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TECHNICAL INFORMATION ON BUILDING MATERIALS  
FOR USE IN THE DESIGN OF LOW-COST HOUSING

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THE NATIONAL BUREAU OF STANDARDS  
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SUBMERGED CORROSION OF FERROUS METALS

The first paper of this series, entitled "Corrosion of Metals Used in House Construction" (TIBM No. 1), contains a brief description of three common types of corrosion affecting metals in different parts of a house, viz., "atmospheric", "submerged", and "underground". Atmospheric corrosion has been discussed in TIBM's No. 10 and 17 and underground corrosion will be discussed later.

Some Characteristics of Submerged Corrosion

Typical locations in which submerged corrosion may occur are range boilers, heating-plant boilers, service pipes carrying water and water-storage tanks, the latter being probably the simplest case. In a partially filled tank, there are three zones of corrosion:

- (a) Metal exposed to the air above the water
- (b) Metal at the air-water boundary
- (c) Metal covered by the water

As the water level in the tank changes, these zones usually change correspondingly.

Corrosion of the part of the tank occupied by air is similar to the atmospheric type of corrosion described in TIBM No. 10. In an open storage tank, oxygen is available in unlimited quantity from the atmosphere which may vary in severity of corrosion according to where the house is located (See TIBM No. 10). The water necessary for corrosion is available, however, only while the walls are wetted. As soon as the surface dries, corrosion is interrupted until the walls are again wetted as a result of changes in water level within the tank. In a closed tank, the oxygen needed for corrosion is limited to that originally present in the air space, plus that brought in in dissolved form with the water. Since the air in a closed tank is compressed,

the concentration of the oxygen is increased and the severity of attack may also be increased. Another factor tending to increase corrosion in a closed tank is the fact that the walls are wet most of the time.

Conditions for corrosion at the air-water boundary are usually very favorable and the attack in this zone is often quite severe.

Since the attack of the submerged part of the tank proceeds by the action of oxygen dissolved in the water which can dissolve only relatively small amounts of oxygen, the rate of corrosion in this zone is generally not nearly so rapid as at the "water line".

The corrosion product that forms on the metal in the three zones differs considerably. In the air space, the rust is similar to that formed by outdoor corrosion and is often rather adherent. The rust formed in the submerged zone, especially with soft waters (see below), is generally non-adherent. At the air-water boundary an intermediate kind of rust is observed. An adherent rust coating has been found effective in many cases in retarding the rate of atmospheric corrosion, but on submerged surfaces such protection is not afforded and corrosion may proceed continuously.

#### Effect of Kind of Water Used

The character of the water in the system has an important influence on the durability of tanks or boilers. Two general types of water are of special importance (a) scale forming, and (b) non-scale forming. The "soft" waters belong to the latter class and the "hard" waters to the former. Another class, (c), is water containing sulphates or chlorides in amounts sufficient to cause corrosion, particularly, if scale-forming substances are not present. The effect of scale-forming waters is most noticeable in boilers or other installations in which the water is heated, one effect of the heat being precipitation of the scale-forming constituents. A layer is gradually built up on the metal surface which tends to decrease the corrosion rate. In the absence of scale-forming substances, especially if the water contains chlorides or sulphates, corrosion of tanks and boilers may be very severe. A prediction of the service behavior of the water may often be made with considerable assurance on the basis of a suitable chemical analysis.

Scale deposits from the water may sometimes be a disadvantage in iron or steel pipes since they tend to reduce the water carrying capacity. Such trouble if experienced will, of course, be worse in the hot water pipe system than in the cold water pipes. Experience has shown that less difficulty is encountered from this cause when brass or copper pipes are used. Many advances have been made in the treatment of waters at municipal filtration plants to reduce their corrosive properties or their tendencies to deposit abnormal amounts of scale in water pipes, such for instance, as treatment with lime

filtration, settling in reservoirs after adding substances to clarify the water, and other steps of similar nature.

### Submerged Corrosion of Range Boilers or Heating Plant Boilers

The submerged type of corrosion is least destructive in the boiler of a hot-water heating plant because frequent additions of fresh water are not necessary in such systems. The amount of air in a properly installed and maintained hot-water house-heating system is limited, and after the oxygen has been consumed by corrosion, further attack is very slight. On the other hand, in steam heating boilers or range boilers to which fresh water is frequently supplied, corrosion can be progressive unless scale formation retards it.

### Submerged Water Corrosion Tests Made by the American Society for Testing Materials

The American Society for Testing Materials conducted, from 1920 to 1930, submerged corrosion tests of ferrous metals. Since the conditions were somewhat analagous to those in water storage tanks, the method and conclusions of this test are briefly summarized here.

Samples of uncoated sheets (16 and 22 gage) representing commercially available steels and irons, with and without added copper, were set up in long narrow wood boxes through which water was passed. At Washington, D. C., tap water was used and at Annapolis, Md., Severn River water passed. A water level sufficient to cover the sheets at all times was maintained, and the rate of flow was such that there was complete change of water every 16 minutes. A sheet was considered to have failed when perforated at one or more places. The characteristics of the waters affecting corrosiveness are shown in Table 1 and the results of the test in Table 2.

As shown in Table 2, the 22 and 16 gage sheets lasted much longer at Annapolis (58 percent longer life for the 22 gage sheets) than at Washington, although the water at Annapolis (see Table 1), was more highly contaminated with sulphates and chlorides than the Washington water. The conditions of corrosion, however, were such that metal attack proceeded at Washington without appreciable formation of protective scale on the sheets, whereas the reverse was true at Annapolis. This factor compensated in large measure for the more corrosive nature of the Annapolis water. The test is, therefore, an illustration of the importance, in retarding corrosion, of self-formed protective coatings of this kind. It will be noted, both at Washington and Annapolis, that the kind of ferrous metal used, whether made with or without copper, was of secondary importance to the conditions under which corrosion took place. This latter condition is believed to hold generally for submerged corrosion and is in contrast to atmospheric service, for which steels or irons with added copper are considered more durable (see TIBM No. 10).

No galvanized sheets were included in the submerged corrosion tests. However, it is known that galvanizing is helpful in some parts of a building where submerged corrosion may take place, such as range boilers, water service pipes, etc.

#### General Conclusions

1. Waters that form adherent protective coatings on submerged metal surfaces are less corrosive than those which do not build up such deposits.
2. Hot-water heating plant boilers usually suffer least and steam heating and range boilers most, from submerged water corrosion.
3. In the "submerged" corrosion of steels and irons, the composition of the metal is subordinate in importance to the corrosion characteristics of the water.
4. A galvanized coating on iron or steel may often be advantageous in submerged corrosion service.

TABLE I

DESCRIPTION OF WATERS, AMERICAN SOCIETY FOR TESTING MATERIALS SUBMERGED WATER CORROSION TEST  
AT ANNAPOLIS, MD. AND WASHINGTON, D. C.

LOCATION	AVERAGE TEMPERATURE °C	P A R T S P E R M I L L I O N										
		ALKALINITY IN TERMS OF CaCO <sub>3</sub>	CARBONATE (CO <sub>3</sub> )	CHLORIDE (CL)	SULPHATE (SO <sub>4</sub> )	POTASSIUM (NA)	SODIUM AND CALCIUM (CA)	MAGNESIUM (MG)	IRON AND ALUMINUM OXIDES (AL <sub>2</sub> O <sub>3</sub> , FE <sub>2</sub> O <sub>3</sub> )	SILICA (SiO <sub>2</sub> )	TOTAL SOLIDS	DOXY
ANNAPOLIS*	14.6	57.0	NONE	8440.0	1169.0	4782.0	192.0	567.0	3.1	2.3	15491.0	5
WASHINGTON**	17.1	61.0	1.2	4.8	22.3	NOT DETERMINED	24.8	1.5	1.9	1.9	124.0	5

\* ANALYSIS MADE IN 1923.

\*\* ANALYSIS MADE IN 1929.

TABLE II

LIFE OF STEEL AND IRON SHEETS IN THE AMERICAN SOCIETY FOR TESTING MATERIALS SUBMERGED CORROSION TEST\*

CLASS OF MATERIAL	WASHINGTON, D. C. (TAP WATER)			ANNAPOLIS, MD. (SEVERN RIVER WATER)		
	NO. 22 GAGE	NO. 16 GAGE	NO. 16 GAGE	NO. 22 GAGE	NO. 16 GAGE	NO. 16 GAGE
	NUMBER OF SAMPLES	AVERAGE LIFE IN DAYS	NUMBER OF SAMPLES	AVERAGE LIFE IN DAYS	NUMBER OF SAMPLES	AVERAGE LIFE IN DAYS
BESSEMER STEELS WITHOUT ADDED COPPER	18	899.1	12	1932.8	12	1307
BESSEMER STEELS WITH ADDED COPPER	18	890.1	24	1858.5	24	1429
BASIC OPEN-HEARTH STEELS WITHOUT ADDED COPPER	18	874.8	24	1908.0	24	1341
BASIC OPEN-HEARTH STEELS WITH ADDED COPPER	36	863.8	30	1963.0	30	1343
BASIC OPEN-HEARTH IRON WITHOUT ADDED COPPER	18	899.7	24	2049.0	24	1268
BASIC OPEN-HEARTH IRON WITH ADDED COPPER	18	907.6	18	2074.0	18	1311
ACID OPEN-HEARTH STEEL WITHOUT ADDED COPPER	6	821.8	6	1858.5	6	1420
PUDDLED IRON WITHOUT ADDED COPPER	6	740.5	6	1747.1	6	1104
PUDDLED IRON WITH ADDED COPPER	6	791.5	6	2028.0	6	1728

\* THE TEST ALSO INCLUDED SAMPLES SUBMERGED IN ACID WITH WATER AT ONE, AND IN SEA WATER AT TWO LOCATIONS, BUT THESE RESULTS ARE NOT INCLUDED HERE.