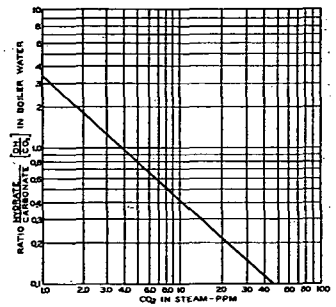
ment to minimize dissolution in the condensate of the deleterious gases entrained with the steam, (3) chemical treatment of the condensate, (4) use of resistant metals.

Boiler Feedwater Treatment. Elimination of oxygen from boiler feedwater and, therefore, from the steam developed, can be accomplished either mechanically or chemically. In some steam generating stations, both expedients are employed.

Tests[25] have indicated that in small low-pressure heating boilers, where the boiler input contains less than about 50 ppm of carbonate hardness, the CO_2 in the steam can be controlled by adding calcium hydroxide to the boiler. In Fig. 6 are shown the equilibria conditions proposed for boilers operating at pressures up to about 5 psi gage. This



(All analytical values are ppm by weight)

Fig. 6 . . . . Relation of Hydrate/Carbonate Content in Hard Boiler Water and CO_2 in Steam at About 5 Psi Operating Pressure

expedient may *not* be used in higher pressure boilers, because of the possibilities of scale and sludge formations. In the latter, the only method used to date for treating the feedwater consists of removing the alkaline earth salts, i.e., softening, and subsequent acidulation followed by deaeration at temperatures near the atmospheric boiling point of water.[26]

Design of Condensing Equipment. In the design of water heaters and comparable types of condensing equipment,[27] it is possible to shift the accumulation of non-condensable gases to a location away from the condensate level and, subsequently, vent these gases to the atmosphere. The venting of an amount of steam equal to about one-half percent of the total steam entering the condenser is the optimum vent rate.

Venting is of little practical value when the CO_2 content of the incoming steam is below about 5 ppm. When the steam contains more than 5 ppm, venting provides a means of producing a condensate containing a minimum of about 3 ppm. However, even as little as 3 ppm of dissolved CO_2 can produce active corrosion if large amounts of condensate are flowing.

Chemical Treatment of Condensate. Condensates containing comparatively large amounts of oil, are practically non-corrosive, due to the protective film provided by the oil. When oil is intentionally added to condensate,[28] inadequate quantities may accelerate rather than decelerate corrosion on those surfaces not covered by the oil. Sodium silicate added to CO_2-bearing condensate has been shown to decrease, but not entirely prevent, corrosive action. It is not known whether the protection afforded by silicate solutions is due to the establishment of a protective film on the metal surface or to neutralization of the CO_2 by the alkali in the silicate solution.

It has been postulated that ammonia,[29] cyclohexylamine,[30] ethylene diamine, and morpholine[31] will retard corrosion of condensate lines. Tests with benzylamine have also been reported.[32] Where copper and its alloys are involved, the use of alkaline inhibitors is believed inadvisable. The use of small amounts of sodium hexametaphosphate has been suggested too, but tests[33] indicate that this salt accelerates rather than decelerates, the rate of attack on steel by condensate containing CO_2 and oxygen. Whether chemical treatment of steam or condensate is feasible, must be determined not only upon the basis of the acuteness of corrosion troubles, but also upon the uses made of the steam or condensate.

Use of Resistant Metals

Steam condensates vary greatly in their ability to corrode metals. The amount of gases that have been dissolved are the determining factors, with oxygen and carbon dioxide, which turns to carbonic acid, being the most common.

Steel, wrought iron, and copper are the metals ordinarily used for pipelines carrying steam condensate. All of these materials have been used with various degrees of success, but under severe corrosive conditions only a few years of service can be anticipated. With the proper metal or alloy carefully selected to suit the existing corrosive conditions, a service life of 15 to 20 years or more is not at all unusual. To obtain a long service life, an analysis must be made of the existing conditions, and if the condensate contains undue amounts of oxygen, carbon dioxide, and other harmful impurities, mechanical elimination of these gases should be a requirement. Treatment of the boiler water and the condensate itself has also proved to be somewhat effective.

Copper and ferrous metals are attacked by combinations of carbon dioxide and oxygen. When the condensate is being returned to the boiler, any copper corrosion products in the water occasionally present a serious problem. The copper that goes into solution is carried along in the condensate, and upon reaching ferrous materials in the boiler and elsewhere will plate out on the ferrous surfaces and set up galvanic corrosion due to the contact of dissimilar metals.

One of the most successful means of preventing corrosion near the junction point of copper and ferrous piping, or where copper piping is connected to steel tanks or boilers and other ferrous vessels, is to install a *throw-away* section at or near the junction. Since the corroding effect will always be found on the ferrous side of the junction rather than on the copper or copper-alloy side, and the effect is usually localized in the immediate vicinity of the joint, the installation of a ferrous pipe section 8 to 10 in. long will absorb practically all of the corrosion. When this *throw-away* section becomes corroded, it can readily be replaced. It should be noted, however, that in ordinary hot water heating systems this problem of potential corrosion at junctions of dissimilar metals seldom presents itself. Where there is any suspicion in this regard, precaution can be readily and commonly taken by separating the two metals electrically by means of a simple insulating union.

No paint or similar protective coating has thus far proven satisfactory where dissimilar metals are used in the same condensate pipe runs. Tests of cement-lined and vitreous-lined pipe have shown the linings to be readily dissolved by the hot condensates. At condensate temperatures, galvanizing on iron or steel pipe has not proved to have any advantages, and in some cases has been found to be detrimental.

ATMOSPHERIC CORROSION

Most of the problems originated by atmospheric corrosion occur in connection with the fire-side of boilers and furnaces (including their flues and stacks), sewer vents, air ducts, and coal and ash handling equipment. Usually such equipment is fabricated from common types of ferrous metals.

Generally little or no atmospheric corrosion occurs at temperatures higher than the boiling point of water, because at such temperatures little or no condensate is formed. If it does form at the higher temperatures; only negligible amounts of carbon dioxide and oxygen present in the atmosphere, will dissolve in the hot liquid, but sulfur gases may dissolve and cause rapid attack. Oxygen, sulfur dioxide, sulfur trioxide, and carbon dioxide are the deleterious gases most frequently accountable for corrosion in moist atmospheres.

Coal Storage and Handling Equipment

Virtually all coals contain sulfur in the form of pyrite, and some moisture. In storage, the pyrite is likely to be decomposed by oxidation. Moisture dissolves the products of decomposition forming sulfurous and sulfuric acid. The acid solutions vigorously attack the supporting metal.

Rubber linings have been developed for coal chutes and bins to effectively resist corrosion and the abrasive action of the coal, but they are expensive.[34] Concrete linings for steel bunkers have also been effectively employed.[35]

The use of high chromium steels is not always a sure cure, especially with coals treated with dust-allaying agents high in chlorides.

Flues, Stacks, and Fire-side of Boilers

The surfaces of flues and boilers contacting the products of combustion, seldom experience corrosive attack when the equipment is in operation. Breechings, smoke hoods, and canopies in contact with flue gas may, however, be subject to attack during the warming-up period of an appliance, or when the rate of operation is so low that the temperature of the flue gas is below the dew point. It is common practice to use cast-iron or acid-resistant vitreous enameled steel in flue gas connections to appliances, to prolong the life of these parts. The shut-down period, when condensation of moisture occurs on the metal surfaces, is usually the time when most damage is done.[36] In those sections of the stacks where flue gas temperature drops below the dew point, corrosion is inevitable during operation.

It is clear that where long shut-down periods are anticipated, a practical method for mitigating corrosion is to clean the surface thoroughly and to provide adequate clean, dry air circulation to prevent condensation. (See also Care of Idle Heating Boilers, Chapter 35.)

Protective coatings with organic binders are destroyed rather rapidly above 400 F because of the decomposition of the organic materials. The surfaces of metals, whose temperature does not exceed 400 F, may be protected by periodically applying paints such as those specified in the following paragraphs entitled Air Ducts.

Air Ducts

The most practical method for protecting air duct surfaces made of steel from atmospheric corrosion, is to apply protective paints. One of the most effective protective coatings is red lead paint.

Three coats of paint should be applied, of which the first two coats should be rust-inhibitive paint such as red lead paint, with the second coat tinted to a light brown color with carbon black, and the finishing coat may be red lead paint tinted to a black or brown color, black paint made according to *Federal Specification* TT-P-61, red iron oxide paint conforming to *Federal Specification* TT-P-31, or white or light tinted paint made according to *Federal Specification* TT-P-40.

Another paint which has had some use for priming iron and steel is zinc chromate paint.

Under some conditions, a chlorinated rubber base paint made according to *Federal Specification* TT-P-91 may be used for the finishing coat, particularly where the presence of highly corrosive gases or contact with strong alkaline water would injure the standard paints. Rubber base paints should be used only for the finishing coat over regular priming and second coats.

BURIED PIPE LINES

Lines that are cold and in intimate contact with the earth are corroded from the same causes as in mineral waters, but pitting is usually more intense due to variations in concentration of salts and oxygen in solution, acidity, drainage, and presence of solid materials (such as cinder) in contact with metal pipe. Galvanic currents, induced by contact of certain dissolved constituents in the soil, often act over a large area, and accelerate corrosion where they leave the pipe line.

Certain bacteria that thrive in the absence of oxygen have the power to obtain hydrogen and dissociate sulfates in the soil, with a resultant production of hydrogen sulfide which attacks iron to form iron sulfide.

Stray electric currents from electric power generating stations sometimes find their way into buried steel structures, and do damage in proportion to the current density where the current leaves the metal to enter the ground.

Pipe Materials

Some underground corrosive environments found in the air-conditioning and heating industries require special materials. The selecton of such materials must be based upon an economic evaluation, as the use of expensive first cost materials is not wise if the life of lower cost materials is adequate. On the other hand, a material low in cost and corrosion resistance should be avoided if it leads to costly shut-downs, repairs, and early replacements. Underground piping materials should be selected for their ability to resist exterior as well as interior corrosion, and careful evaluation of the soil and water should be made.

Underground corrosion of metals is particularly difficult to predict. There are many different types of soils varying in composition and in ability to corrode both ferrous and non-ferrous metals. Where excessively corrosive soils are encountered, special materials may be necessary, but gener-