flow reduction from this cause. On the other hand, the flow-reducing deposit may be an accumulation of corrosion products, in which case softening would only aggravate the problem. Cleaning or pipe replacement may be necessary to improve flow conditions. Also, attention should be directed towards preventing redeposition of scale or corrosion products by initiating proper water treatment and control, better temperature control, or other operating changes or combinations thereof.

Symptoms

From the symptomatic viewpoint, the water-caused problems of potable water systems may be classified as those which reduce the potability of the water, those which reduce the operating efficiency of the water system, and those which reduce the life of the water system.

Reduction in Potability

Symptoms of degraded potability in a building's sanitary water supply may be detected by the average user or may require laboratory tests to be identified. Most users can readily recognize the appearance of off-tastes, odors, color or sediment in the water, and stains on porcelain fixtures, laundry and silverware. Laboratory examination of water samples are needed to detect evidence of bacterial or chemical contamination, such as trace metal concentrations which may be significant but too low to be recognized by taste.

Reduction in Operating Efficiency (Deposits)

Water-caused operating problems in potable water systems are generally manifested in the reduction of water flow rate, reduced pressure, reduced capacity for heating water, interference with the operation of such system components as temperature-controlled mixing valves or shower heads, staining of porcelain fixtures, malfunctioning of ice cube machines, and the plugging of valves, meter screens, etc.

Reduction in System Life

Some of the above symptoms are also associated with the reduced life of potable water systems as a result of corrosion. These include the development of leaks and the reduction of flow when the cause is an accumulation of corrosion products for which there may appear to be no practical method of removal. Interference with the operation of system components such as bellows-type expansion joints, meters, valves, safety valves, and faucet seats, may also occur as a result of clogging with corrosion products. Back-flushing performed by competent specialists may prove effective in removing accumulations.

Miscellaneous

Symptoms independent of the design of operation of the building water system may appear. Leaks can develop from purely mechanical causes or from freezing bursts. Reservoir conditions can lead to the delivery of off-taste, discolored, or turbid water to a building. Water main repairs or a fire in the area can produce the same effects.

Diagnosis of Cause of Symptoms

The appearance of any of the symptoms discussed above should initiate a series of diagnostic steps aimed at determining whether the cause of the symptom lies within or without the building and then, if internal, at identifying the cause so that effective corrective measures can be taken. A knowledge of the water-based causes of abnormal performance of symptoms in potable water systems also makes it possible to take preventive steps when designing and constructing new potable water systems or when making alterations, additions, and repairs.

Causes of Symptoms

The water which once flowed like a torrent now appears as little better than a trickle, even though there has been no reduction in the pressure of the water entering the system. Variously reported as poor flow, low pressure, or partial blockage, this symptom is a result of the buildup of a deposit or deposits in the piping. Ultimately, the piping can become completely blocked so that there is no flow of water.

Second only to the "there is only a trickle of water" symptom is the complaint that "the water isn't hot enough" or, more exactly "the hot water isn't as warm as it used to be." This symptom is usually caused by a buildup of mineral deposit on the heat transfer surfaces of the hot water generator and circulating systems. This interference is caused by the same deposits that cause poor flow, but the effect on heating water is usually noticeable long before there are significant reductions in flow because the deposits are such effective insulators of the hot water generator heating surfaces.

Under conditions of high hot water demand throughout a building, reversal of flow may occur and cooled downstream return water may flow to faucets furthest away from the heater. The same conditions may occur during off-peak periods if a corrosion fouled check valve is held in open position.

Hardness Scale

Deposits which reduce the flow of water may be a fairly uniform buildup of calcium carbonate ("lime" or "limestone") scale caused by precipitation of hardness from the water, particularly in the hot water system. This is the most common cause of poor flow and reduced hot water temperature. Hardness scale is usually an off-white color (frequently tan or rust-tinted), hard, and crystalline material. Magnesium hydroxide, a white slimy insulating type scale, may form on hot water heater surfaces when the water supply is lime-softened and not properly adjusted to a lower pH.

When domestic water is heated in so-called "instantaneous heaters" or other multiple tube heat exchangers, the reduction of water velocity often allows particles of sand, corrosion products, or organic matter from the water supply to settle out in these tubes. Although the amount of such sediment may be extremely small, in time it can accumulate to the point that it appreciably reduces the temperature of the hot water generated.

The formation of hardness scale also causes both destruction and malfunction of water system components. The formation of scale on resistance-type electrical heating elements in hot water generators commonly causes these elements to over-heat and burn out. Scale buildup is also a common cause of functional failure of thermostatically controlled hot water mixing or tempering valves.

Corrosion Products

Poor flow can also be caused by an accumulation of corrosion products. The familiar buildup of rust or iron oxide in the form of tubercles on iron or steel pipes is an example of this. These tubercles are usually rust-colored and soft on the outside and both harder and darker toward the inside. They frequently grow together so as to form a deposit of irregular thickness which coats the entire inside surface of the pipe. Accumulations of corrosion products are much less uniform than scale deposits and may be quite localized, frequently at threaded joints.

In iron or steel pipe that carries water which is both corrosive and hard, the pH changes that take place at cathodic areas during corrosion may cause the precipitation of hardness from the water. Under such conditions, deposits may build up more rapidly and will consist of a mixture of rust and calcium carbonate.

The corrosion of other metals can also result in deposit formation, although usually to a much lesser degree than in the case of ferrous piping. In the older water systems of yellow brass piping, white tubercles of basic zinc carbonate formed when plug type dezincification occurred. Much smaller green to blue-green tubercles of copper corrosion products may develop when copper tubing becomes pitted.

Corrosion is easily recognized as the cause of leaky pipes. It also causes other system malfunctions, such as the partial plugging of piping with corrosion products or plugging expansion joints so that they fail to operate properly.

Off-Tastes, Odors, Contamination and Suspended Matter

One of the more common symptoms is the unattractive appearance of the water. This may take the form of rusty or red water, black water, or non-descript turbidity or sediment in the water. Off-tastes from corrosion products resulting from the corrosion of galvanized steel or copper may be observed. The former Drinking Water Standards (1962)[1] limited zinc to 5 mg/L because of the possible metallic taste resulting from the corrosion of zinc in galvanized piping.

The appearance of drinking water will be degraded by any source of sediment or color. Iron from well water or formed by corrosion can create a red or rusty-water condition and cause rust stains on fixtures. Corrosion of copper may cause blue-green staining and occasionally, even green or blue water. Manganese from a water supply may cause black stains. Closely related is the development of rusty, blue-green, or black stains on light-colored porcelain fixtures even when there is no obvious discoloration in the water itself. Turbid water will develop if sudden flow changes or other incidents disturb sediment which has settled out in the mains or storage tanks. Failure to install an approved backflow prevention device may be the cause of contamination and sediment by backflow from laundry tubs and other appliances. Colored water has been known to develop from degradation of leaves and other organic matter that entered roof storage tanks which were improperly screened. A poorly balanced system allowing stagnant areas to develop may cause corrosive conditions and poor water quality.

Odors develop almost exclusively from organic materials. Musty or fishy odors may enter with surface water supplies or may develop from organic matter accumulated in the system. If accumulations are large enough, anaerobic decomposition of such material can develop a "rotten egg" odor in the water. A few water supplies may have such an odor when they enter the building system.

Bacterial contamination may result from an external source or from internal cross connections. This may occasionally occur in the water supply itself, although it is more frequently found in private well supplies not protected by chlorination.

The preceding paragraphs point out the occasional interrelationship between different symptoms—taste or odor and bacterial contamination, for example. Similar relationships occur between other symptoms. Thus, a single cause—corrosion—may lead to the development of rusty water, rust stains on sinks, a tepid hot water supply, poor flow, leaks in a system piped with steel or galvanized steel or leaks from erosion-corrosion of copper tube.

CHAPTER 2
CORRECTIVE MEASURES

A variety of measures are available for correcting symptoms of abnormal performance of water systems in buildings. Whenever possible, it is always best to correct the basic problem, but in existing buildings it is not always feasible to do this.

Correction of Scale Problem

Scale within building potable water systems may often be reduced or brought under control by one of three techniques, namely: (1) Maintaining hot water temperature below a maximum of 60 C (140 F); water temperatures of 60 C (140 F) and above can cause scaling problems, (2) softening to 60-120 mg/L hardness (as $CaCO_3$), and (3) applying polyphosphate at threshold dosages (generally the least effective method). Where the water supply is scale-forming at temperatures above 60 C (140 F), control of the hot water temperature at or below 60 C (140 F) may be adequate to avoid the buildup of undesirable quantities of deposits. The one certain way to prevent scale in these systems is to pass the water through a salt-regenerated cation exchange (zeolite) water softener.

It is undesirable, however, to soften a water completely, as a completely softened water may be quite corrosive. Installation of a bypass around the softener permits the adjustment of the final water to a hardness level [60-120 mg/L (as $CaCO_3$)] which is usually not sufficient to form appreciable scale, but which reduces the corrosive tendencies of the water supply. In some cases the feeding of a few mg/l (threshold treatment) of a glassy polyphosphate is adequate to prevent calcium carbonate formation. It should be recognized, however, that polyphosphate is not an effective corrosion inhibitor at these low dosages and that the thin protective scale layer of calcium carbonate, which is often effective in inhibiting corrosion, will not form in the presence of polyphosphate.

Correction of Corrosion Problem

Symptoms which develop as a result of corrosion can be corrected by (1) changes to a more corrosion resistant material, (2) separation of the corroded material from the corrosive water, (3) changing the water composition to make it less corrosive, or (4) modifying the operating conditions in the system.

Selection of materials that will not be corroded by the water to be supplied is the most important step that can be taken during the design *of a new building.* Consultation with a corrosion or water treatment specialist is suggested to obtain advice concerning the proper choice of materials for use with a particular water supply and the need for application of corrective treatment. Changing materials of construction later to alleviate corrosion in an existing water system can be extremely costly so the application of corrective treatment may prove more practical.

Also, it is important in the design stage to consider the influence on the overall life of the system of such parameters as flow rate, temperature and pressure, the inclusion of temperature and pressure control devices, lining or cathodic protection of storage tanks, where applicable, and man-holes or hand-holes, backflush connections, and similar clean-out devices.

Once a domestic water system has been put into operation, corrosion-caused problems can be minimized by (1) ensuring that temperature, pressure, and flow-controls are kept in adjustment, (2) cleaning or flushing is performed periodically where appropriate means have been provided, and if necessary (3) treating the water for corrosion control.

Treatment of the water in potable systems within buildings is limited by public health requirements and space limitations. Calcite filters can be, but rarely are, used for this purpose, primarily because the life of the filter ingredient may be limited and because they require large amounts of space. The more usual water treatment technique for controlling corrosion within buildings is the proportional application of a high silica-to-sodium ratio sodium silicate (water glass), sometimes supplemented with caustic soda for pH adjustment.

Sediment is best controlled by eliminating its sources through regular cleaning and flushing programs or by the application of corrosion inhibiting treatment if the sediment source is caused by corrosion occurring within the building. When sediment enters the building regularly from outside sources, it may be necessary to install filters for its removal. These may be the typical sand or other granular filters. However, such filters occupy so much space that it may be more feasible to install tubular type strainers, although these may not remove as much or as fine a sediment as does a sand filter.

Correction of Taste and Odor Problems

Tastes and odors that develop within a building can usually be corrected and then prevented in the future by maintaining a regular cleaning schedule for storage tanks and other locations where organic matter may build up. Under extreme circumstances, it may be necessary to disinfect the piping system by circulating a chlorine-containing solution through it in order to eliminate the organic material that is causing the tastes and odors.

Magnesium anode rods installed for providing cathodic protection may be responsible for hydrogen sulfide odors. Removal of these rods may solve this odor problem, as reported in the cathodic protection section in Chapter 5, although an alternate solution to the corrosion problem will then be required.

If tastes and odors are caused by sources outside a building, a partially successful method of removal is the installation of an activated carbon filter on the incoming water line. It may be less expensive and less space-consuming to install such filters only on lines that supply drinking fountains, kitchens, or other points of use at which off-tastes or odors may be experienced. Caution is recommended to provide proper maintenance and replacement of these carbon filters since they may provide breeding places, after prolonged use, for bacterial growths responsible for bacterial contamination, bad taste and obnoxious odors.

Elimination of bacteria from a potable water system is almost exclusively a matter of prevention of cross-connections or backflow. This means careful supervision and maintenance of any additions or alterations to the potable water system.

Should bacterial infection be detected despite such precautions, its source should be tracked down and eliminated; and the entire system should be chlorinated in order to disinfect it.

CHAPTER 3
MECHANICAL DESIGN FACTORS

Piping system design can have an important influence on providing a corrosion-free acceptable domestic hot water supply in a building. Some of the factors which should be considered bv the piping system designer are:

1. Selection of the proper materials of construction (as discussed in detail in Chapter 4) is the most important single factor in designing a long-life system. Advice on materials selection should be obtained from a competent corrosion specialist who has knowledge of the corrosivity of the existing water supply at the site and the possible changes or seasonal variations of this supply, as well as the need for supplementary treatment.
2. Compatible materials (with respect to corrosion) should be installed in building water systems.
3. Basic load calculations and hydraulic data for the entire system, the anticipated average, peak and minimum water usage should be taken into consideration, as well as possible changes in water usage resulting from changes in occupancy or utilization, or from building expansion.
4. A thermostatically controlled hot water circulating system should be installed which is properly designed for uniform and proper flows throughout the building at rates recommended for the particular piping material.
5. Domestic hot water temperatures should be set at 52-57 C (125-135 F) in order to prevent possible override of the maximum temperature setting. If higher temperatures are required at some locations, booster heaters should be installed to provide the water required for dishwashers, laundries, etc.[1]
6. If there is any possibility that the water supply is, or may become corrosive or scale-forming, by-pass valving, as shown in Figures 1 and 2, should be included and space should be provided to permit convenient installation of appropriate water treatment equipment in the event that a need for this equipment be demonstrated later. If a water softener is to be installed, a space at least ample for the softener, brine tanks and working area should be provided.

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(1) Hospitals now specify automatic regulation of the water supply temperature so that the temperature does not exceed 43 C (110 F) terminally at shower, bathing, and hand-washing facilities. Temperature control devices shall be installed to be inaccessible to unauthorized personnel, patients, and the public.

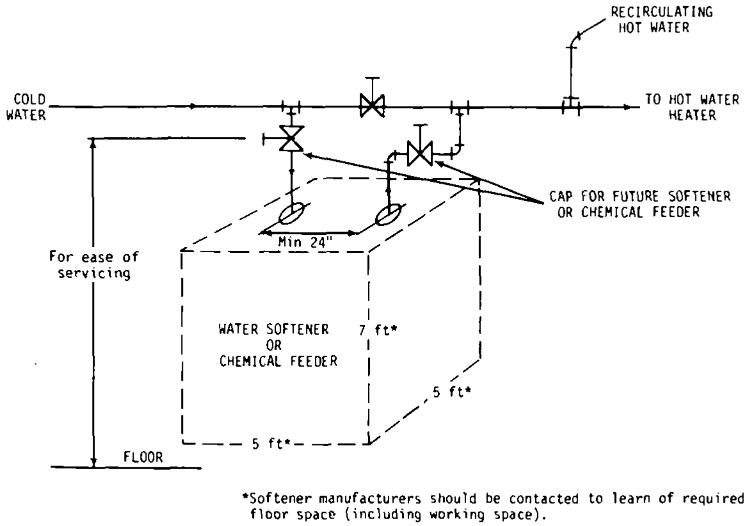


FIGURE 1 — Horizontal cold water make up supply piping to heater including valves. *Softener manufacturers should be contacted to learn of required floor space (including working space).

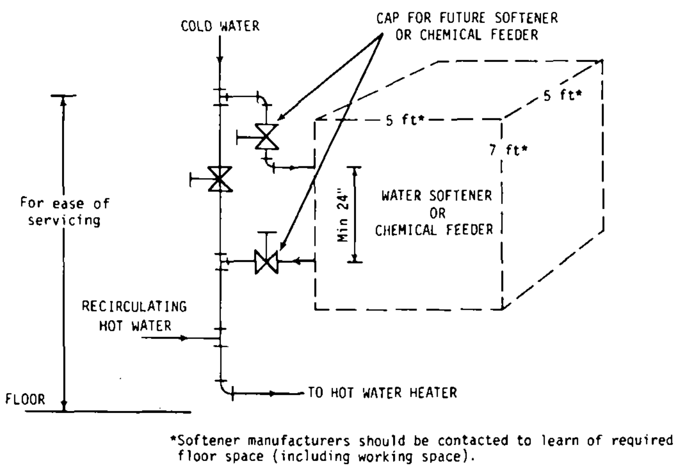


FIGURE 2 — Vertical cold water make up supply piping to heater including valves. *Softener manufacturers should be contacted to learn of required floor space (including working space).

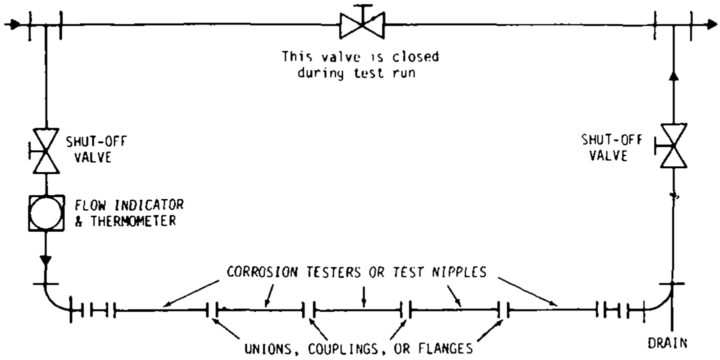


FIGURE 3 – Corrosion tester installations.

7. *Connections for corrosion test specimens or readily removable test* sections of pipe (See Figure 3) for observing scale formation or corrosion under service conditions should be installed at several appropriate locations at the time of construction. These test specimens should be placed at locations where there is appreciable flow which is representative of flow conditions in the building system.
8. There are numerous good design and fabrication features which will provide improved service and longer life. Some examples are:

   a) Gate valves should be installed rather than globe valves, because gate valves offer less resistance to flow and they do not permit the accumulation of sediment as do globe valves.
   b) Water storage tanks should be provided with full-size manholes to permit proper cleaning.
   c) Dirt and sediment traps, in the form of clean-out tees with drain valves, should be installed at the heels of all vertical lines. Convenient flush-out points should also be provided for horizontal lines.
   d) Supply branches from horizontal mains should be installed from the top half of the pipe. This avoids the formation of sediment traps and pocketing of air.
   e) Ground joint unions should not be used in galvanized piping systems. Experience has shown that the brass seats provided in such union have caused abnormal localized corrosion within the union, resulting in the eventual restriction of flow.

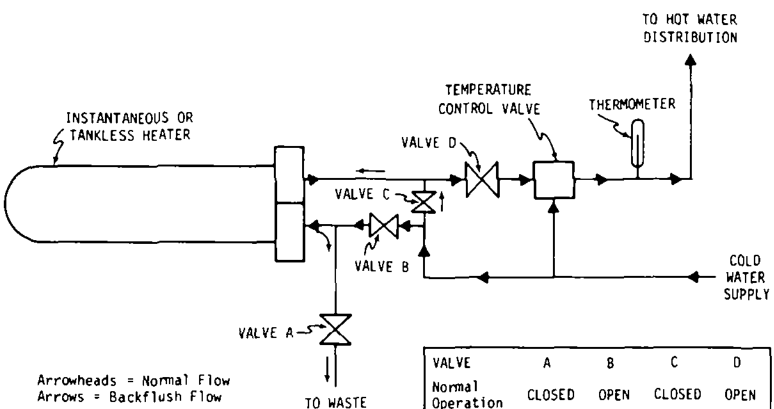
f) Every effort should be made to ream the pipe ends properly to prevent burrs caused by pipe cutting, because such burrs provide places for sediment to accumulate, may cause restrictions to flow, and provide possible crevice corrosion sites.

g) The use of bushings, street ells and reducing fittings should be minimized because they, too, cause restrictions to flow by providing a shoulder for the build-up of deposits, and an increase in water velocity or turbulence.

h) Pipe compound should be spread on the male pipe threads only and not on the thread of the female fitting. If the application is made to the female fitting, the compound is frequently pushed into the fitting where it solidifies and restricts water flow.

i) When dissimilar metals, such as steel pipe and brass valves or fittings are joined, the installation of insulating (dielectric) unions or fittings may be justified to reduce galvanic attack, particularly in some aggressive waters and waters of high dissolved solids content. However, if a good protective carbonate or silicate film is formed, this is usually unnecessary.

j) Instantaneous or tankless heaters should be provided with the necessary connections for "backwashing" to remove sediment that otherwise tends to accumulate (See Figure 4). Dirty coils cause reduced production of hot water and encourage the operator to compensate by raising temperatures above recommended levels.



VALVE	A	B	C	D
Normal Operation	CLOSED	OPEN	CLOSED	OPEN
Backflush	OPEN	CLOSED	OPEN	CLOSED

FIGURE 4 — Instantaneous heater installation.

k) Abandoned piping systems within a building provide stagnant and possibly corrosive conditions and therefore should be removed or disconnected from the water system.
l) Piping manufacturers' recommendations for fluxes, solders, and soldering procedures should be followed in detail.
m) The designer should provide for the installation of means of measuring temperature and flow in the various main circuits of a water system so that balancing cocks in these circuits can be properly adjusted to provide uniform flow and prevent too high velocity (erosive) conditions or too low flow (stagnant, concentration cell corrosion) conditions.

CHAPTER 4
SELECTION OF MATERIALS

Design engineers are aware that the choice of materials for piping, fittings, valves, and equipment is limited by availability, cost, local building codes, properties of materials with respect to pressure and temperature of use, coefficient of expansion of material, etc. They should also be aware that no single material is suitable for waters of different composition and that chemical treatment may be required for corrosive or scaling waters.

Copper tubing and galvanized steel pipe are, by far, the most common materials in use today in water distribution systems in buildings in the USA. The corrosion resistance of copper, in general, is satisfactory in most water supplies, whereas galvanized steel is generally restricted to the harder water supplies (approx.140 mg/Land above), although with proper corrosion inhibitor application, it is also generally usable.

Particularly under circulating water conditions, hot water temperatures above 60 C (140 F) are corrosive to both copper and galvanized steel and therefore iron containing 90-10 copper nickel (Copper Alloy number C70600) is usually recommended for this service. Higher silicate treatment levels are reported to be effective in controlling corrosion of both copper and galvanized steel at these higher temperatures.

Copper

Copper is readily available as tubing for water service. The copper tubing customarily supplied for this application is 99.90% pure copper deoxidized with phosphorous referred to as Copper Alloy Number C12200.[(2)] ASTM[(3)] Designation: B88 is the standard specification for "Seamless Copper Water Tube." Copper plumbing tube is produced in four categories: Types K, L, M, and DWV. Types K, L, and M are available in both drawn and annealed tempers, whereas DWV is available only in drawn temper. Each type represents a series of sizes with different wall thicknesses. As an example, the normal wall thickness of a 2-inch copper tube is 2.11 mm (0.083 inch) for Type K, 1.78 mm (0.070 inch) for Type L, and 1.47 mm (0.058 inch) for Type M.

[(2)]Copper alloy designations used in this manual are according to the American Society for Testing and Materials (ASTM)/Society of Automotive Engineers (SAE) *Unified Numbering System for Metals and Alloys.* SAE, Warrendale, PA.

[(3)]American Society for Testing and Materials, Philadelphia, PA.

Copper and brass are also available as pipe for water service. The copper pipe is available as Copper Nos. C10200, C10300, C10800, C12000, and C12200 as specified in ASTM Designation: B42 for Seamless Copper Pipe. Also, Copper Alloy No. C23000, an 85% copper—15% zinc brass alloy, is used as specified in ASTM Designation: B43—Seamless Red Brass Pipe.

Copper tube, copper pipe, and brass pipe can be joined using either cast or wrought copper fittings. The following American National Standards Institute specifications apply to these fittings:

Wrought copper and bronze solder-joint pressure fittings
ANSI B16.22 – 1973
Cast copper alloy solder-joint pressure fittings
ANSI B16.18 – 1978
Cast copper alloy fittings for flared copper tubes
ANSI B16.26 – 1975
Cast copper alloy threaded fittings, 125 and 250 pound
ANSI B16.15 – 1978

By selecting the proper fittings, copper tubing or pipe may be joined by soldering, brazing, threading, or flaring.

Copper water tube is generally corrosion resistant, however, there are a few potentially troublesome areas which are exceptions to this general rule. These troublesome situations are of three main types: (1) aggressive, hard well waters that cause pitting, (2) soft waters and waters high in carbon dioxide which do not form a protective film inside the copper tube, and (3) system design which results in excessive water velocity in the tube.

A recent computer analysis of well water having pitting tendencies indicates that the water is characterized by a pH of less than 7.8 and containing more than 17 mg/L carbon dioxide, more than 17 mg/L sulfate and a sulfate-to-chloride ratio of about 3:1.

Pitting can also be caused or intensified by faulty workmanship which leaves excessive amounts of residual aggressive flux (*e.g.,* "self-cleaning" fluxes) inside the tube after installation. If the joints have been overheated during installation and the excess residual flux has polymerized, a veritable pitting epidemic can result.

Aggressive waters which cause pitting corrosion of copper can be treated to bring their composition within acceptable limits. A qualified water treatment engineer can specify a treatment for any given aggressive water to make it non-aggressive to plumbing materials. In general, this involves raising the pH and neutralizing free CO_2 or applying silicate treatment.

Excessive water velocity causes erosion-corrosion or impingement attack in plumbing tube and piping systems. To avoid erosion-corrosion problems in copper tube, flow in a plumbing system should not exceed 1.22 m/s (4 fps). Design velocities should be lower for types L and M which have thinner wall thicknesses than type K. Velocity effects are compounded if the water is also chemically aggressive due to low pH, high hardness or gas content as discussed previously, or if solids (silt) are entrained in the flow. The combination of a flow rate that is otherwise acceptable and a water chemistry that is on the threshold of being aggressive can cause corrosion that would not result from either aggressive factor by itself. Excessive water velocity may exist and be especially harmful if flow regulating valves are not installed on hot water return lines to the hot water heater in manifold type water distribution systems.

Erosion-corrosion can also be aggravated by sharp bends (Figure 5) and faulty workmanship. For example, if burrs are left behind at cut

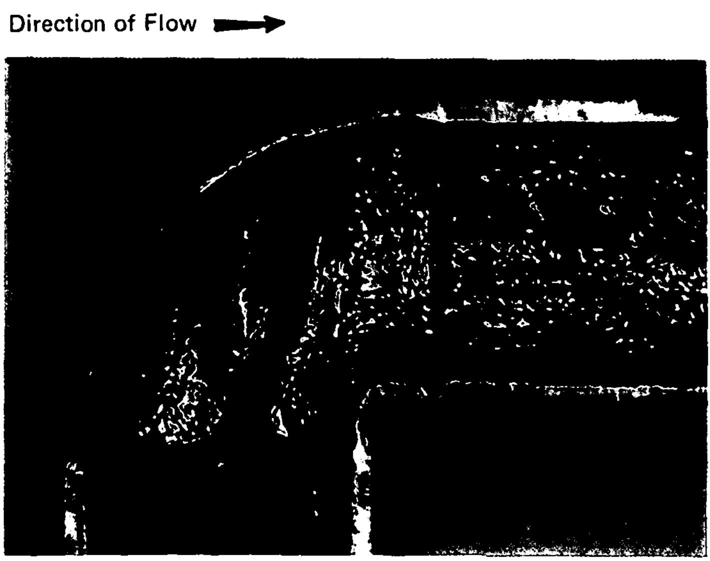


FIGURE 5 – Erosion-corrosion at a sharp bend in a copper tube installation.

tube ends, they can upset the streamlined flow and cause turbulence and localized high velocities.

Copper alloys are available as pipe, tube, and fittings in a range of chemical compositions. From long experience, red brass (85% Cu - 15% Zn) (Copper Alloy Number C23000) pipe, ASTM B43, has proven to be resistant to many corrosive waters, however 90-10 copper-nickel (Copper Alloy Number C70600) is now considered a better recommendation, though it is also higher in cost. It is often recommended where conditions are too severe for the use of copper tube or galvanized steel pipe, as in 82 C (180 F) hot water systems. Copper Alloy Number C19400, an iron modified copper, is also available in water tube. Bronze valves and fittings have also performed satisfactorily in corrosive water service.

Experience with yellow brass (67% Cu - 33% Zn) in corrosive waters has generally not been satisfactory. Reports of failures with yellow brass tube (ASTM B135) and fittings have been frequent. Failures have largely been the result of a corrosion phenomena called dezincification. This term is used to describe selective attack of the zinc component in yellow brass. Soft waters and waters high in chlorides are corrosive to this metal, particularly at high temperatures or in the presence of high carbon dioxide. Yellow brass is no longer offered for potable water use.

Galvanized Steel

Galvanized steel pipe is manufactured in a full range of sizes and weights (ANSI B36.10) for use in potable water systems in buildings. Standard weight (Schedule 40) pipe, for example, 5 cm (2 inch) pipe with a 0.391 mm (0.154 inch) wall thickness is commonly employed in potable water service.

Galvanized steel pipe (ASTM A120) is most suitable for potable water service in high hardness, high alkalinity well water supplies but is generally unsatisfactory for low hardness surface water supplies (about 140 mg/L total hardness and below) unless the water is properly treated with inhibitors, such as silicate. ASTM A120 pipe requires a hot-dipped zinc coating of not less than 489 g per m^2 (1.6 oz./sq. ft.) [approximately 0.069 mm (.0027 inch) in thickness] on the inner and outer surface of the pipe.

The corrosion rate of zinc in most domestic waters is considerably lower than that of steel. When applied over steel, zinc acts as a barrier coating and as an anode providing galvanic protection to the steel to protect it from corrosive attack at breaks in the coating. The duration of this protection varies depending on the aggressiveness of the water in different areas of the country. Certain chemical constituents, such as nitrate or carbonate-bicarbonate in domestic waters, especially, at elevated temperatures, can cause zinc to lose its ability to provide galvanic protection to the steel. Hubbard and Shanahan have shown that pressure of oxygen above atmospheric pressure is necessary for this to occur in susceptible waters, however the presence of chloride ions at concentrations over 10 mg/L tends to ensure that zinc maintains its galvanic protection. In waters of the analyses specified above, maintenance of domestic hot water temperatures below 60 C (140 F) generally ensures that the galvanized coating maintains its ability to protect the steel at gaps in the coating.

Steel and galvanized steel are also subject to corrosion by small quantities (as 0.01 mg/L) of soluble heavy metals (as copper) which can plate out and form microcells and cause pitting. As with copper tubing, completely softened waters should be blended with hard water to provide at least 60 mg/L hardness. The water may need to be treated with chemicals such as lime or caustic soda to raise the pH or have sodium silicate inhibitor added to provide a protective film. Optimum sodium silicate treatment depends on the pH. Waters of lower pH, such as 7.6, require higher silicate dosages (up to 20 mg/L SiO_2), whereas waters of higher pH require lower silicate dosages (4-10 mg/L SiO_2). Where these precautions cannot be taken and, particularly at hot water temperatures above 60 C (140 F), a more corrosion-resistant material such as 90-10 Copper-Nickel, Alloy Number C70600, is suggested.

Scaling of galvanized steel and copper pipe used to convey high hardness waters was once a common problem. Through the increased application of the softening processes by municipal and private water suppliers, reports of this problem are less frequent today. Scale problems can still be encountered with hot unsoftened water. Hardness of about 100-140 mg/L (as calcium carbonate) is considered the maximum which can be tolerated at temperatures of about 52-57 C (125-135 F). Where water supplies of higher hardness must be used, sodium zeolite softening and blending to provide a hardness level of about 60-120 mg/L is generally recommended.

Cast Iron

Cast iron pipe (AWWA C102) is available for water service and is often used in underground water supply lines. It is not, however, ordinarily installed in potable water systems within buildings. This is due, in part, to the unavailability of cast iron pipe in small [under 10 cm (4 inch)] sizes. Fittings and valves of either cast or malleable iron are commonly used with galvanized steel pipe in building systems.

Corrosion rates for cast iron in potable waters differ little from those of carbon steel. Slightly longer service life may be experienced with cast iron due to its thicker section but a protective coating is necessary for satisfactory use in potable water systems. Cast iron pipe or ductile iron pipe and fittings (AWWA C104-74) is now commonly specified to be cement mortar lined (standard or double thickness) as it is more corrosion resistant. Iron body gate valves with exposed surfaces bronze-coated (bronze mounted) are also specified.

Stainless Steel

Stainless steel tube, which is a generic term referring to steel mainly containing at least 12% chromium as a primary alloying element, is noted for its corrosion resistance. There are many stainless steels of different composition. In general, their higher cost makes their application appear uneconomical in the usual rather mildly corrosive potable waters. Like the copper alloys, various alloys are offered, and care should be exercised in their selection. It should be recognized also that waters having pitting tendencies may cause perforation of the normally thin-walled stainless steel tubing.

AISI 304,[4] chromium-nickel austenitic stainless steel (ASTM A269) has been used for domestic water service in the United Kingdom since 1966. Reports indicate generally favorable results except for a susceptibility to pitting in waters of high chloride content or when chloride-containing solder fluxes are used in joining. In the United States two types of ferritic stainless steel tubing (ASTM A268) were available, however AISI 409 (11% Cr) is no longer manufactured as it was found to be unsatisfactory due to its being highly susceptible to chloride pitting attack. AISI 439, modified, (containing 18% Cr and stabilized with Ti) has provided satisfactory service in installations made in 1972, however this tubing is also currently unavailable.

Alloy Steels

Low alloy steels, containing small amounts of chromium, nickel, and copper are available as pipe. Their primary use has been as a replacement for wrought iron pipe. There have been reports that these steels are less subject to pitting but experience has been insufficient to date to obtain proper evaluation.

Aluminum

Aluminum tube (ASTM B210) and fittings, in general, are considered unsatisfactory for potable water systems in buildings because pitting is initiated by waters containing extremely small

(4) American Iron and Steel Institute, Washington, D. C.

amounts ($\propto$0.1 mg/l or less) of soluble iron or copper, which may be present in these systems. These soluble heavy metals deposit to form microcells causing pitting of the aluminum. Aluminum is also susceptible to crevice corrosion.

Plastic

Plastic piping is a general term and covers a wide range of products of quite different composition. Each type bears the name of the base resin from which it is manufactured but its properties will depend on its formulation and the method of manufacture.

The more common thermoplastic types, as polyethylene (PE), polyvinyl chloride (PVC), chlorinated polyvinyl chloride (CPVC), and cellulose acetate butyrate (CAB) are manufactured by extrusion and/or molding operations. Thermosetting types such as the common polyester, epoxy, or phenolic resins are manufactured in a laminate construction and employ reinforcing materials, such as different types of glass fibers, flake glass, and invert pigments. Plastic piping to be installed in a potable water system should have National Sanitation Foundation (NSF) approval to be assured of its suitability.

Plastic piping for hot water service must be selected carefully to be sure its mechanical properties, including temperature effects on structural strength, rigidity and coefficient of expansion, are proper.

Plastic piping has many advantages in being corrosion resistant, having a low coefficient of friction factor, light in weight and low in relative cost. However, the disadvantages of limited resistance to temperature, low mechanical strength requiring supports, high coefficient of thermal expansion and poor resistance to physical abuse and fire (generation of fumes) have limited its acceptance for building piping systems.

Plastic lined steel piping, probably most commonly lined with polyvinylidene chloride (Saran),[5] or polypropylene, with appropriate fittings, provides a corrosion-resistant piping system of sufficient mechanical strength even at high water temperatures, however, it is very costly to install.

Compatible Materials

Compatible materials with respect to corrosion should be installed throughout the water system whenever possible or practical.

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[5]Trademark, Dow Chemical Company.

Materials for Storage and Hot Water Heaters

Storage equipment and hot water heaters are generally constructed of steel and therefore, as pointed out earlier, they must be coated or lined to protect them from corrosion by potable waters. This subject is covered in Chapter 5, Auxiliary Equipment.

Corrosion Testing

Provisions should be made in the piping system for the insertion of test specimens. The corrosivity of domestic waters may be evaluated by periodic removal and examination of nipples mounted in a test loop (Figure 3), by machined nipples (ASTM D 2688—Method C), or by other corrosion testing techniques to indicate corrosion occuring on the piping walls. Corrosion testing should be done under the guidance of a qualified corrosion specialist.

CHAPTER 5
AUXILIARY EQUIPMENT

Cold Water Storage Tanks

Although cathodic protection can be used to protect uncoated tank interiors, it should not be considered as a substitute for the application of a high quality, protective organic coating, such as vinyl copolymer or polyamide-epoxy which meets FDA[6] requirements with respect to extractables for cold water up to 30 C (86 F). Minimum maintenance costs are realized through the combined use of protective coatings and cathodic protection. For example, significantly less cathodic current is required to protect a well-coated tank; coating decreases the anode consumption rate and greatly extends the life of the cathodic protection system. The presence of a coating inside the tank also increases the "throwing power" or cathodic current to the corners and crevices where coating defects generally exist. It should also be remembered that steel above the water level and exposed to high humidity but not to the water cannot be cathodically protected; these areas of the tank can only be protected by a coating.

A qualified corrosion specialist should decide whether a sacrificial anode system or an impressed-current cathodic protection system should be installed. Regardless of the type of cathodic protection system selected, it is important that adequate protective direct current be applied to the exposed steel. For coated tanks, it is equally important that the structure not be overprotected. Excessive current can cause blistering of the protective coating.

It should be appreciated that the cathodic current required for protection can vary because of coating deterioration, polarization effects, and changes in temperature, water level, water chemistry, and velocity. In order to insure that adequate cathodic current is always available, the installation of automatic-potential-controlled cathodic protection systems may be justified. These systems provide a reliable safeguard for insuring that the immersed steel surfaces are receiving complete protection from corrosion without excessive use of current or damage to the coating. Regardless of whether the cathodic system is manually or automatically controlled, it must be properly maintained. This should include a monthly rectifier check and an annual tank-to-water potential survey. It is also desirable to annually inspect the anodes and establish whether all sections of the tank are being adequately protected. This can be done at the same time the water level is lowered for inspection of the coating.

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[6]U. S. Food and Drug Administration, Washington, D. C.

Pumps

The size of the piping and the pump capacity are largely dictated by the demands on the system. The choice of pumps and pipe sizes should be chosen carefully to avoid extremely low or excessively high velocities, which can cause increased corrosion of pump interiors or the piping.

Cavitation damage, in the form of closely spaced pitting, is a special form of erosion-corrosion, which is caused by the formation and collapse of vapor bubbles in a liquid near a metal surface. It is the result of both corrosion and mechanical effects. It is often observed on the impellers of pumps where hydrodynamic pressure differences exist. It may be prevented by (1) changing the pump design to reduce these pressure differences, (2) substituting more corrosion resistant metals, and (3) providing smooth surfaces or coating metallic surfaces with resilient coatings.

Temperature Controls

Providing water with temperatures no higher than 57 C (135 F) to allow for possible higher temperature override and minimizing water temperature fluctuations are important factors in minimizing scale and corrosion problems. Three types of temperature controls are available for this purpose.

Mixing Valves

For hot water systems which depend upon mains or pneumatic tank pressure for circulation, thermostatically controlled mixing valves should be installed for blending cold water with water from the heater to provide water of the desired temperature. A thermometer should always be installed downstream of this valve in order to provide a convenient means for checking the operation of the mixing valve (See Figure 4).

Thermostatic Switches

For hot water systems which utilize circulation pumps, thermostatic switches (aquastats) should be installed for controlling hot water temperatures. In order to insure a uniform and constant hot water temperature, three aquastats may be used. One may be used to sense the water temperature in the heater and to turn on the burner of electric heater when the water drops below a specified level, the second to sense the water temperature in the storage tank and to turn on the tank circulation pump when the return water temperature drops below 43-49 C (110-120 F) and the third to sense the water temperature in the main circulation return line and to adjust the heat input accordingly.

Thermometers

Installation of accurate thermometers in prominent positions in hot water storage tanks, delivery, and return hot water lines is recommended so that operating personnel may be readily aware of system temperatures and be able to detect any malfunction of temperature controls. Temperature recording is desirable and is justified for large installations or for institutions in which maximum water temperature must be limited for certain patients.

Hot Water Generators and Storage Tanks

Heat Source – Steam, Hot Water, or Electric

Most buildings will have water storage tanks which may hold as much as 4000 liters (1000 gallons) or more of heated water. In the smaller sizes—100 to 300 liters (30 to 80 gallons)—the tanks combine the heating operation and the storage operation in one vessel, with relatively simple, low powered, energy sources incorporated into the structure, as they meet the need for intermittent and relatively low volume usage. As the need for hot water increases, the energy inputs increase, and the size of the tank increases. In many installations, the energy source is then external to the tank, so that the tank serves only for storage. Whatever the tank size and whether the energy transfer is inside the tank or outside, the corrosion problems encountered are the same in principle.

Water heated in tankless coil units immersed in the water of steam or hot water heating boilers may be expected to provide increased scaling and corrosion problems because the temperature gradient is usually high and the skin temperature is correspondingly high. Installation of a means for backflushing (See Figure 4) is essential, otherwise scale and sludge accumulations may eventually cause heater failures. In one known tankless coil installation employing copper heating coils, serious corrosion of the galvanized piping system occurred because soluble copper from the heater caused the formation of galvanic cells on the galvanized steel piping and serious galvanic corrosion (pitting) of the galvanized piping resulted. This case is an illustration of the need for installing compatible piping materials in a domestic hot water system to avoid galvanic corrosion problems. It is recognized that brass valves, bronze pump impellers and copper-nickel steam coils are commonly installed in galvanized steel hot water systems. However, these surfaces do not usually contribute the degree of soluble copper provided by a recirculating copper tube system or heating coil and therefore the formation of galvanic cells is much less of a problem.

Hot water generators employing external or internal heat exchangers generally are designed for passage of the steam or high temperature water (HTW) through the tubes and for the domestic hot water to be heated on the outside of the tubes. The outside surfaces can be more easily cleaned by blowing down sludge accumulations from the exchanger, by cracking the scale free by alternate applications of heat and cold, or by acid cleaning. Shell and tube heat exchangers often utilize copper alloy tubing. Either Copper No. C12200 or Copper Alloy No. C70600 (90% copper–10% nickel) is used for tubing in these heat exchangers with steam or HTW as the primary heating medium. For higher temperatures and velocities, the 90% copper–10% nickel alloy tubing offers superior corrosion and corrosion-erosion resistance.

Electric resistance heaters and heating elements are more commonly used for household hot water heating. Copper No. C12200 sheathed elements are used in most domestic or commercial water heaters. In a ceramic-lined water heater using a sacrificial magnesium anode, the anode may be plated with tin (or zinc) to prolong its life. The accumulation of scale deposits from hard waters may cause overheating and ultimate failure of the heating elements. Also, corrosive water may result in shortened service life. In applications where hard water, corrosive water, or high temperatures are required, AISI 316L stainless steel or Incoloy[7] Alloy 800 Sheathing is often recommended.

Chemical inhibitors are ineffective in controlling corrosion which occurs in low velocity areas, such as hot water heaters and storage tanks. Glass or cement linings, as described in the next section, provide the needed corrosion protection.

Linings

While there are some exceptions, particularly in small systems, the economics of tank construction almost universally dictate that the structures be made from steel–which is susceptible to corrosion in many potable waters. Consequently, steps must be taken to limit or prevent corrosion in order to obtain an economical tank life.

One approach to the problem of minimizing corrosion of hot water tanks is to line the internal surfaces with a material which will prevent the water from contacting the surface of the steel. The four basic

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[7]Trademark of Huntington Alloys, Inc., Huntington, West Virginia.

groups of materials used to accomplish this purpose are glass or ceramic coatings, organic coatings, cement type coatings, and copper linings.

Glass or ceramic coatings: These types of coatings will protect the steel tank for many years providing that the coatings do not suffer mechanical damage during shipment or installation, are not subjected to water temperatures in excess of normal building demands, and a sacrificial magnesium anode is installed to cathodically protect defects in the coating and exposed metal at fittings.

Organic coatings: These vinyl and epoxy resin coatings are easily applied by spraying and are cured at room temperature, or at slightly elevated "low baking" temperatures. Properly selected and applied, these coatings have proven to be quite durable.

Cement type coatings: These coatings are made from a powdered siliceous cement mix which is mixed with water, and which hardens by a chemical reaction between the powder and the water. A calcium oxide cement(8) is recommended for waters having a pH greater than 7. An aluminum silicate cement(9) should be used when the water is soft or has a pH of less than 7. This material is applied in relatively thick layers by troweling or by other techniques. A two-coat application with a total cement thickness of about 13 mm (0.5 inch) to 15 mm (0.6 inch) has been found to provide a relatively inexpensive, durable and effective coating. The bonding to the steel of the tank is minimal, so that the cement is essentially a "cast" tank inside the steel wall, with the steel providing the strength to support the pressure of the water system. Various application innovations can enhance the capability of hydraulic-cement linings to provide even more effective corrosion control for hot-water storage tanks. For example, when lining manhole covers, steel-wire mesh should be tackwelded to the cover. This provides an "anchor" which aids in keeping the coating intact. Immediately after lining of the tank is complete, the tank should be filled with water to prevent cracking of the lining due to shrinkage.

Copper linings: Copper, in strip or sheet form, may be used to line water storage tanks. The copper lining is welded at every seam of the lining and at every connection and opening by various techniques developed by the different manufacturers. The ductility of copper precludes any problems of separation from the steel shell because of thermal expansion. All copper lined tanks are provided with vacuum

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(8)The cement lining should contain not more than 35% calcium oxide and not less than 25% silica.

(9)The cement lining should be aluminum silicate cement containing no free calcium oxide and not less than 25% silica.

breakers to prevent ruinous damage to the lining if an internal vacuum is allowed to develop in the tank.

Installation of Cathodic Protection for Corrosion Protection

Another method of providing corrosion protection to hot water heaters or storage tanks is to apply cathodic protection. However, because of the geometry used in the construction of some tanks, there is a problem in obtaining uniformity of protection. The ideal for uniformity of protection is to use an anode which is equidistant from all surfaces of the tank. This is not possible in most tank constructions, so any anode installation may be a compromise, in which uniformity of protection distribution is sacrificed for economy in installation costs.

In addition to tank geometry, the amount of cathodic current generated depends upon the conductivity of the water. In a few water supplies, the dissolved solids concentration is so low that the cathodic current generated by galvanic anodes is inadequate to be effective with most anode arrangements. On the other hand, a number of water supplies are so high in dissolved solids that an external resistance is required in series with the anode in order to maintain the cathodic current sufficiently low to prevent the formation of hydrogen gas.

A corrosion specialist in cathodic protection should be consulted in order to obtain advice on the proper anode material and the means for control of the cathodic protection current.

Isolation of heating elements: In systems where heat is supplied by electrical heating elements or steam heating exchangers which are immersed in the stored water, it is important to insulate electrically such heat sources from the tank, by the use of insulated joints, to prevent the formation of corrosion couples between the steel of the tank shell (the anode) and uninsulated heating surfaces. Acceptable insulation of heating coils from the tanks may likely be provided by cement fill and sleeve type construction.

Odor problems: Magnesium rods which are installed in hot water storage tanks to provide cathodic protection may be responsible for the development of hydrogen sulfide odors. Removal of the offending magnesium anode may be the easiest solution to the odor problem, however, the corrosion reaction is then allowed to continue unabated. The corrosion reaction may be inhibited by installation of an appropriate anode material as recommended by a cathodic protection specialist.

Expansion Joints

The deterioration of expansion joints can be controlled by choosing an alloy of construction which will withstand the environment to which it will be subjected. Compatible copper based alloys should be specified for non-ferrous piping systems.

Care must be taken in the selection of materials and design of expansion joints to avoid "stagnant water type" crevice corrosion which may be experienced in aggressive waters. An example of this is the occurrence of crevice corrosion failures in the casings of so-called "stainless steel" bellows type expansion joints. Manufacturers may claim their equipment is of stainless steel construction, while only the bellows may be observed to be constructed of stainless steel and the casing (where stagnant water areas exist) may actually be steel.

Faucets, Valves

Erosion of Plated-Brass Valve Seats

The term "wire drawing" has been used to describe the erosion-corrosion of plated-brass water faucet valve seats. A serious problem in certain geographical areas, the damage ultimately results in the loss of significant amounts of water. In one study,[2] the presence of appreciable chloramine residuals in the potable water was reported to be an accelerating factor in the "water drawing" phenomenon. The use of monel can generally eliminate the erosion-corrosion which occurs to brass valve seats.

Dezincification of Brass Valve Stems

It is known, but not widely appreciated, that commonly-used valve-stem brasses can suffer serious dezincification when they are exposed to certain potable waters. These include the copper alloys: C874, C694, and C697. Alloys, however, are commercially available to minimize the dezincification problem with Cu-Zn-Si alloys.[3] An inhibited valve-stem brass should be specified when dezincification is a problem. Arsenic additions to the brass are effective for preventing dezincification in both hot and cold waters; phosphorus additions are reportedly effective only in cold waters. Regardless of the inhibited alloy selected, it should be specified that the alloy be heat treated to produce an alpha-zeta metallurgical structure.

Pressure Regulating Valves

Pressure regulating valves should be the usual diaphragm type constructed of materials known to provide proper corrosion resistance. Valves composed of a cast bronze body, screwed-in Monel body seat and with reinforced nylon diaphragms and including an inbuilt strainer are reported to provide long life.

CHAPTER 6
ADDITIONS, ALTERATIONS, AND REPAIRS

When changes in a building water system are planned, full consideration should be given to the possible effects that these changes may have on the whole system.

Materials for additions or alterations to an existing facility should be selected to prevent galvanic corrosion between dissimilar metals. Copper tube should not be installed in an addition and connected into a circulating galvanized steel system, or vice versa. There have been numerous instances observed in the field and reported in the literature in which soluble copper in the circulating water has been responsible for causing pitting of galvanized steel due to the plating of copper and the forming of microcells on galvanized steel piping.

Serious deterioration of a hot water system can result when inadequate provisions in design have been made for increasing the hot water heater or softener load, controlling the hot water temperature, and the hot water recirculation rate. It should be recognized that rebalancing of the system circuits may be necessary after additions or alterations have been completed. It is also important to give careful consideration to pipe sizing when altering or adding to an existing system in order to avoid upsetting the original hydraulic pattern of the system. For example, changes which increase flow rates through an existing copper pipe could result in failure by erosion-corrosion attack. Also, the required maintenance in the existing system should be given full consideration as far as corrosion, temperature, and flow problems are concerned in order to determine whether improvements in material selection, water treating, control and operation, should be made in the new system.

CHAPTER 7
BUILDING OPERATION AND MAINTENANCE

Preoccupancy Considerations for Water Supply Systems

Prior to the occupation of a building in which a new or restructured potable water system has been installed, a number of procedures are advised to ensure proper future service by the water supply system. The procedures which are discussed in the following paragraphs are intended to prolong the period of acceptable service of a building potable water supply system.

Inspection

An inspection of the water system should be made by the building operating personnel before a building is occupied and the system is in use. The operating personnel should have the manufacturer's instruction and maintenance manuals on hot water heaters, storage tanks, softeners, pumps, water treating equipment, temperature controllers, and other equipment in order to provide proper maintenance of the various water systems.

Cleaning and Flushing

Shortly after installation, new piping must be flushed to *thoroughly clean* the system by removing paint, oil, rust, and other foreign material from the piping. Otherwise, under-deposit corrosion may cause serious pitting of the piping and water handling equipment. This flushing should be done by the piping contractor as a part of the cleaning and disinfection procedure. A large drain valve with a minimum size of 5 cm (2 inch) should be installed in the low part of the system in order that effective flushing of the major components of the circulating water systems can be performed. After thorough cleaning and flushing, the complete system and treating system should be properly chlorinated (according to American Water Works Association[10] Standard Procedure (C101) for disinfecting water mains) to rid the system of bacterial contamination. Additional flushing may be required on a periodic basis to reduce zinc, copper, or iron corrosion products that may develop in the stagnant new piping system. Daily bleedoff that simulates expected daily usage should be started so the water system reaches equilibrium by the time it is opened for occupancy.

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[10] American Water Works Association, Denver, Colorado.

System Startup

Hard water should preferably be employed in the hot water system for the first month in order to build up a slight protective scale layer. (In case a hard water is not available, a dilute calcium carbonate or lime solution may be circulated.) Then, water softeners included in the system should be regenerated and placed in operation as recommended by the softener manufacturer.

The water treatment consultant will likely recommend blending hard water into the softener effluent by means of a bypass or blending valve. Initially, daily hardness tests of the blended water may be required until the blending valve setting is properly adjusted. Monthly checking of the hardness is suggested after proper blending valve adjustment. In many buildings, installation of a 2.5 cm (1 inch) bypass globe valve has served very satisfactorily to blend sufficient hard water with the softened water.

The building operating personnel should arrange for the water treatment consultant to be present when the chemical treating equipment is initially started. The consultant should provide the necessary information and instructions for treatment control. All water treatment equipment and supplies, including water testing equipment, should be inspected to determine whether they are adequate.

Pipe specimens or corrosion testers (as ASTM D2688 Method C or equivalent, illustrated in Figure 3) should be installed for monitoring the corrosion or scaling that may occur in the system. An initial inspection of these specimens is recommended, to be sure they are placed in representative locations under normal velocity and temperature conditions.

Temperature controllers on water heaters, storage tanks, and recirculating lines must be checked for proper operation and control. It is recommended that, for domestic uses, the temperature not exceed 57 C (135 F) except where required for laundries, dishwashers, etc. In these cases, a booster heater should be installed close to the point where water enters the equipment requiring the higher temperature [usually 82 C (180 F)] water.

Maintenance

Proper design of an in-building water system will not guarantee a long system life unless good operation and maintenance programs are practiced. The preventive maintenance program for a building should include the complete water system. This includes the water heaters, water softeners, storage tanks, pumps, treating equipment, pipe, and fittings and controls.

Water Softeners

A periodic check of the hardness of the softener effluent is recommended to prevent excessive overruns of softener capacity. Valves in automatic and manually operated softeners can fail to function properly and can allow hard water or brine into the water system, thus causing scale and corrosion. Reduced softener capacity, hardness leakage during service, and a high head loss across the softener during service are indications that a softener should be inspected and proper maintenance performed.

A softener should be opened and inspected yearly. The volume of the ion-exchange material should be checked for resin losses. The ion-exchange resin should be inspected for suspended iron, slime growths, and chlorine attack and cleaned if necessary. The internal piping should be inspected if there is evidence of malfunction.

An operational check of the softeners is suggested annually to determine backwash effectiveness, salt dosage, brine concentration, rinse volume, and capacity. Variations from the softener design values should be noted and corrected.

Brine tanks should be inspected monthly or more frequently to assure the presence of adequate salt and should be cleaned annually. The brine tanks should be inspected and the necessary maintenance performed to correct for the expected corrosive attack on the steel tank and associated piping. Plastic tanks and epoxy lined tanks are now being more generally specified for salt brine.

Records should be kept, listing the gallons of water softened, the brine dosage, brine concentration and frequency of regeneration so that an accurate operating history of the equipment is available for future reference in case of operating difficulties.

Water Heaters

There are numerous water heater manufacturers and several basic water heater designs encountered in building installations. The manufacturer's instructions should be followed in the operation and maintenance of the hot water heater.

Since water heaters or storage tanks contain low velocity areas, where scale and corrosion products accumulate, periodic flushing of the bottom of these tanks may be required. Removal of these deposits is necessary to prevent interference with normal heat transfer and to prevent the development of under-deposit corrosion. Heater or storage tank linings should be checked annually to see that linings are providing complete corrosion protection of the steel.

Temperature controllers, temperature recorders, and thermometer sensing elements should be cleaned periodically in order to provide for accurate temperature control.

Water heater exchangers provide the most common maintenance problem encountered in building operation. When soft water is employed in a hot water system, scaling of the heat exchanger surface may be avoided, however, serious corrosion problems may occur throughout the piping system or in the exchanger unless blending with hard water is performed. Monitoring the temperature readings of the hot water effluent will indicate the extent of scaling of the heat exchanger and the possible need for cleaning. Periodic visual inspection of the heat exchanger surfaces is recommended. Heat exchangers heated by hot water boilers may indicate tubing failure by overflow of head tanks or pressure relief valves in the closed systems and, therefore, monitoring of overflow should be given regular attention.

Pressure and temperature relief valves should be checked periodically for leakage and maintenance performed as recommended by the manufacturer of the valves.

Periodic cleaning to remove deposits from the tubes of the heat exchangers may be required. The heater manufacturer's recommended cleaning procedures should be followed. For removal of sedimentary deposits, the operating staff may backflush (See Figure 4) periodically or as loss of heat transfer becomes apparent. Acid cleaning of heat exchanger surfaces may prove to be the least expensive method of removing hardness scale, but this procedure should be supervised by a qualified corrosion engineer, water consultant, or chemical cleaning engineer. Repeated acid cleaning is discouraged, since metal deterioration will gradually result. Substitution of a more effective means of water treatment should then be considered.

Recommendations for chemical treatment of a potable water system to reduce corrosion or scale formation or for disinfection purposes should be prescribed by a qualified water consultant and controlled under a qualified supervisor. The treating equipment and chemicals should be located in a clean, dry, and locked room, accessible only to qualified personnel. The treatment chemicals employed must be approved for use in potable water and may require licensing or supervision by a public regulatory agency. Chlorinating chemicals should be applied to the water treatment chemical solutions to combat bacterial contamination unless assurance is given by the chemical treatment consultant that this is unnecessary.

Proper corrosion and scale control should be provided throughout the entire potable water system. Weekly testing of the water may be required to determine whether the chemical feeder is operating properly. Frequent inspection of the chemical vat or tank is advised to ensure continuous chemical application. A water meter should preferably be installed to be assured that proper proportional treatment is being applied.

Pipe or corrosion test specimens should be removed every six months or annually for evaluation of scale formation or corrosion in the piping system. The specimens should be examined by the water treatment consultant.

The manufacturer's maintenance recommendations should be followed with respect to all chemical pumps and chemical feeders, meters, electronic timers, etc.

Potable Water Treatment Services

In a number of metropolitan areas, there are firms which provide complete potable water treatment services for a fixed regular fee, which includes supplying the chemical feeder, the treatment chemicals and their application, adjustment and maintenance of the equipment, water testing control, and technical supervision. In some cities, licensing requirements limit the treatment of potable water to qualified service organizations of this type.

CHAPTER 8
WATER AND WATER TREATMENT

Water

In general, the majority of waters along the East Coast, Gulf Coast, Southeast, and Rocky Mountain areas are classified as corrosive. Most waters in the Midwest are classified as scale-forming. Obviously, water quality in all areas will vary, just as that from a single source may vary. Intelligent material selection cannot, therefore, be made without a complete and representative water analysis. Knowledge of hardness (as calcium carbonate), alkalinity, calcium, silica, chloride, sulfate, dissolved oxygen, carbon dioxide, dissolved solids and pH (at the site) are most important. Without complete knowledge of water constituents, an estimation of the scaling or corrosive tendencies of a particular metal in a water may not be accurate. Also, the conditions under which the water is used, such as temperature, pressure, and flow rate should be known, since these factors have a pronounced effect on the scaling or corrosive tendency.

Many factors contribute to the scale-forming and corrosive tendencies of potable waters. The primary factors are:

1. Concentration of hardness, alkalinity, chloride, sulfate, and silica present.
2. Concentration of dissolved gases (O_2 and CO_2).
3. pH.
4. Temperature.
5. Velocity.

Calculation of the Langelier saturation index determined from the calcium, total alkalinity, total dissolved solids, temperature and pH of a water provides an indication of the tendency of a water to form calcium carbonate scale. Other factors, such as chloride, sulfate, alkalinity, silica, dissolved oxygen, pH, temperature and velocity, must be considered when the tendency to corrode is to be evaluated.

Water Treatment

Filtration

When the water entering the building is turbid or discolored, it may be necessary to filter it. Large sand filters [2.2 $l/m^2/s$ (3.3 $gal/ft^2/min$)], which occupy a considerable amount of space are often employed for this purpose and two filters are usually installed so that one may be backwashed while the other is in service. Adequate filtration can be provided in a smaller space by installing tubular strainers, banks of which can be wall mounted and automatically backwashed. If the turbidity or discoloration is not serious, small cartridge type filters or strainers may be installed by the individual householder or the apartment dweller. Since the filter medium may become a serious source of bacterial contamination, frequent inspection to determine need for cartridge replacement is essential.

Scale Control

As previously stressed, scale formation, particularly in hot water heaters, may be a problem if the hardness exceeds about 100-140 mg/L. Installation of a salt regenerated cation exchange (zeolite softener) is the simplest method of preventing serious scale formation. Sufficient hard water should be blended with soft water to provide 60-120 mg/L hardness in the hot water supply in order to reduce corrosive tendencies.

Sodium polyphosphate fed by proportional feeding equipment or the application of the slowly soluble type fed through simple bypass pot feeders(11) at the rate of a few mg/l also can be employed fairly successfully in controlling hot water scale formation.

Taste and Odor Control

Passage of water through activated carbon filters of household or larger sizes will remove undesirable tastes and odors. Attention to replacement of these cartridges is necessary, because the absorption capacity is limited and because contamination from bacterial growths may be derived from the filter elements.

Corrosion Control

Discolored, turbid water, and also off tastes and odors may result from corrosion occurring in building water systems. This is an indication of the need for the application of corrective chemical treatment. Neutralizing filters composed of limestone granules as the filter medium have been used effectively in some systems, however, the filter medium generally becomes coated with rust and other matter and eventually the medium becomes ineffective as a neutralizer. The medium, of course, can be replaced, but this becomes costly.

Adjustment of the pH with caustic soda to provide a slightly positive Langelier saturation index is another method of reducing the corrosivity of water. Essentially, this means increasing the pH of the water so that the scaling tendency of the water (determined from the

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(11)These feeders may not be accepted under some city ordinances.

pH, calcium, alkalinity, temperature and dissolved solids) increases to the point that a slight layer of calcium carbonate scale forms. In addition, the application of liquid sodium silicate at rates of 4-20 mg/l as silica (SiO_2) in conjunction with pH adjustment is particularly effective in controlling corrosion, however it should be recognized that the low velocity areas in tanks, etc. are not protected from corrosion by inhibitors (See Chapter 2).

For further information on corrosion control methods, refer to Chapters 2 and 4, which have already covered this subject in some detail.

Non-Chemical Treatment Devices

Electrical, magnetic or catalytic devices which are claimed to provide immunity from scale or corrosion problems have been appearing on the market for the past 50 years or more. The claims for these devices, often supported by testimonials, state their effectiveness is due to catalysis, magnetism, and electronics, but no quantitative data supported by scientific fact is presented. The former Inter-Society Corrosion Committee of the Electrochemical Society recommends, "extreme caution in the application of devices for control of corrosion and scaling that are characterized by supposed operation without any apparent basis of sound scientific principles and for which no adequate engineering performance data are available."[4] Numerous references, articles, and editorials, appearing in *Materials Performance, Corrosion, Industrial and Engineering Chemistry, Journal American Water Works Association, Power, Heating, Piping, and Air Conditioning* and in various books on corrosion written by reputable authors, have pointed out the fallacies of claims made by the manufacturers of these devices.

For further information, the reader should examine articles in the list of references discussing these devices, included in Chapter 10.

CHAPTER 9
LEGAL AND HEALTH ASPECTS OF MATERIAL SELECTION AND DESIGN OF WATER SYSTEMS

The National Safe Drinking Water Act

Drinking water standards have received general and widespread attention since the Public Health Service Drinking Water Standards were first issued in 1914. Since then, there have been several revisions to keep the standards up to date with scientific advancements. There are also local health codes which are applicable to water problems characteristic of that particular area.

The criteria for potable water are now set forth in "The National Safe Drinking Water Act" (PL93-523), of which the Interim Primary Drinking Water Regulations are a part, which became effective in June, 1977. These regulations state that the substances given in Table 1, in excess of the amounts shown constitute grounds for rejection of a potable water supply.

Maximum levels for organic chemicals are also listed in Table 1. For a full explanation and further details concerning turbidity, chlorine residual, monitoring, and necessary frequency of sampling, refer to Part 141 of the *Federal Register* (Dec. 24, 1975).

TABLE 1

Substance	Maximum Allowable Concentration in mg/L
Arsenic	0.05
Barium	1.0
Cadmium	0.01
Chromium	0.05
Lead	0.05
Mercury	0.002
Nitrate (as N)	10.0
Selenium	0.01
Silver	0.10
Fluoride	1.4-2.4[(1)]

[(1)]Exact limit is based on the maximum daily air temperature for the location, as for example, 26.7C-34.1C (63.9F-70.6F), 1.8 mg/l.

These limits do not relate to the scaling or corrosivity of a water supply. However, the more recent Secondary Regulations address this feature and extend the responsibility of the water producer to the customer's tap. These proposed limits are listed in Table 2.

TABLE 2 – Secondary Regulations

Contaminant	Level
Chloride	250 mg/L
Color	15 Color Units
Copper	1 mg/L
Corrosivity	noncorrosive
Foaming Agents	0.5 mg/L
Hydrogen Sulfide	0.05 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
Odor	3 Threshold Odor Number
pH	6.5-8.5
Sulfate	250 mg/L
TDS	500 mg/L
Zinc	5 mg/L

While these limits are not federally enforceable and are intended as guidelines to the States, one must recognize that this is the direction toward which Federal and State agencies are presently focusing their attention and will be in the years to come. There has been considerable reaction to these tentative proposed esthetic standards that don't directly affect human health and it is expected that considerable time will elapse before final limits will be established for this secondary list of contaminants.

Water companies supplying water in most cities and towns treat the water with various chemicals to clarify, control bacterial contamination, retard corrosion, and soften hard waters. The actual chemicals used and their amounts are supervised by public health officials or the Environmental Protection Agency. Chemical and bacteriological tests are required at regular intervals to ensure that these standards are met. Alum, activated carbon and coagulant aids are added to remove suspended materials from surface water supplies and to control taste and odor problems. Fluoride is added to reduce the incidence of tooth decay and chlorine is added to control bacterial contamination. The water may be aerated to remove odors and dissolved gases and filtered before it goes into the mains.

The responsibility of having a private well tested both chemically and bacteriologically rests with the property owner. If the water is to be used by the general public in establishments or transportation systems involving 15 service connections or 25 or more people, such as schools, apartment complexes, shopping centers, and industrial complexes, the water quality must be tested at regular intervals as specified by the EPA and local health regulations.

In many commercial and industrial buildings, the water required for other purposes may be derived from potable systems, however, no physical connection between the distribution system of a public potable water supply and that of any other water supply shall be permitted, unless the other water supply is of safe sanitary quality and the interconnection of both supplies is approved.

EPA-approved backflow prevention devices must be installed to prevent the possibility of backflow or back-siphonage from all nonpotable water sources. For example, if a public potable water supply is used to fill a tank which is subject to contamination or contains nonpotable water or supplies, *e.g.*, a swimming pool or cooling tower, the water inlet should be above the maximum level of the tank or pool as specified in EPA regulations.

State and City Health Codes

State plumbing codes may also advise the design engineer and plumber what materials can be used to construct water systems in buildings. Plastic piping is not allowed in some areas because of toxic products that may be formed when the plastic is subjected to combustible temperatures. The installation of lead pipe may not be allowed because of the accumulative toxic effect of lead in extremely low doses in the body.

The addition of corrosion inhibiting chemicals such as caustic soda, sodium silicate, zinc phosphate and polyphosphate to a building system may be in contradiction to EPA, city, or state health or plumbing regulations. This is understandable, since these bodies have established certain plumbing regulations to protect the public health. Certain cities, such as Detroit, New York, and others, permit the application of these chemicals to building systems and have city codes which regulates this activity. New York City, for example, has a section of its Health Code which concerns this type of operation. It includes the following:

1. Only qualified and licensed responsible water treatment companies are permitted to carry out this activity.

2. Only a fail-safe type chemical feeder is allowed, which must be approved by the City's Board of Standards and Appeals after testing under conditions of a wide range of flow, reduced pressures, and backflow.
3. The chemical feeder must be installed by a licensed plumber.
4. The code specifies chemicals which may be used and the maximum dosages which may be applied.
5. The Health Department must be notified of the initiation and of the discontinuation of treatment at each location.
6. The code specifies the minimum frequency with which each installation must be checked and the water analyzed for the dosage of chemical being applied.
7. Water analyses and other findings must be recorded on each visit and records maintained and made available for Health Department inspection.
8. Department of Health inspectors make unannounced inspections of each installation, checking the condition of the installation and analyzing water samples.

At one time, limits of 10 mg/L of silicate (as SiO_2) and polyphosphate (as PO_4) were suggested. However, with the apparent recognition that corrosion control is important in keeping possible toxic chemicals (corrosion products) as safe levels, these limits have never been enforced. It is recognized that somewhat higher levels of silicate (*e.g.,* 20 mg/L SiO_2) have definite beneficial corrosion inhibiting effects, particularly during initiation of treatment. There is no known literature indicating that this level of silica has toxic effects. In fact, it has been reported that people throughout the world have been consuming waters containing more than 20 mg/L SiO_2 for hundreds of years with no known adverse physiological effects.

The designer should recognize the need for care in design of such chemical treatment systems in buildings, should work closely with his water treatment consultant or corrosion engineer, and should adhere to local, state and federal plumbing and health regulations.

CHAPTER 10
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INDEX

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